FATIGUE STRESS ANALYSIS OF HELICAL COMPRESSION SPRING:A REVIEW

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ABSTRACT

The objective of this review paper is to provide the information about the fatigue stress for the helical compression spring. Springs are mechanical shock absorber system. A mechanical spring is defined as an elastic body which has the primary function to deflect or distort under load, and to return to its original shape when the load is removed. The researchers throughout the years had given various research methods such as Theoretical, Numerical and Experimental. Researchers employ the Theoretical, Numerical and FEM methods.This study concludes Finite Element method is the best method for numerical solution and calculating the fatigue stress, life cycle and shear stress of helical compression spring.

Key words: Helical compression spring, Maximum shear stress, fatigue stress, fatigue life, Finite element method.

INTRODUCTION

A spring is defined as an elastic machine element, which deflects under the action of the load & returns to its original shape when the load is removed [1]. Mechanical springs are used in machine designs to exert force, provide flexibility, and to store or absorb energy. Springs are manufactured for many different applications such as compression, extension, torsion, power, and constant force. Depending on the application, a spring may be in a static, cyclic or dynamic operating mode. A spring is usually considered to be static if a change in deflection or load occurs only a few times, such as less than 10,000 cycles during the expected life of the spring. A static spring may remain loaded for very long periods of time. The failure modes of interest for static springs include spring relaxation, set and creep. [2]

Classification of spring

In general, spring may be classified as:

1. Wire spring such as helical spring of round or square wire, made to resist and deflect under tensile, compressive and torsional loads.

2. Flat spring which is includes cantilever elliptical types, wound motor or clock type power spring, a flat spring washers, usually called Belleville springs.

3. Special shaped springs.

4. Theoretical development

To determine the stress generated in the spring, consider a helical spring subjected to an axial load *F*, see Fig. 1(a). [2][12]

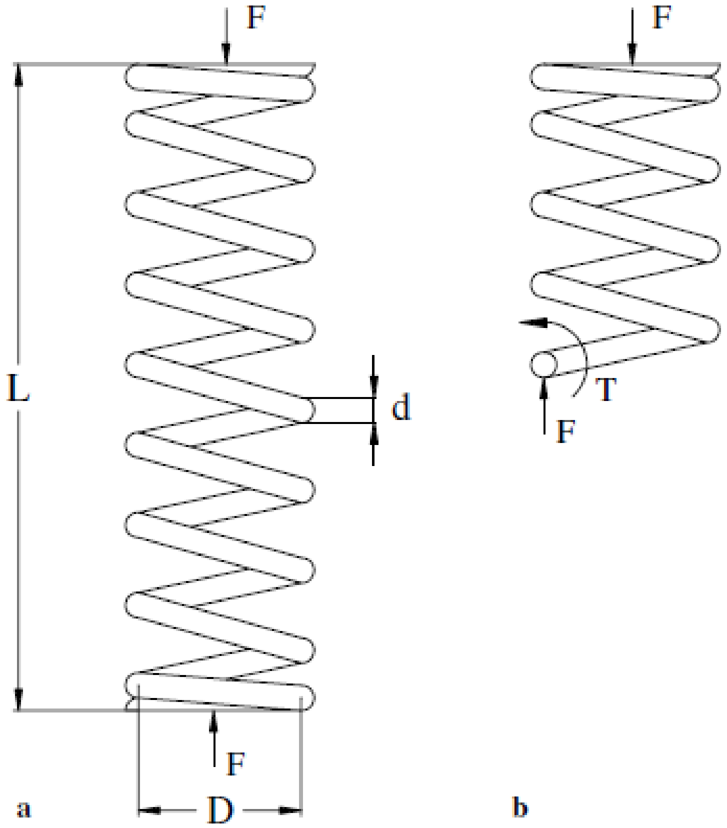

Fig. 1(a) Helical spring with axial load and (b) free body diagram.

