Fatigue Analysis of a Compression Spring Used in Two-Wheeler Horn

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Abstract:

Most of the vehicles available today in the Indian market are overdesigned, especially at the fatigue life of a spring. This is either done to account for the type of usage and simply to extend the safety and product life. The work is focused on quantifying the fatigue life analysisof a spring. A fatigue testing machine used to assess the fatigue life variation. The suitability of stainless steel compression spring on two-wheeler horn selected for analysis. Material is selected upon the fatigue life and tensile strength factor.The objective is to present experimentation, modeling and analysis of compression spring for fatigue. Experimentation is carried out using fatigue life analysis fatigue testing machine (M08) is used. Modeling is done using CATIA V5 and ANSYS. Analysis is carried out by using HYPERMESH as a preprocessor NASTRAN as a solver And Hyperview as a post processor.ANSYS14.0 software also used for analysis for better understanding and comparison result with NASTRAN.The axial fatigue study was performed using the fatigue software MSC-FATIGUE as well as in ANSYS. It is observed that the fatigue life of spring is very good. It is safe for design and manufacturing.

***Keywords:**– Helical compression Spring; Fatigue analysis; Ansys; Nastran.*

1. Introduction:

The so-called ''fatigue limit'' has currently become the object of numerous discussions and more recent investigations. Some kinds of technical spring elements, especially such as horn springs systems in automobile, are expected to survive a very high number of cycles with high mean as well as amplitude stresses. In order to determine fatigue strength diagrams according to Goodman extensive fatigue tests on helical spring

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The process requires several inputs, such as geometry, load history, environment, design criteria, material properties and process effects. With these inputs, fatigue design is performed through analysis and testing. The process from design, analysis and test is highly interactive and iterative. The number of loops is directly related to the quality of the inputs, and the accuracy to predict the life of the component or system. In this work, the focus will be on just one part of the flow, which is related tofatigue life.

2. Theoretical fatigue analysis of a spring:

2.1 Fatigue life estimates using Goodman diagrams:

The purpose of spring manufacturers should estimate the fatigue life of a helical compression springs during the design phase. These calculations will be presented along with a comparison to the results of traditional graphical methods [4].

The cyclical stresses are usually used to create a Goodman diagram. In this diagram the alternating stresses are on the y axis and the mean stresses are on the x axis. The value for the endurance limit is then placed on the alternating stress axis and the ultimate tensile strength on the mean stress axis. These are then connected with the Goodman line (infinite life). A line drawn from the origin with the slope of the alternating stress to the endurance limit is the load line. To find the life of the spring one finds the point located buy the mean stress and the alternating stress (this should be on the load line). Figure 1shows a basic Goodman diagram [4].

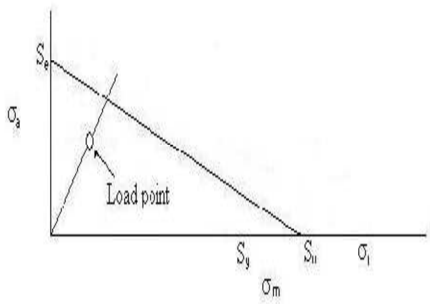

Figure 1. Goodman diagram [4]

2.2 Particularities of helical compression spring

Spring design for fatigue applications involves more than simply selecting the proper cross section and spring style to fit the available space and carry the required loads. It also requires choosing an efficient and economic material that satisfies the life requirements under given load, stress, and environmental conditions. What's more, material costs can be critically important in fatigue applications. For example, environmental factors may, dictate selection of stainless steel over carbon steel, while high quality material may be needed to improve fatigue resistance at critical stress levels [6].

2.3 Fatigue life verification

The results obtained from the failure analysis were verified with an analytic calculation to estimate the fatigue life of the springs and to check that the rupture was not a consequence of a design/selection. Stress calculation in helical springs with circular wire section under axial load (main spring axis).

1. Determination of ultimate shear strength and fatigue shear strength for the spring material.

2. Security factor calculation for current spring design considering fatigue conditions and ‘‘infinite life” design using the Goodman model.

