International Journal For Technological Research In Engineering (IJTRE)
Volume 2, Issue 7, March-2015
ISSN: 2347-4718

Fatigue Analysis for Helical Compression Spring for Determining Design Alternatives for Enhanced Life and Performance

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Abstract - **In the Internal Combustion Engine, valve opening and closing is done by cam follower mechanism with the help of helical compression spring. As per the failure data, percentage ratio of premature fatigue failure of an exhaust valve spring of a constant speed I.C. engine is more. So the springs must be designed for reliability. The major loading on the springs happens during the start/stop time causing an oscillatory displacement. The springs must be designed to support the fatigue process. For safety, the life of the spring is expected to be about 50,000 cycles as per the standards, for particular frequency of applied load. Static and fatigue analysis of compression spring used for IC Engine valve of a two-wheeler is carried out using simulation software for better design features, better performance and long life. The spring is modelled using CAD software CATIA V5. This is further evaluated using FEA software (CAE) for Fatigue Analysis (MSC Fatigue) since the spring is subjected to cyclic loading. The analysis established the expected life of the spring while it is subjected to the predetermined loads during its operation. The analysis for fatigue life has been done by making few design changes and performing numbers of iterations. By comparing the fatigue life of modified springs higher life spring design is finalized. To verify new design the Fatigue test experimentation is carried out on the fatigue test machine (Special Purpose Machine).**

Keywords –valve spring, compression spring failure, fatigue life, static and fatigue analysis

1. INTRODUCTION

A spring is a device which is used for the efficient storage and release of energy.A spring can be used in different shapes, such as the helical coil of a wire, a piece of stamping or a flat, wound-up strip or depending upon the requirements,. Helical compression springs are most commonly used spring type applications. They can be found in almost all mechanical products and have a wide range of applications. A two wheeler IC Engine valve spring has problem of warranty rejection which is caused mostly due to fatigue failure. Following objectives are defined to rectify problem associated with valve spring.

a. Modify and Design the spring with the help of fatigue analysis for life enhancement of spring.
b. To reduce the incidence of fatigue failure for the working life of the component (50,000 cycles)
c. Design analysis with iterations with different modified design.
d. Introduce variations in the configuration of the spring
e. Document and suggest solution

2. LITERATURE REVIEW

A.González Rodríguez et al., (2011) have proposed an adjustable-stiffness actuator composed of two antagonistic non-linear springs ,B. Pyttel et al., (2010) gives overview of the present state of research on fatigue strength and failure mechanisms at very high number of cycles (Nf > 107),B. Pyttel et al., (2013) compared the results of the different spring sizes, materials, number of cycles and shot peening conditions. Michalczyk [2012]have presented analysis of elastomeric coating influence on dynamic resonant stresses values in spring ,Matjazˇ Mršnik et al., (2012) have compared methods used for fatigue-life ,Nenad Gubeljaka et al., (2011) proposed methods to determine allowed size of inclusions in spring's steel.Sid Ali Kaoua et al., (2010) have presented a 3D geometric modeling of a twin helical spring and employed finite element analysis to study the spring mechanical behavior under tensile axial loading, Stefanie Stanzl-Tschegg [2012] have presented the principles and testing procedures of very high cycle fatigue tests ,Touhid Zarrin-Ghalami,Ali Fatemi[2013] have proposed study of a general methodology for life prediction of elastomeric,Wei Li et al.,[2013]have proposed very high cycle fatigue (VHCF) properties of a newly developed clean spring steel were experimentally examined under rotating bending and axial loading ,Yuxin Penga et al.,[2011] have proposed stranded wire helical spring (SWHS) a unique cylindrically helical spring, which is reeled by a strand that is formed of 2x16 wires.

3. ADOPTED METHODOLOGY

The static and fatigue analysis has been performed on the warranty claimed compression spring using CAE tools. Number of iterations has been performed by making some changes in design parameters to finalize a new design for higher fatigue life. The above said work was planned in following phases.