Now imagine the spring is sectioned at some point, Fig. 1(b). Internal forces are generated to maintain the remaining portion shown in Fig. 1(b) in equilibrium. A direct shear force *F* and a torque *T* appear. The maximum shear stress on the wire can be calculated by the following equation [2,3]

$$\tau_{max} = \pm \frac{T_r}{J} + \frac{F}{A} \quad (1)$$

Where *J* is the polar moment of inertia, *A* is the cross section area and *r* is the wire radius. The first term corresponds to torsion contribution and the second term is the direct shear stress. Considering a wire with circular cross section of diameter $d(= 2r)$, the last equation may be reduced to

$$\tau = \frac{8FD}{\pi d^3} + \frac{4F}{\pi d^2} = \mathrm{K}\,\frac{8FD}{\pi d^3} \quad (2)$$

Where D is the mean coil diameter, K is the Wahl factor, C is the spring index defined by

$$K = 1 + \frac{0.5}{C}, \quad C = \frac{D}{d} \qquad (3)$$

When the external load, F, is variable, the induced stress is variable as well. The mean stress τ_m and the amplitude τ_a are defined by

$$\tau_m = K_s \frac{8F_m D}{\pi d^3} \quad \text{and} \quad \tau_a = K_b \frac{8F_a D}{\pi d^3} \qquad (4)$$

Where K_s and K_b are correction factors due to curvature [2,12] and F_m and F_a are the mean load and load amplitude, respectively.[2]

Helical compression spring

Helical compression springs becomes quite necessary to do the complete stress analysis of the spring. As these springs undergo the fluctuating loading over the service life, it becomes essential to find out the fatigue limit of the same. Mechanical spring is defined as an elastic body that has the primary function to deflect or distort under load, and to return to its original shape when the load is removed. First step in the design of spring in general, is to determine the loads and the deflections required for a given spring application depending upon the type of the loading.

Type of Compression spring

There are four standard types on helical compression springs. They are plain end, squared end, plain-ground end, and squared-ground as illustrated in fig. (2)

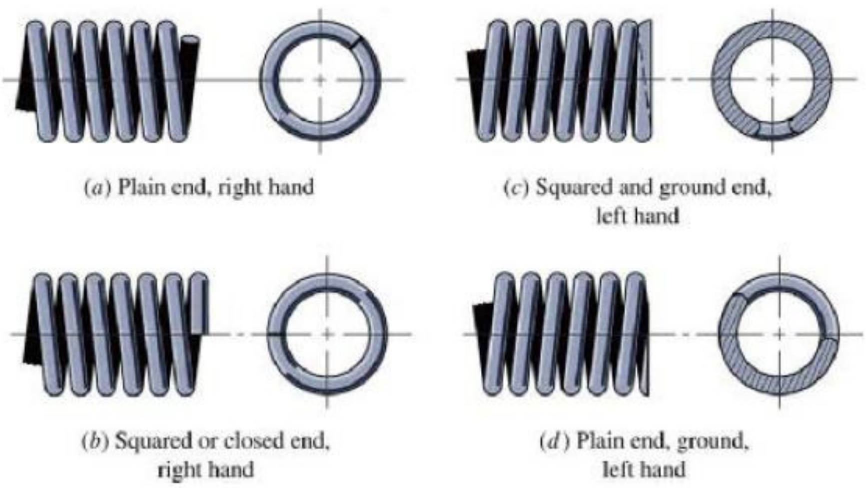

Fig. 2: Shows the geometry of four standard types on helical compression springs [2]

- A spring with plain ends has a non-interrupted helicoides the ends are the same as if a long spring had been cut into sections.
- A spring with plain ends that are squared or closed is obtained by deforming the ends to a zero-degree helix angle.

- Springs should always be both squared and ground for important applications, because a better transfer of the load is obtained.
- A spring with squared and ground ends compressed between rigid plates can be considered to have fixed ends.[2]

Concept of spring design

The design of a new spring involves the following considerations [2]

• Space into which the spring must fit and operate.

• Values of working forces and deflections.

• Accuracy and reliability needed.

• Tolerances and permissible variations in specifications.

• Environmental conditions such as temperature, presence of a corrosive atmosphere.

• Cost and qualities needed.

The designers use these factors to select a material and specify suitable values for the wire size, the number of turns, the coil diameter and the free length, type of ends and the spring rate needed to satisfy working force deflection requirements. The primary design constraints are that the wire size should be commercially available and that the stress at the solid length be no longer greater than the torsional yield strength. [2]

LITERATURE REVIEW

A few papers where discussed about developing and validating procedures for predicting the fatigue stress analysis.