Where F is the axial force acting on the spring, D is the mean diameter and d is the wire diameter. Defining the spring index C = D/d, the previous equation can be arranged as follows:

$$\tau_{max} = K_s \frac{8FD}{\pi d^3}$$

With,

$$K_s = 1 + \frac{1}{2 * C}$$

Where, Ks is the correction factor of direct shear stress.

When the spring is working under fatigue loads, it is necessary to consider also the curvature effect. This effect appears as an overload, concentrated in the inner face of the spring coil. Both corrections (direct shear stress and curvature effect) can be integrated in what is called the Wahl factor (KW):

$$K_w = \frac{4C - 1}{4C - 4} + \frac{0.615}{C}$$

2.4 Fatigue loading

The springs have to sustain millions of cycles of operation without failure, so it must be designed for infinite life. Helical springs are never used as both compression and extension springs. They are usually assembled with a preload so that the working load is additional. Thus, their stress-time diagram is of fluctuating nature. Now, for design we define,

$$F_a = \frac{F_{max} - F_{min}}{2} F_m = \frac{F_{max} + F_{min}}{2}$$

Certain applications like the horn spring of a two-wheeler. The springs have to sustain millions of cycles of operation without failure, so it must be designed for infinite life. Thus, their stress-time diagram is of fluctuating nature [8]. The stress amplitude and mean stress values are given by:

$$\tau_a = K_w \frac{8F_a D}{\pi d^3} \tau_m = K_s \frac{8F_m D}{\pi d^3}$$

Under fatigue conditions, the stresses can be considered as the sum of two components, an alternating shear stress τ_a and a mean shear stress τ_m. The curvature effect must be applied only to the alternating shear stresses, the components that may cause fatigue.

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

$$\tau_m = K_s \frac{8F_m D}{\pi d^3}$$

Where, F_a&$F_m$are the alternating and mean forces respectively and can be calculated through the following expressions:

$$F_a = \frac{F_{max} - F_{min}}{2}$$

$$F_m = \frac{F_{max} + F_{min}}{2}$$

Being F_{max}= 6.0372 N and F_{min}= 1 N

From these expressions and the values it has been obtained that:

τ_a=352.14 N/mm^2 and τ_m=449.84 N/mm^2

2.5 Ultimate and fatigue shear strength determination:

A helical compression spring is subjected to purely compressive forces.

For cold-drawn steel wires:

S_{se}= 0.21S_{ut}

S_{sy}= 0.42S_{ut}

Where, S_{ut} is the ultimate tensile strength.

The Goodman fatigue diagram for the spring is shown in figure 1. The mean stress (τ_m) is plotted on the abscissa, while the stress amplitude (τ_a) on the ordinate.

Considering, a value for S_{tu}of2150 N/mm^2.S_{su}=903 N/mm^2 and S_{se}=451.5 N/mm^2.

When we put the above value in figure 1 and draw the graph. It is found to be that the present spring is safe for design and manufacturing.

3. Experimentation fatigue analysis of a spring:

The standard or reference data available for the past design / validation as standards or reference normally proves to be very useful while considering experimentation. The spring design once identified as suitable for the application is subjected to trials for checking the fatigue life by using MSC-Fatigue. Fatigue experimentation is carried out using a “Life Testing SPM” of a suitable type and capacity. The spring is held in position with other operating conditions identical to the application.

The trials are conducted in a very controlled environment with focus on the variables influencing the fatigue life. A 300000 cycles trial is conducted to ensure consistency/ repeatability of the spring behavior. Present spring is found to be safe for 300000 cycles.

3.1 Experimental work analysis

Figure 2 shows the geometry of the samples used in the tests. The wire material was Stainless Steel (Bright drawn, Bright finish) whose chemical composition and mechanical properties are shown in Table 1 and table 2 respectively.

The principle of operation of that equipment is based on the slider-crank mechanism. The mechanism allows force application along the spring axis. The equipment especially developed to this end was used to perform these tests. Fatigue tests were conducted under a constant mean stress, τ_m= 447.37 N/mm^2, with a constant stress amplitudeτ_a. To do this, the preload and connecting rod amplitude displacement were adjusted for test. Spring constant was measured before test. Once the spring is mounted on the equipment to a desired value of τ_a the test was run until spring fracture. When the failure occurred, the number of cycles was registered and another test with a new spring was performed with a different value of τ_a. Following this procedure the S–N curve was constructed (stress amplitude τ_a – Number of cycles to failure). But in this project report our spring is to be tested only for 300000 cycles. Our spring is not failed after 300000 cycles.