Phase I – Study and review the design for the existing compression spring.
Review of different papers had taken to understand the previous work done, study various reasons, results obtained by researchers and scientists.

Phase II - Analysis for the compression spring using CAE.
Fatigue analysis of a CAD model of the spring is done using Finite element analysis and Fatigue analysis software. Results are in the form of parameters like maximum deflection/deformation of spring, maximum vonMises stress, maximum shear stress and the minimum fatigue life of the spring (no. of cycles).Finite Element Analysis procedure is shown in Figure 1

3.1 Flow chart:

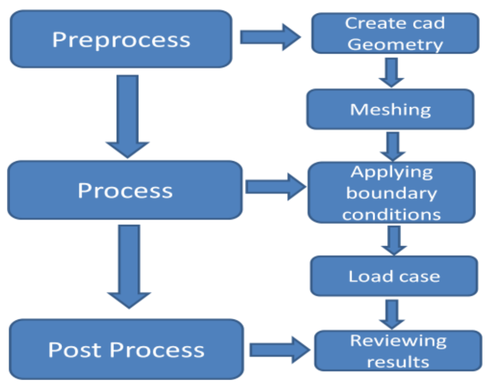
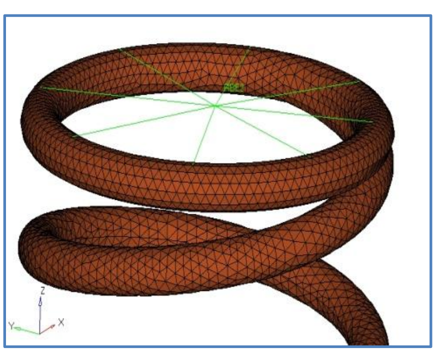


Figure 1: Finite Element Analysis Flow Chart

3.2 FEA Pre-processor:

The pre-processor stage in FEA for the compression spring is as follows:

a. Creating Geometrical model: **-** Modeling was done using CATIA V5R20 and analysis was carried out by using NASTRAN 2010 software.
b. Element type Selection:-Tetra 10 (Tetrahedral shaped, 3 Degree of Freedom, quadratic shape element) is used for analysis. The load and the constraints are applied on the mater node which is connected to the spring by 1D rigid RBE2 and RBE2 element as shown in the Fig 2a and Fig 2b



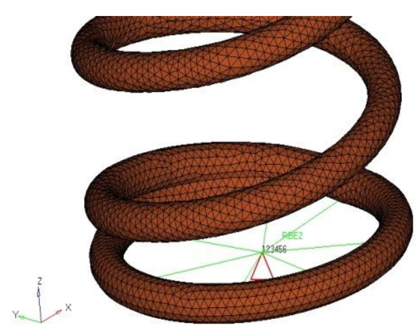


Fig 2(a) Tetrahedral mesh model zoom view **Fig 2(b)** Rigid and solid element connectivity

c. FE Model Creation (Meshing): - Mesh generation is a process of dividing the structure continuum into a number of discrete parts or finite elements. If the mesh is finer, the results are also better but the analysis time is longer. Therefore, a compromise between accuracy & solution speed is made.
d. Assigning material properties: - Material properties Young's modulus & Poisson's ratio are defined
e. Applying loads: - Some types of load are usually applied to the analysis model. The loads may be applied to a point, an edge, a surface or an even a complete body. A load of 100 N is applied on the top rigid element RBE3 at the master node, whereas the boundary condition is applied at the bottom rigid element RBE2 at the mater node as shown in Fig 3a and Fig 3b

