Static Analysis of Helical Compression Spring Used In Vibration Absorber with Nonlinear Parameters

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Abstract - In this paper static analysis of helical compression spring is carried out theoretically, numerically and experimentally in order to find out effect of geometric nonlinearities. For Numerical analysis ANSYS software is used. Experimental set up is developed in order to find out load-displacement characteristics of spring. Load-displacement characteristics are studied in order to find out nonlinearities present in spring. Nonlinear model to describe nonlinearities in spring is developed.

Keywords: ANSYS, Dynamic, Geometric Nonlinearity, Helical.

I. INTRODUCTION

Many practical systems are sufficiently nonlinear so that the important features of their performance may be completely overlooked if they are analyzed and designed through linear techniques. A linear spring is one with a linear relationship between force and displacement, meaning the force and displacement are directly proportional to each other. A graph showing force vs. displacement for a linear spring will always be a straight line, with a constant slope. A nonlinear spring has a nonlinear relationship between load and displacement. A graph showing load vs. displacement for a nonlinear spring will be more complicated than a straight line, with a changing slope.

The Non-linearity of spring can stem from two: their material, in which one speaks of material nonlinearities or their geometry, in which case one speaks of geometric nonlinearities. Note, moreover that a mechanical system composed of linear springs can exhibit geometric nonlinearity in presence of large relative displacements at the ends of the springs. Hard springs exhibit a force-displacement curve whose absolute value of force increases as absolute value of displacement increases. The slope at any point of a force-displacement plot represents, in fact, the local spring stiffness of the nonlinear spring at hand. Thus, hard springs become stiffer as their deformation increases; soft spring becomes more compliant as their deformation increases [1].

II. THEORETICAL ANALYSIS

A spring is defined as an elastic body, whose function is to compress when loaded and to recover its original shape when the load is removed. In other words it is also termed as a resilient member. Springs are elastic bodies (generally made up of metals) that can be twisted, pulled, or stretched by some force. A spring is a flexible element used to exert a force or a torque and, at the same time, to store energy [2].

1) Deflection in Helical Spring:

The deflection of spring is due to torsional moment 'T' and force 'F' acting on the wire. When the spring is being subjected to an axial load, the wire of the spring gets twisted like a shaft. If θ is the total angle of twist along the wire and δ is the deflection of spring under the action of load W along the axis of the coil, so that [3]

$$\delta = \theta * \frac{D_m}{2} \qquad (2.1)$$

Where, Dm=Mean Coil Diameter of spring.

We know torsional formula,

$$\frac{T}{J} = \frac{\tau}{r} = \frac{G\theta}{l} \qquad (2.2)$$

T= Torque (N-m)

J= Polar Moment of Inertia of the Spring Wire (mm4)

Putting values of J, r and l, we get

$$\delta = \frac{8FDm^3}{Gd^4} * n$$

also we know,

$$k = \frac{W}{\delta}$$

Therefore,

$$k = \frac{W}{\delta} = \frac{Gd^4}{8Dm^3 n} \qquad (2.3)$$

Where k = Spring Stiffness (N/m).

III. NUMERICAL ANALYSIS

The finite element method (FEM) is practical application often known as finite element analysis (FEA) is a numerical technique for finding approximate solutions of partial differential equations (PDE) as well as of integral equations [5]. Finite Element Analysis is a simulation technique which evaluates the behaviour of components, equipment and structures for various loading conditions including applied forces, pressures and temperatures [6]. Thus, a complex engineering problem with non-standard shape and geometry can be solved using finite element analysis where a closed form solution is not available. The finite element analysis methods result in the stress distribution, displacements and reaction loads at supports etc. for the model. The three dimensional model of spring is drawn in CATIA V5 R16 environment. This geometry is imported to ANSYS environment. 20 node hexahedral element SOLID-95 used for meshing of the geometry. Meshing is done by Hexagonal Sweep. The geometry can be meshed by 10 node tetrahedron element as well but tetrahedron is stiffer as compared to hexahedron element so results in lower accuracy [7]. Meshing of spring is as shown in Fig.1, it has 86771 no of nodes, and 17803 no of elements.

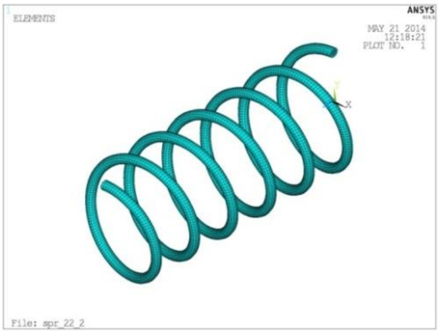

Fig.1: Meshing of Helical Compression Spring

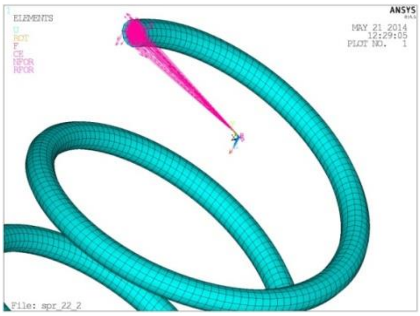

Fig.2: Rigid Element with mass

For calculating the stiffness of spring the load is applied gradually at one ground surface by fixing other surface. From the deflection of spring for applied load, we get the stiffness. While applying load end coils do not taken part into compression process, hence only active no of coils are modeled for FEA. In order to fix one end of spring all degrees of freedom set to zero at that end. At another end to apply the load uniformly, the mass element of negligible mass is created at center as shown in Fig.2. This mass element has been connected to another end of the coil by means of rigid elements as shown in Fig.2. Fig.3 Shows numerical results obtained for force of 63.765N.

