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Literature Review on Design, Analysis and Fatigue Life of a Mechanical Spring

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Abstract

In this paper there is reviewed some papers on the design and analysis spring performance and fatigue life prediction of spring. There is also the analysis of failure in spring. The aim of this review paper is to represent a general study on the analysis of spring. Compression springs are commonly used in the I.C. Engine valves,2 wheeler horn & many more and are subjected to number of stress cycles leading to fatigue failure. A lot of research has been done for improving the performance of spring. Now the automobile industry has shown interest in the replacement of steel spring with composite spring. In general, it is found that fiberglass material has better strength characteristic and lighter in weight as compare to steel for spring. We can reduce product development cost and time while improving the safety, comfort, and durability of the vehicles produce. The CAE tool has where much of the design verification is now done using computer simulation rather than physical prototype testing.
Keywords: Spring, finite element analysis, FEM, CAE tool.

1. Introduction

Springs are mainly used in the industry as members absorbing shock energy as well as for restoring the initial position of a part upon displacement for initiating a given function. Compression springs are coil springs that resist a compressive force applied axially. Compression springs may be cylindrical, conical, tapered, concave or convex in shape. Coil compression springs are wound in a helix usually out of round wire. Every two-wheeler has a provision for a sounding a horn to be used while communicating so as to warn the passer-by of the approaching vehicle as well as a signal for maintaining a safe distance or to communicate for any other reasons for safety. It has been reported by the warranty/ maintenance department that frequent complaints are being received over the failures of these springs well within their intended life span. The springs must be designed for reliability. The springs must be designed to withstand the cyclic loading during operation. Therefore in this dissertation work it is proposed to carry out the design and fatigue analysis of compression spring used for Horn in a two-wheeler so as to have better performance in terms of longer life.

2. Some of the important design considerations in spring work

To adhere to proper procedures and design considerations, some of the important design considerations in spring work are outlined here.

2.1. Selection of material for spring construction

a. Space limitations: Do you have adequate space in the mechanism to use economical materials such as oil-tempered ASTM A229 spring wire? If your space is limited by design and you need maximum energy and mass, you should consider using materials such as music wire, ASTM A228 chrome vanadium or chrome silicon steel wire.

b. Economy: Will economical materials such as ASTM A229 wire suffice for the intended application?

c. Corrosion resistance: If the spring is used in a corrosive environment, you may select materials such as 17-7 PH stainless steel or the other stainless steels (301, 302, 303, 304, etc.).

d. Electrical conductivity: If you require the spring to carry electric current, materials such as beryllium copper and phosphorous bronze are available.

e. Temperature range: Whereas low temperatures induced by weather are seldom a consideration, high-temperature applications will call for materials such as 301 and 302 stainless steel, nickel chrome A286, 17-7 PH, Inconel 600, and Inconel X750. Design stresses should be as low as possible for springs designed for use at high operating temperatures.

f. Shock loads, high endurance limit, and high strength: Materials such as music wire, chrome vanadium, chrome silicon, 17-7 stainless steel, and beryllium copper are indicated for these applications.

2.2. General spring design recommendations

a. Try to keep the ends of the spring, where possible, within such standard forms as closed loops, full loops to centre, closed and ground, and open loops.

b. Pitch. Keep the coil pitch constant unless you have a special requirement for a variable pitch spring.

c. Keep the spring index [mean coil diameter, in/wire diameter, in (D/d)] between 6.5 and 10 wherever possible. Stress problems occur when the index is too low, and entanglement and waste of material occur when the index is too high.

d. Do not electroplate the spring unless it is required by the design application. The spring will be subject to hydrogen embrittlement unless it is processed correctly after electroplating.

Hydrogen embrittlement causes abrupt and unexpected spring failures. Plated springs must be baked at a specified temperature for a definite time interval immediately after electroplating to prevent hydrogen embrittlement. For cosmetic and minimal corrosion protection, zinc electroplating is generally used, although other plating such as chromium, cadmium, and tin are also used per the application requirements. Die springs usually come from the die spring manufacturers with coloured enamel paint finishes for identification purposes.

2.3. Special processing either during or after manufacture

a. Shot penning improves surface qualities from the standpoint of reducing stress concentration points on the spring wire material. This process can also improve the endurance limit and maximum allowable stress on the spring.

b. Subjecting the spring to a certain amount of permanent set during manufacture eliminates the set problem of high energy versus mass on springs that have been designed with stresses in excess of the recommended values. This practice is not recommended for springs that are used in critical applications.