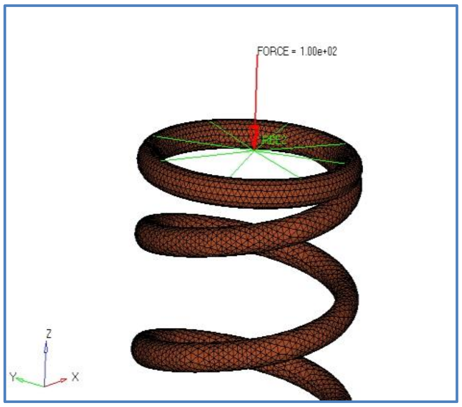


Fig 3(a) Spring with Load applied

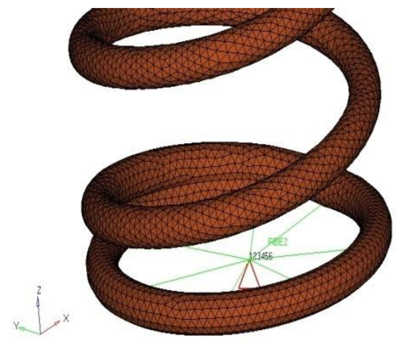
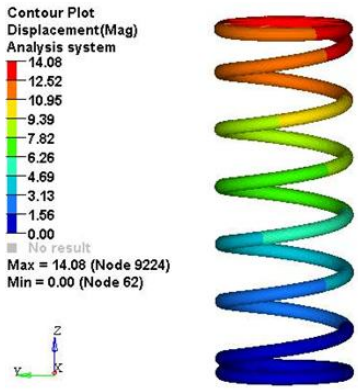


Fig 3(b) spring with Boundary condition

f. Applying boundary conditions: - If any load is applied to the model, then in order to stop it accelerating through the computer's virtual ether (mathematically known as a zero pivot), at least one constraint or boundary condition must be applied. Constraint is applied at bottom.

3.3 Static Structural analysis of the original spring:

A static structural analysis is carried out with the given loading condition in the NASTRAN solver. Preprocessing of helical compression spring is done by using HYPERMESH software. Where the 3D tetrahedral mesh is done and the input deck is prepared for NASTRAN solver.
The result are shown in Fig 4 and Fig 5



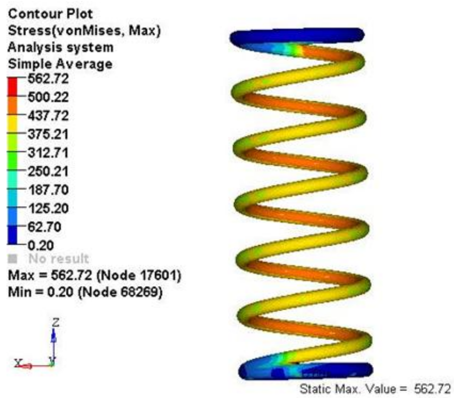


Fig 4: Maximum deflection of spring

Fig 5: Maximum von Mises stress in the spring

3.4 Fatigue analysis of original spring:

After NASTRAN solver the result file and the input deck file is imported in the MSC FATIGUE software for fatigue predication of a helical compression spring. Steps involved are,

1. Reading input file in the MSC FATIGUE software.
2. Reading the static result file for fatigue life prediction
3. Defining the fatigue properties as
    - **Solution Parameter:** Fatigue solution parameter like stressed based fatigue is used by defining the SN curve with Goodman mean stress correction and the signed von Mises stresses are consider for fatigue analysis
    - **Material Information:** Spring steel material parameter is defined from the fatigue software library is SAE 1045_705_QT. The SAE material of steel spring properties is selected. The SN data with Young's modulus of elasticity and Ultimate tensile stress are selected.
    - **Loading Information:** A triangular load curve is defined as a cyclic load acting on the compression spring the loading information and the load curve is plotted.

3.5 Spring Fatigue life Predication of the original spring:

Original spring fatigue is simulated and the result is shown Fig 6

Life predication: The minimum life shown in the simulation analysis is shown in Fig 6. It is 1.14e4 which is more than 50,000 cycles.