James M. Meagher et al. (1996) the author presents theoretical model for predicting stress from bending agreed with the stiffness and finite element model within the precision of convergence for the finite element analysis. The equation is calculated by principal stresses and von misses stress and it is useful for fatigue studies. A three dimensional finite element model is used for two coil of different wire model, one is MP35N tube with a 25% silver core and other a solid MP35N wire material helical conductor and the result is compared with the proposed strength of material model for flexural loading.[4]

M. T. Todinov (1999) author gives for helical compression spring with a large coil radius to wire radius ratio, the most highly stressed region is at the outer surface of the helix rather than inside. The fatigue crack origin is located on the outer surface of the helix where the maximum amplitude of the principal tensile stress was calculated during cyclic loading, according to the author fatigue design should be based on the range of the maximum principal tensile stress.[5]

Kotaro watanabe et al. (2001) a new type rectangular wire helical spring was contrived by the authors is used as suspension springs for rally cars, the stress was checked by FEM analysis theory on the twisting part. The spring characteristic of the suspension helper spring in a body is clarified. Manufacturing equipment for this spring is proposed.[6]

B. Ravi kumar et al. (2003) author was analysed the failure of a helical compression spring employed in coke oven batteries surface corrosion product was analyzed by X-ray diffraction (XRD) and scanning electron microscope - energy dispersive spectroscopy (SEM–EDS). Here used various testing procedure as chemical, surface corrosion product, fracture surface analysis. The conclusion of this work that the most probable cause of failure of the helical compression springs was corrosion fatigue accentuated by loss of surface residual compressive stress.[7]

Dammak Fakhreddine et al. (2005) In this paper the author presents an efficient two nodes finite element with six degrees of freedom per node, capable to model the total behaviour of a helical spring. the working on this spring is subjected to different cases of static and dynamic loads and different type of method (finite element method, dynamic stiffness matrix method) is governing equations by the motion of helical spring. This element permits to get the distribution of different stresses along the spring and through the wire surface without meshing the structure or its surface.[8]

L. Del Llano-Vizcaya et al. (2006) In this paper author used a critical plane approach, Fatemi–Socie and Wang–Brown, and the Coffin–Manson method based on shear deformation. The stress analysis was carried out in the finite element code ANSYS, and the multiaxial fatigue study was performed using the fatigue software nCode and compared with experimental results in order to assess the different criteria. A failure analysis was conducted in order to determine the fatigue crack initiation point and a comparison of that location with the most damaged zone predicted by the numerical analysis is made. The M (Manson) method to estimate strain-life properties from the monotonic uniaxial tension test, gives better predictions of the spring fatigue lives than the MM (Muralidharan) method.[9]

C. Berger, B. Kaiser (2006) In this paper the author presents the first results of very high cycle fatigue tests on helical compression springs. The springs tested were manufactured of Si–Cr-alloyed valve spring wire with a wire diameter between 2 and 5 mm, shot-peened and the fatigue tests are continued up to 10^8cycles or even more. The aim should be to elaborate results about and insights concerning the level of the fatigue range in the stress cycle regime up to 10^9cycles, about the mechanisms causing failures and about possible remedies or measures of improvement.[10]

Chang-Hsuan Chiu et al. (2007) In this paper the author present, four different types of helical composite springs were made of structures including unidirectional laminates (AU), rubber core unidirectional laminates (UR), unidirectional laminates with a braided outer layer (BU), and rubber core unidirectional laminates with a braided outer layer (BUR), respectively. It aims to investigate the effects of rubber core and braided outer layer on the mechanical properties of the aforementioned four helical springs. According to the experimental results, the helical composite spring with a rubber core can increase its failure load in compression. Therefore, author wants to say that the shock absorbers with high performance might be expected to come soon.[11]