2.4. Stress considerations

Design the spring to stay within the allowable stress limit when the spring is fully compressed or “bottomed.” This can be done when there is sufficient space available in the mechanism, and economy is not a consideration. When space is not available, design the spring so that its maximum working stress at its maximum working deflection does not exceed 40 to 45 percent of its minimum yield strength for compression and extension springs and 75 percent for torsion springs. Remember that the minimum tensile strength allowable is different for differing wire diameters; higher tensile strengths are indicated for smaller wire diameters.

3. Literature Review

K. Michalczyk [1] The analysis of elastomeric coating influence on dynamic resonant stresses values in spring is presented in this paper. The appropriate equations determining the effectiveness of dynamic stress reduction in resonant conditions as a function of coating parameters were derived. It was proved that rubber coating will not perform in satisfactory manner due to its low modulus of elasticity in shear. It was also demonstrated that about resonance areas of increased stresses are wider and wider along with the successive resonances and achieve significant values even at large distances from the resonance frequencies.

B. Pyttel , I. Brunner, et al. [2] Long-term fatigue tests on shot peened helical compression springs were conducted by means of a special spring fatigue testing machine at 40 Hz. Test springs were made of three different spring materials – oil hardened and tempered SiCr- and SiCrV-alloyed valve spring steel and stainless steel. With a special test strategy in a test run, up to 500 springs with a wire diameter of d = 3.0 mm or 900 springs with d = 1.6 mm were tested simultaneously at different stress levels. Based on fatigue investigations of springs with d = 3.0 mm up to a number of cycles N = 109 an analysis was done after the test was continued to N = 1.5 _ 109 and their results were compared. The influence of different shot peening conditions were investigated in springs with d = 1.6 mm. Fractured test springs were examined under optical microscope, scanning electron microscope (SEM) and by means of metallographic microsections in order to analyse the fracture behaviour and the failure mechanisms. The paper includes a comparison of the results of the different spring sizes, materials, number of cycles and shot peening conditions and outlines further investigations in the VHCF-region.. For comparison the results for the springs with d = 1.6 mm and d = 3.0 mm and Ps = 98% are summarised in Fig. 1. Except for springs made of the stainless steel wire, the fatigue strength of springs with d = 3.0 mm is higher than for springs with d = 1.6 mm. The size effect would imply higher fatigue strength for smaller wire diameters.

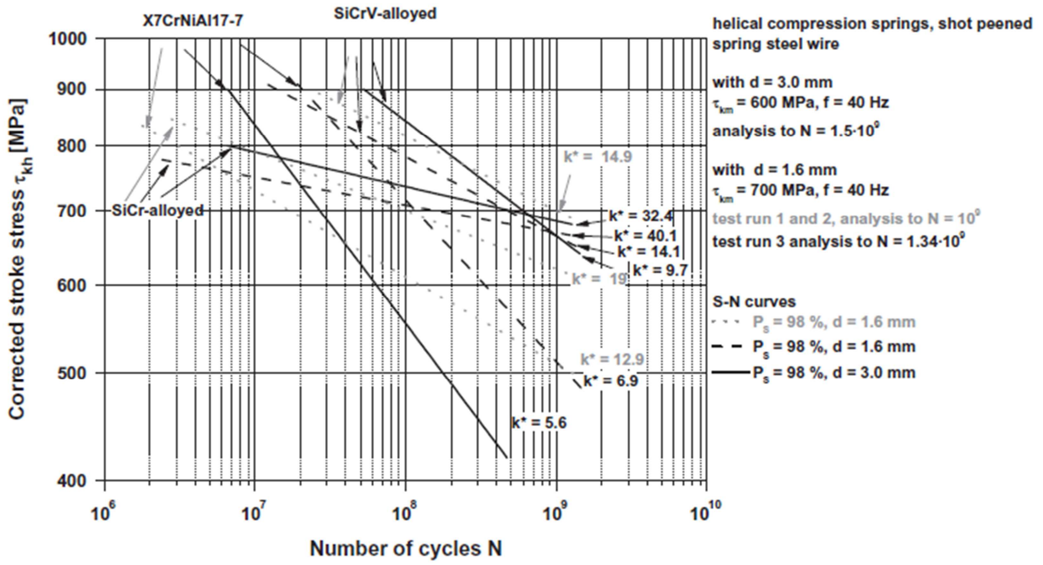

Fig. 1 Comparison of fatigue strength of springs made of various spring steel wires with d = 1.6 mm and d = 3.0 mm at P_s = 98%.