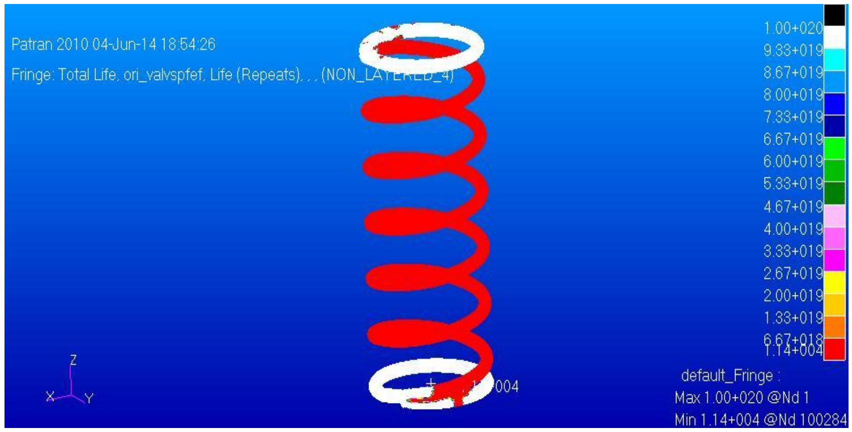


Fig 6: Total life plot of compression spring

Phase III –Modified Design by considering the factors affecting fatigue life.

By taking into account the results from the analysis the new design for the existing compression spring is proposed. Modification in design parameters such as pitch values and wire diameter are suggested to enhance the fatigue life of an original spring.

3.6 Fatigue and Static results of modified spring:

Modification has done by taking different values for pitch and wire diameter. For these modified design the Finite Element Analysis has been done in four numbers of iteration. The analysis results of maximum deformations, vonMises, shear stress and fatigue life for different diameters and pitch values are as shown in the Table 1. By comparing the results spring with higher value of fatigue life has been selected as a final design and it is considered for validation.

Table 1 Modified spring analysis result for no of iteration

Design Modification	Deformation	VonMises Stress	Shear Stress	Life
Iteration 1	14.62	463.98	267.14	1.87e1
Iteration 2	14.02	455.83	262.38	1.40e4
Iteration 3	20.6	642.28	355.69	4.13e3
Iteration 4	11.25	439.75	250.30	7.40e4

Phase IV - Validation of the Design through Trials and Testing of the Compression Spring for fatigue failure.

Fatigue test experimentation is carried out on the fatigue test machine (SPM) as shown in Figure 7a and Figure 7b for a helical compression spring for validation. The trials are conducted to test the life in terms of minimum number of predetermined cycles sustained by the test sample during cyclic loading; it is in a very controlled environment with focus on the variables influencing the fatigue life.

Figure 7(a): Fatigue testing machine

Figure 7(b): Fatigue test rig

As per the validation test report the minimum limit for the fatigue life being 50, 000cycles, the component has withstood the same without failure. During and after testing no cracks and no fracture found.

4. RESULTS AND DISCUSSION

Original compression spring shows the maximum deflection of 14.08 mm which is well within the permissible limit. Maximum vonMises stress is observed to be 562.72 MPa near the rigid element and spring element connection. Maximum shear stress is observed to be 318.46 MPa near the rigid connection. The minimum life predicated by simulation is about 1.14e4 cycle for the original spring design. The damage sum of the original spring design is less than 1. Hence the design is safe for fatigue life. But in reality as per the case study compression spring failed due to premature failure. Modified compression spring shows the maximum deflection of 11.257 mm which is well within the permissible limit as shown in Figure 8.

4.1 Result comparisons of original and modified compression spring:

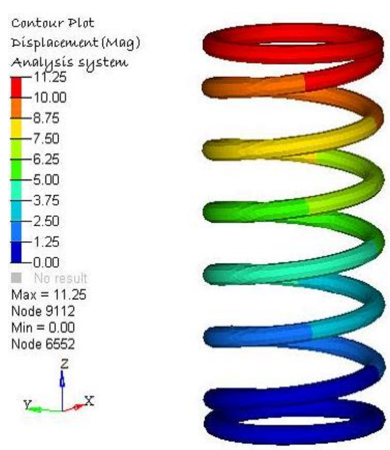


Figure 8: Maximum deflection of spring

Maximum von Mises stress is observed to be 439.75MPa near the rigid element and spring element connection shown in Figure 9. Maximum shear stress is observed to be 250 MPa near the rigid element connection. The minimum life predicated for optimized design of spring is about 7.40e4 cycle shown in Figure 10. Comparison graph is shown in Figure 11