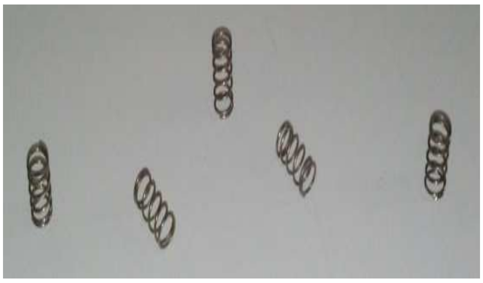

Figure 2. Spring to be tested

Table 1. Chemical composition

Component	Wt. %
C	Max 0.08
Cr	18 – 20
Fe	66.345 – 74
Mn	Max 2
Ni	8 - 10.5
P	Max 0.045
S	Max 0.03
Si	Max 1

Table 2. Material properties for helical compression springs

Sr. No.	Parameter	Descriptions
1	Material	Stainless steel
2	Young's Modulus E	1.93 x10^5 N/mm^2
3	Density ρ	8 X10^{-6} kg/mm^3
4	Poisson's ration	0.3

5	Modulus of Rigidity	7300N/mm^2
6	Ultimate tensile strength	2,150N/mm^2

3.2 Geometrical dimension of a spring

The compression spring used in this study is stainless steels. The physical dimensions of the specimens for fatigue tests are shown in table 3. The material of spring is stainless steel (AISI 304 / ASTM A 313):

Table 3. Physical dimensions of a spring

Sr.No	**Description**	**Spring Specification**
2	Diameter of spring wire	0.450mm
3	Outer diameter of spring,	4.800mm
4	Inner diameter of spring	3.9mm
5	Mean diameter of spring	4.35mm
6	Free length of spring	10.20mm
7	Number of active coils	4
8	Number of total coils	6

3.3Fatigue tests

A fatigue testing machine has been designed to determine the S–N curve of helical compression springs. The mechanism allows force application along the spring axis. The equipment especially developed to this end was used to perform these tests. The fatigue testing machine is shown in Figure 3. A slider-crank mechanism is used to convert the motor rotary motion into rectilinear alternating motion and finally a cyclic deformation is applied to the tested spring. The machine includes a 5HP electrical motor which provides the necessary driving force to deform the spring active coils at 12000±500 cycles/hour. When the spring fails, the fatigue testing machine stops manually and a digital cycle counter registers the spring fatigue life. Fatigue tests were conducted under a constant mean stress, τ_m= 449.84 N/mm^2, with a constant stress amplitude τ_a.

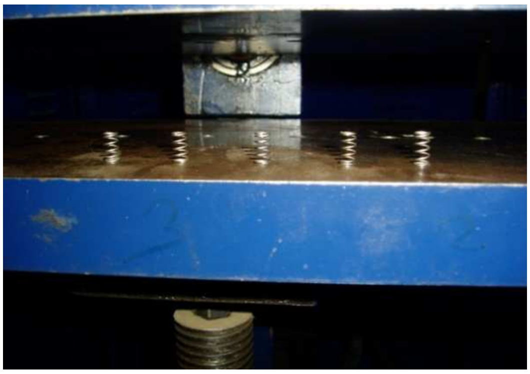

Figure 3.Spring mounted on fixed plate

Figure 4. Spring fatigue testing machine

4. Fatigue analysis of spring by FEA

4.1 Finite element based fatigue analysis

The fatigue analysis is used to compute the fatigue life at one location in a structure. For multiple locations the process is repeated using geometry information applicable for each location. Necessary inputs for the fatigue analysis are shown in Figure 5. The three input information boxes are descriptions of the material properties, loading history and local geometry. All of these inputs are being discussed in the following sections.

1. Material information-cycle or repeated data is used on constant amplitude testing.
2. Load histories information-measured or simulated load histories applied to a component. The term loads used to represent forces, displacements, accelerations, etc.
3. Geometry information-relates the applied load histories to the local stresses and strains at the location of interest. The geometry information is usually derived from finite element (FE) results.