L. Del Llano-Vizcaya et al. (2007) according to the author gives an experimental investigation has been conducted to assess the stress relief influence on helical spring fatigue properties. First S–N curves were determined for springs treated under different conditions (times and temperatures) on a testing machine. Next the stress relief effect on spring relaxation induced by cyclic loading was evaluated. This methodology used in the experimental work and procedures used in the relaxation tests, fatigue tests and residual stress measurements. Finally, residual stresses were measured on the inner and outer coil surfaces to analyze the effect of heat treatment. The results of this work will help in the spring design and manufacture methodologies.[12]

Y. Prawoto et al. (2008) author gives an automotive suspension coil springs, their fundamental stress distribution, materials characteristic, manufacturing and common failures. A coil's failure to perform its function properly can be more catastrophic than if the coil springs are used in lower stress. As the stress level is increased, material and manufacturing quality becomes more critical. This paper discusses several case studies of suspension spring failures. The finite element analyses of representative cases were finite element modeling in metallurgical failure analysis synergizes the power of failure analysis into convincing quantitative analysis.[13]

Yuuji Shimatani et al. (2010) In this paper author present a two types of specimen were processed by grinder and cutting tool, both specimens showed clear duplex *S-N* curve, composed of three or two types of failure mode depending on the stress amplitude, such as, a surface inclusion induced failure mode (S-mode), a subsurface inclusion-induced failure mode without (I-mode) and with granular bright facet (GBF) area in the vicinity of inclusion (IG-mode). Fatigue life in very high-cycle regime was almost same between the both specimens because of the existence of almost same size inclusion at crack origin.[14]

C. Berger, B. Kaiser et al. (2011) In this paper the author presents a long-term fatigue tests up to a number of 10^9 cycles on shot peened helical compression springs with two basic dimensions, made of three different spring materials. The test springs were manufactured of oil hardened and tempered of SiCr and SiCrV-alloyed valve spring steel wires and of a stainless steel wire with diameters of 1.6 mm and 3.0 mm with shot peened. Method to be used experimental procedure the VHCF-test on spring. It becomes obvious that the various spring types in test exhibit different fatigue properties and different failure mechanisms in the VHCF regime.[15]

Mehdi Bakhshesh et al. (2012) In this paper author used helical spring is the most common used in car suspension system, steel helical spring related to light vehicle suspension system under the effect of a uniform loading has been studied and finite element analysis has been compared with analytical solution and steel spring has been replaced by three different composite helical springs including E-glass/Epoxy, Carbon/Epoxy and Kevlar/Epoxy. Numerical results have been compared with theoretical results and found to be in good agreement.[16]

Brita pyttel et al. (2012) in this paper author present is helical compression springs are used generally in fuel injection system of diesel engines, where it undergoes cyclic loading for more than 10^8 numbers of cycles and along the length of the spring at inner side. Finite element analyses were carried out, using ABAQUS 6.10. The simulation results show an oscillatory behaviour of stresses along the length at inner side. Shear stresses along the length of the spring were found to be asymmetrical and with local maxims at starting of each middle coil. The FEA need to be modified further for cyclic analysis and failure analyses to be used with ABAQUS.[17]

C. Berger, B. Kaiser et al. (2013) In this paper the author presents a long-term fatigue tests on shot peened helical compression springs were conducted by means of a special spring fatigue testing machine at 40Hz. Test springs were made of three different spring materials- oil hardened and tempered SiCr- and SiCrV-alloyed valve spring steel and stainless steel up to 500 spring with a wire diameter of d = 3.0 mm or 900 spring with d = 1.6 mm were tested at different stress levels. Method to be used experimental procedure the VHCF-test on different wire diameter of spring. The paper includes a comparison of the result of the different spring sizes, materials, number of cycles and shot peening conditions and outlines further investigations in the VHCF-region.[18]

CONCLUSION

The above literature review presents that the helical compression springs becomes quite necessary to do the complete stress analysis of the spring. These springs undergo the fluctuating loading over the service life. In addition, FEM software has been use for performing meshing simulation. Almost in all of the above cases, fatigue stress, shear stress calculation play more significant role in the design of helical compression springs. This study shows that shear stress and deflection equation is used for calculating the number of active turns and mean diameter in helical compression springs. Comparison of the theoretical obtained result by the shear stress equation to the Finite Element Analysis result of helical compression springs is the mode of our present work, by this analysis it will possible in future to provide help to designers for design of spring against fatigue condition.

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