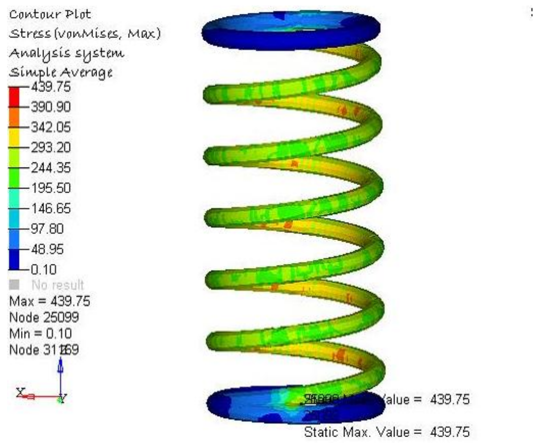


Figure 9 : Maximum von Mises stress in the spring

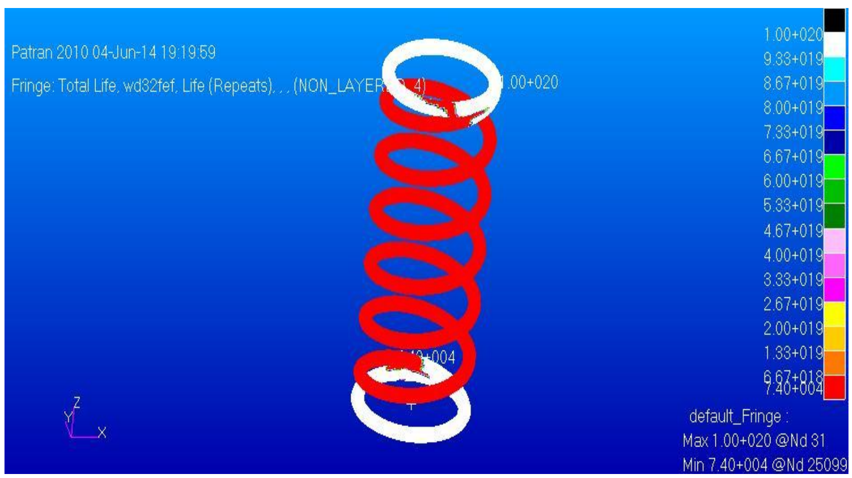


Figure 10: Total life plot of modified spring

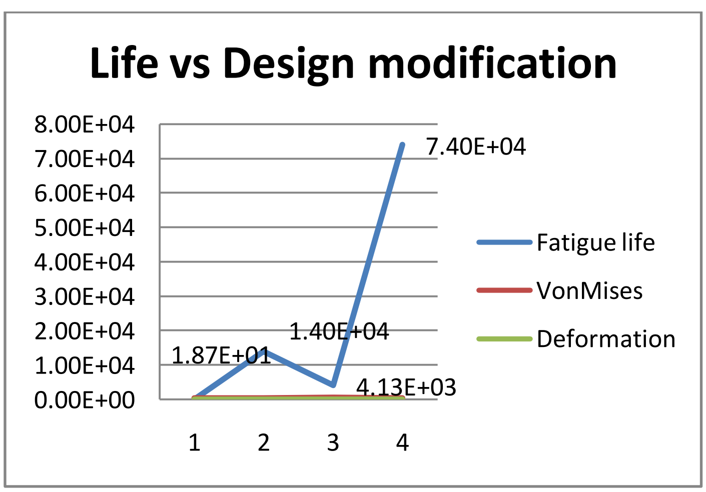


Figure 11: Comparison curve of Modified and Original spring

Table 2: Analysis results between original and modified spring

Sr. No.	Compression Spring	Original Compression Spring	Modified Compression Spring
1	Maximum Deformation of the spring (mm)	14.08	11.25
2	Maximum von-Mises Stress in the spring (MPa)	562.72	439.75
3	Maximum Shear stress in the spring	318.46	250.30
4	Minimum fatigue life in the spring (No. of cycle)	1.14e4	7.40e4