Touhid Zarrin-Ghalami, Ali Fatemi[3] Elastomeric components have wide usage in many industries. The typical service loading for most of these components is variable amplitude and multiaxial. In this study a general methodology for life prediction of elastomeric components under these typical loading conditions was developed and illustrated for a passenger vehicle cradle mount. Crack initiation life prediction was performed using different damage criteria. The methodology was validated with component testing under different loading conditions including constant and variable amplitude in-phase and out-of-phase axial–torsion experiments. The optimum method for crack initiation life prediction for complex multiaxial variable amplitude loading was found to be a critical plane approach based on maximum normal strain plane and damage quantification by cracking energy density on that plane. Rain flow cycle counting method and Miner's linear damage rule were used for predicting fatigue life under variable amplitude loadings. The fracture mechanics approach was used for total fatigue life prediction of the component based on specimen crack growth data and FE simulation results. Total fatigue life prediction results showed good agreement with experiments for all of the loading conditions considered.

Wei Li , Tatsuo Sakai , et al. [4] Very high cycle fatigue (VHCF) properties of a newly developed clean spring steel were experimentally examined under rotating bending and axial loading. As a result, this steel represents the duplex S–N property only for surface-induced failure under rotating bending, whereas it represents the single S–N property for surface-induced failure and interior inhomogeneous microstructure-induced failure under axial loading. Surface small grinding defect-induced failure is the predominant failure mode of this steel in VHCF regime. The surface morphology of the interior inhomogeneous microstructure with distinct plastic deformation is much rougher than that of the ambient matrix, which means the stress concentration resulted from the strain inconsistency between the micro structural in homogeneity as soft phase and the ambient matrix as hard phase plays a key role in causing interior crack initiation. Considering the effect of surface compressive residual stress, the threshold stress intensity factor for surface small defect-induced crack propagation of this steel is evaluated to be 2.04 MPam1/2, which means that the short crack effect plays a key role in causing the surface small defect-induced failure of this steel in the VHCF regime. From the viewpoint of defect distribution, surface and interior failure probabilities are equivalent under a fixed characteristic value of defect density. If the interior defect size is less than or even equal to the surface defect size, surface defect-induced failure will become the predominant failure mode in VHCF regime, especially under rotating bending.

Sid Ali Kaoua a, Kamel Taibi a, et al. [5] This paper presents a 3D geometric modelling of a twin helical spring and its finite element analysis to study the spring mechanical behaviour under tensile axial loading. The spiralled shape graphic design is achieved through the use of Computer Aided Design (CAD) tools, of which a finite element model is generated. Thus, a 3D 18-dof pentaedric elements are employed to discrete the complex ‘‘wired-shape” of the spring, allowing the analysis of the mechanical response of the twin spiralled helical spring under an axial load. The study provides a clear match between the evolution of the theoretical and the numerical tensile and compression normal stresses, being of sinusoidal behaviour. The overall equivalent stress isovalues increases radially from 0_ to 180_, being maximal on the internal radial zone at the section 180_. On the other hand, the minimum stress level is located in the centre of the filament cross section.

B. Pyttel , D. Schwerdt, et al. [6] The paper gives an overview of the present state of research on fatigue strength and failure mechanisms at very high number of cycles (Nf > 107). Testing facilities are listed. A classification of materials with typical S–N curves and influencing factors like notches, residual stresses and environment are given. Different failure mechanisms which occur especially in the VHCF-region like subsurface failure are explained. There micro structural in homogeneities and statistical conditions play an important role. A double S–N curve is suggested to describe fatigue behaviour considering different failure mechanisms. Investigated materials are different metals with body-centred cubic lattice like low- or high-strength steels and quenched and tempered steels but also materials with a face-centred cubic lattice like aluminium alloys and copper. Recommendations for fatigue design of components are given.

Stefanie Stanzl-Tschegg [7] Ever since high-strength steels were found to fail below the traditional fatigue limit when loaded with more than 108 cycles, the investigation of metals' and alloys' very high cycle fatigue properties has received increased attention. A lot of research was invested in developing methods and machinery to reduce testing times. This overview outlines the principles and testing procedures of very high cycle fatigue tests and reports findings in the areas of crack formation, non-propagating small cracks, long crack propagation and thresholds. Furthermore, superimposed and variable amplitude loading as well as frequency effects are reported.