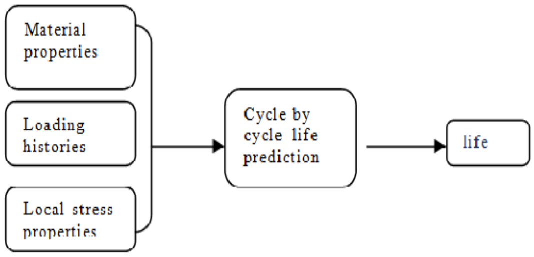

Figure 5. Fatigue analysis prediction strategies

An integrated FE based durability analysis is considered a complete analysis of an entire component. Fatigue life can be estimated for every element in the finite element model and contour plots of life. Geometry information provided by FE results define how an applied load is provided by FE for each load case applied independently. Data provided for the desired fatigue analysis method. The schematic diagram of the integrated finite element based fatigue life prediction analysis is shown in Figure 6. The mechanical properties for the materials are mentioned in table 2.

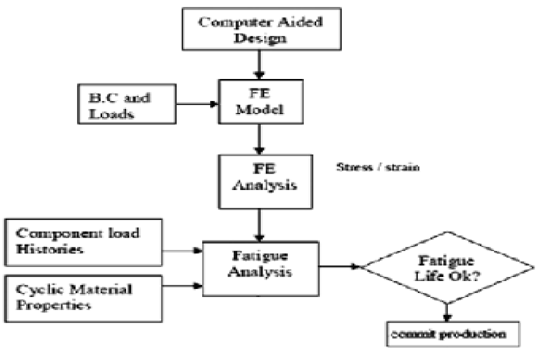

Figure 6. The finite element based fatigue analysis cycle

4.2 Fatigue analysis of a spring by using MSC. Fatigue

Here, HYPERMESH has used for pre-processing, NASTRAN used for solver and HYPERVIEW used for post-processor.

Modeling is done using CATIA V5. Pre-processing is done by using HYPERMESH V 9.0. Analysis is carried out by using MSC-FATIGUE software for better understanding fatigue result. The modeling geometry created in CATIA V5. It is imported in HYPERMESH for pre-processing like (defining loading, boundary conditions, material properties, meshing (HEX). Analysis is carried out by using MSC-FATIGUE software for determine load, deflection, shear stress, von-mises stress, fatigue life etc.

The procedure is same in ANSYS for defining following term because in HYPERMESH user profile selected as an ANSYS for pre-processing.

1. Element type, 2.SOLID185, 3.Input Data, 4. Element Input, 5.Element Name, 6.Nodes, 7.Degrees of freedom, 8.Real constants, 9.Material properties, 10. Surface loads, 11. Body loads, 12.Meshing, 13. Boundary Conditions

Helical compression spring which is modeled and fatigue analyzed.The fatigue loading curve information is as shown in figure 7 and figure 9. The fatigue life model result obtained is as shown in figure 8 and figure 10. It's life is found to be more than 3,00,000 cycles. It is safe for design and manufacturing.

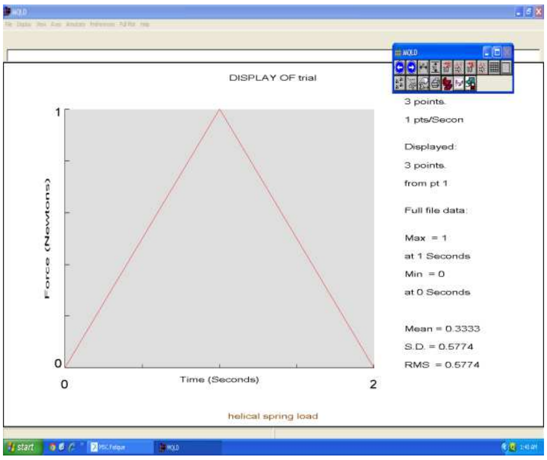

Figure 7. Fatigue load curve (Nastran)