From the above Table 2 and figure 11 the minimum life of modified spring shown in the simulation is 7.40e4 which is more than required life cycle. Hence the modified design shows the permissible life of failure. For the maximum life the vonMises and deformation value has changed very less.

5. CONCLUSIONS

A software-based numerical approach has been applied effectively to solve problem of premature failure of a compression spring. Results indicate that the considerations of changes in design parameters like pitch and wire diameter can increase in fatigue life of spring. The comparative analysis shows that the changes in design parameters like pitch and wire diameter gives minimum fatigue life 7.40e4 cycle which enhances the fatigue life of compression spring ultimately achieved effective and reliable performance of compression springs.Same compression spring has tested for predetermined number of cycles and it withstood the same without failure.

REFERENCES

[1] A.González Rodríguez a, J.M. Chacón b, A. Donoso c, A.G. González Rodríguez d Design of an adjustable-stiffness spring: Mathematical modeling and simulation, fabrication and experimental validation. 5th Jul 2011.
[2] B. Pyttel *, D. Schwerdt, C. Berger Very high cycle fatigue – Is there a fatigue limit? 20th May 2010.
[3] B. Pyttel a,⇑, I. Brunner a, B. Kaiser a, C. Berger a, M. Mahendran b Fatigue behaviour of helical compression springs at a very high number of cycles– Investigation of various influences.
[4] K. Michalczyk: Analysis of the influence of elastomeric layer on helical spring stresses in longitudinal resonance vibration conditions. 28th Oct 2012.
[5] Matjazˇ Mršnik, Janko Slavicˇ, Miha Boltezˇar Frequency-domain methods for a vibration-fatigue-life estimation – Application to real data. 17th Jul 2012.
[6] Marcos Giovani Dropa de Bortoli1, Raul Bosco Jr2, Rinaldo Puff3, “Fatigue Analysis of Helical Suspension Springs for Reciprocating Compressors”, International Compressor Engineering Conference at Purdue, July 12-15, 2010.
[7] Nenad Gubeljaka, Mirco D. Chapettib, Jožef Predana, Bojan Sencic Variation of Fatigue Threshold of Spring Steel with Prestressing.
[8] Sid Ali Kaoua a, Kamel Taibi a, Nacera Benghanem a, Krimo Azouaoui b, Mohammed Azzaz a Numerical modelling of twin helical spring under tensile loading. 8th Sep 2010.
[9] Stefanie Stanzl-Tschegg Very high cycle fatigue measuring techniques. 30th Nov 2012.
[10] Touhid Zarrin-Ghalami, Ali Fatemi Multiaxial fatigue and life prediction of elastomeric components. 22nd May 2013.
[11] Wei Li a, Tatsuo Sakai b, Masami Wakita c, Singo Mimura c Influence of microstructure and surface defect on very high cycle fatigue properties of clean spring steel. 14th Jun 2013.

[12] Yuxin Penga,b,∗, Shilong Wangb, Jie Zhoub, Song Lei b Structural design, numerical simulation and control system of a machine tool for stranded wire helical springs.March 24,2011

[13] ZHOU Jie 1, WANG Shilong 1, KANG Ling 1, And Yang Tianyi 2, "Design and Modeling on Stranded Wires Helical Springs, State Key Laboratory of Mechanical Transmissions, Chongqing University, Chongqing 400044, China, CHINESE JOURNAL OF MECHANICAL ENGINEERING Vol. 24, No. 3, 2011 published electronically March 23, 2011.