Yuxin Penga, Shilong Wangb, et al. [8] A stranded wire helical spring (SWHS) is a unique cylindrically helical spring, which is reeled by a strand that is formed of 2∼16 wires. In this paper, a parametric modelling method and the corresponding 3D model of a closed-end SWHS are presented based on the forming principle of the spring. By utilizing a PC + PLC based model as the motion control system, a prototype machine tool is designed and constructed, which improves the manufacturing of the SWHS. Via the commercial CAD package Pro/Engineering, numerical simulation is carried out to test the validity of the parametric modeling method and the performance of the machine tool. The scheme of the tension control system is analyzed and the control mechanism is set up, which have achieved the constant tension of each wire. A human machine interface is also proposed to achieve the motion control and the tension control. Experimental results show that the tension control system is well-qualified with high control precision.

A.González Rodríguez, J.M. Chacón, et al. [9] An adjustable-stiffness actuator composed of two antagonistic non-linear springs is proposed in this paper. The elastic device consists of two pairs of leaf springs working in bending conditions under large displacements. Owing to this geometric non-linearity, the global stiffness of the actuator can be adjusted by modifying the shape of the leaf springs. A mathematical model has been developed in order to predict the mechanical behaviour of our proposal. The non-linear differential equation derived from the model is solved, obtaining large stiffness variations. A prototype of the actuator was fabricated and tested for different load cases. Experimental results were compared with numerical simulations for model verification, showing excellent agreement for a wide range of work.

Matjazˇ Mršnik, Janko Slavicˇ, et al. [10] The characterization of vibration-fatigue strength is one of the key parts of mechanical design. It is closely related to structural dynamics, which is generally studied in the frequency domain, particularly when working with vibratory loads. Fatigue-life estimation in the frequency domain can therefore prove advantageous with respect to a time-domain estimation, especially when taking into consideration the significant performance gains it offers, regarding numerical computations. Several frequency-domain methods for a vibration-fatigue-life estimation have been developed based on numerically simulated signals. This research focuses on a comparison of different frequency-domain methods with respect to real experiments that are typical in structural dynamics and the automotive industry. The methods researched are: Wirsching–Light, the a0.75 method, Gao–Moan, Dirlik, Zhao–Baker, Tovo–Benasciutti and Petrucci–Zuccarello. The experimental comparison researches the resistance to close-modes, to increased background noise, to the influence of spectral width, and multi-vibration-mode influences. Additionally, typical vibration profiles in the automotive industry are also researched. For the experiment an electro-dynamic shaker with a vibration controller was used. The reference-life estimation is the rainflow- counting method with the Palmgren–Miner summation rule. It was found that the Tovo–Benasciutti method gives the best estimate for the majority of experiments, the only exception being the typical automotive spectra, for which the enhanced Zhao–Baker method is best suited. This research shows that besides the Dirlik approach, the Tovo–Benasciutti and Zhao–Baker methods should be considered as the preferred methods for fatigue analysis in the frequency domain.

Nenad Gubeljaka, Mirco D. Chapettib, et al. [11] High strength steel grade 51CrV4 in thermo-mechanical treated condition is used as bending parabolic spring of heavy vehicles. Several investigations show that fatigue threshold for very high cycle fatigue depends on inclusion's size and material hardness. In order to determine allowed size of inclusions in spring's steel the Murakami's and Chapetti's model have been used. The stress loading limit regarding to inclusion size and applied stress has been determine for loading ratio R=-1 in form of S-N curves. Experimental results and prediction of S-N curve by model for given size of inclusion and R ratio show very good agreement. Pre-stressing and shot-penning causes higher compress stress magnitude and consequently change of loading ratio to more negative value and additionally extended life time of spring.

4. Conclusion

From above papers to conclude that rubber is not suitable material for the coating due to too low value of its modulus of elasticity in shear. Elastomeric coating has a positive impact on the reduction of dynamic stresses in the spring but also contribute to lowering of resonant frequencies. Shorter total life was observed for out-of-phase loading compared to in-phase loading at the same level for both constant and variable amplitude loadings. In finite element analysis of the mechanical behaviour of the twin helical spring under uniaxial tensile load is conducted & findings are compared against those obtained from a theoretical approach based on a transformation of curvilinear coordinates.

The characterization of the fatigue properties of materials and components at very high numbers of cycles necessitates a careful selection of fatigue loading machinery and measuring devices, as well as a diligent application of testing and evaluation procedures.

The present paper proposes a new model of an adjustable-stiffness spring. The proposed device has four leaf springs with nonlinear elastic deformations. The geometry of the leaf spring can be modified by means of an electric motor that adjusts the stiffness of the spring to the desired value. This paper also proposes a mathematical model that allows the leaf springs to be dimensioned for every specific purpose. A prototype of the spring has been built and tested.

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