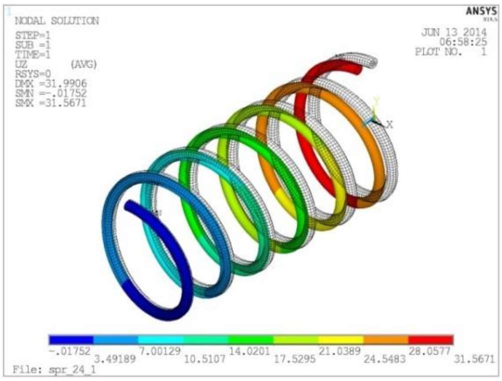

Fig.3: Numerical Results for Force of 63.765 N.

IV. EXPERIMENTAL ANALYSIS

In order to get the load-displacement characteristics of spring, compression test is carried out on spring. Instead of using Universal Testing Machine (UTM), fixture is developed to get the load-displacement characteristics of spring since spring is small. Fig.4shows the experimental setup used to get the load-displacement characteristics of spring.

Fig.4: Experimental Setup for Static Analysis of Spring.

V. RESULT AND DISCUSSIONS

Table 1 shows the Comparative Load-displacement characteristics of Theoretical, Numerical and Experimental Analysis.

Table. 1: Comparative Load-displacement characteristics of Theoretical, Numerical and Experimental

Sr.No.	Load (N)	Theoretical	Numerical	Experimental
		Displacement (mm)	Displacement (mm)	Displacement (mm)
1	4.905	1.865301429	1.9442	1.505386
2	14.715	5.595904286	5.8327	5.606375
3	24.525	9.326507143	9.7213	9.530669
4	34.335	13.05711	13.6098	12.90461
5	44.145	16.78771286	17.4984	16.34627
6	53.955	20.51831571	21.3869	20.61635
7	63.765	24.24891857	25.2754	24.53577
8	73.575	27.97952143	29.1619	27.47652
9	83.385	31.71012429	33.0525	31.33542
10	93.195	35.44072714	36.941	32.6259

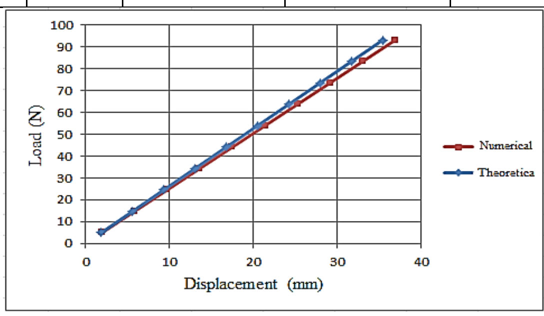

Fig.5: Theoretical and Numerical Load-Deflection Characteristics.

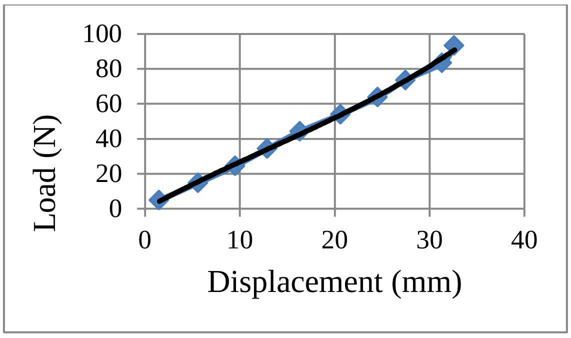

Fig. 6: Experimental Load-Deflection Characteristics.

From Experimental Load-Displacement Characteristics it is observed that spring is hard spring. The non-linear effects included in the spring force fs are modeled as third order polynomial function as

$$f_s = k_0 + k_1 \Delta x + k_2 \Delta x^2 + k_3 \Delta x^3 \quad (5.1)$$

Where the co-efficient are obtained by fitting the experimental data, which resulted in k3 = 0.001 N/m3, k2 =-0.0394 N/m2, k1 = 2.9908 N/m and k0 = -0.1856 N. Hence, in order to model the nonlinearities in spring used in vibration absorber, Eq.5 is used, which includes the nonlinear effects in spring.

VI. CONCLUSION

Comparative static analysis of helical compression spring used in Vibration Absorber is carried out. Nonlinearities present in spring are found out. The theoretical results from Finite Element Analysis showed in general a good agreement with the experimental values. However, differences appear indicating the necessity to improve the model input data and the experimental procedure as well as due to nonlinearities present in the system.

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