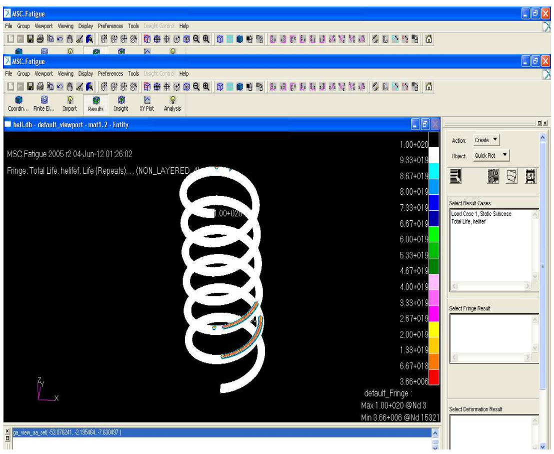

Figure8. Life cycle model (Nastran)

4.3 Fatigue analysis of a spring by using Ansys

The commercial programs ANSYS are used in the spring fatigue analysis to estimate the number of cycles to failure at stress amplitude. The general methodology used in the analysis is presented next.

A finite element model of the spring was created in ANSYS. Analysis is also carried out by using ANSYS 14.0 software for better understanding. SOLID185 element is a higher order 3-D, 8-node element used for analysis. A linear stress analysis was made in ANSYS and the information of the stresses on the spring surface was transferred to solid element of a spring. In order to determine the fatigue life due to constant amplitude loading,

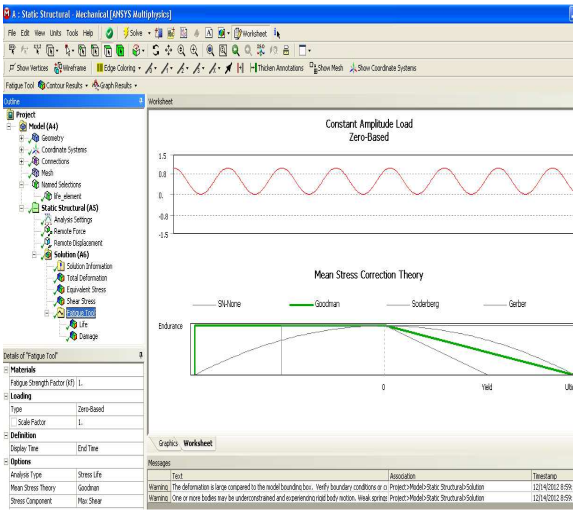

Figure 9. Fatigue load curve (Ansys)

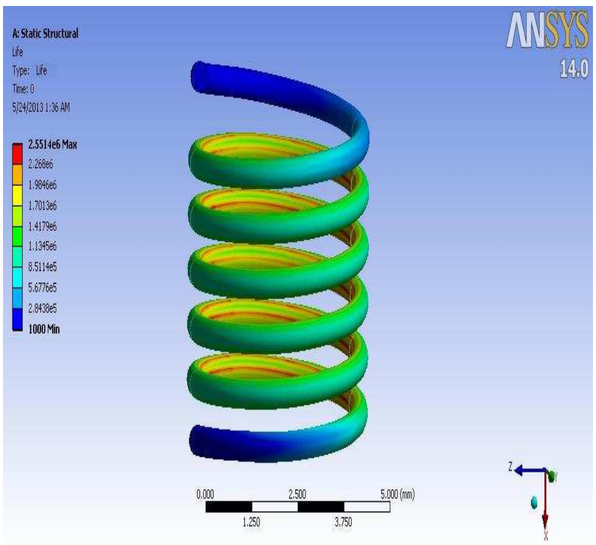

Figure 10. Life cycle model (Ansys)

5. Conclusion

The stainless steel spring complete 3,00,000 cycles. It does not fail before its service period of time (i.e. 300000 cycles).From the study, it is seen that the stainless steel compression spring fatigue life is very good. It satisfied the customer demand and it is safe for design and manufacturing.

The conclusions drawn from the theoretical, FEA and experimental analysis carried out are as, 1.The fatigue life of a stainless steel(AISI 304 / ASTM A 313) spring is 3.66×10^6 (NASTRAN) and 2.55×10^6 (ANSYS).2. The experimental fatigue life of a spring is above 300000 cycles and it is safe.3. The theoretical fatigue life of a spring is good. It is safe for design. 4. The theoretical and experimental results were compared with FEA result. The results show good agreement with theoretical and experimental test results.5. The maximum stress of a sprig observed at the inner side of a spring in figure 8 and figure 10.

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