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Review on Failure Analysis of Helical Compression Spring

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Abstract : **A mechanical spring is an elastic body which has primary function is to deflect under load and return to its original shape when load is removed. Shocks and vibrations generated from the road surface are detached from structure to the passengers by automobile suspension system. Spring undergoes different types of forces like twist, pull, strech, etc. Force is linear tensile or compressive or it can be radial. The torque act on the spring causes rotation .The main purpose of this paper is to enlight some point related to the fatigue stress analysis of spring used in automobile suspension system. Its analysis is carried out Theoretically, experimentally and numerically with the help of different softwares, but FEM is best tool for the analysis.**

Index Terms **- fatigue stress, helical compression spring, Maximum shear stress, Suspension system.**

I. INTRODUCTION

In vehicle suspension system, helical compression spring is one of the primary elastic member. They attach vehicle body with wheel elastically and smooth out shocks which are received from wheel. This shocks generated due to the road irregularities. When spring is compressed due to the force then energy is store in it and it return to its original position after removal of force. Spring rate indicates energy absorption capacity. Coil spring rate depend upon various factors like coil wire material , coil wire thickness and length of active coil[16]. Modern passenger vehicles generally use light coil springs. Light commercial vehicles have heavier springs than passenger vehicles, and can have coil springs at the front and leaf springs at the rear. Each side of the vehicle wheels connected by solid or beam, axles. Then the movement of a wheel on one side of the vehicle is transferred to the other wheel with independent suspension, the wheel can move independently of each other, which reduce body movement. And it is also prevents the other wheel being affected by movement of the wheel on the opposite side and reduces body movement.

The fatigue failure of the suspension spring in a variety of ways Raw materials defect, surface imperfections, improper heat treatment, corrosion and decarburization are generally recognized causes of fatigue failure of suspension spring[8]. In this paper, the review of the work done in failure analysis of helical compression coil spring is enlisted. From this, we are able to understand the fatigue failure and its causes.

II. SPRING DESIGN CONCEPT

Different factors are consider while designing a spring, some are given below which mainly having different stress acting on spring and deflection of the spring.

A. Stresses and Deflection Equations

Consider a helical compression spring of circular wire and subjected to an axial load *W*, as shown in fig.1. Let *D:* Mean diameter of the spring coil, *d:* Diameter of the spring wire, *n* : Number of active coils, *G:* Modulus of rigidity for the spring material, *W* : Axial load on the spring, □ τ: Maximum shear stress induced in the wire, *C:* Spring index is *D*/*d*, *p:* Pitch of the coils and δ□: Deflection of the spring, as a result of an axial load *W*.

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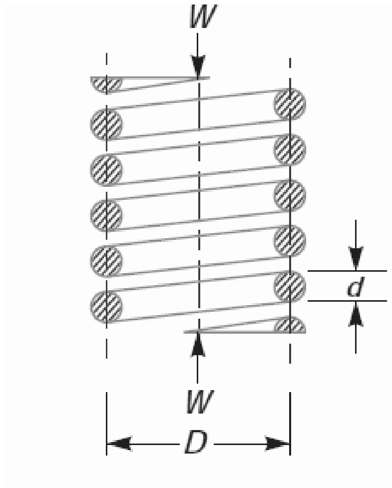

Fig.1:Axially loaded helical spring[18].

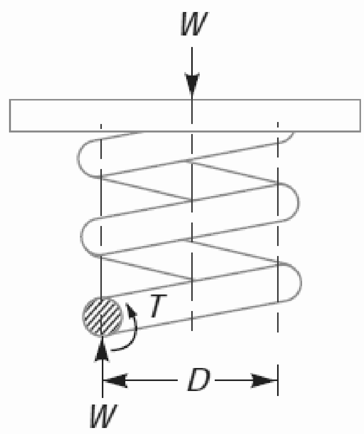

Fig.2: Free body diagram showing that wire is subjected to torsional shear and a direct shear[18].

Now consider a part of the compression spring as shown in Fig. 2. The load W tends to rotate the wire due to the twisting moment (T) set up in the wire. Thus torsional shear stress is induced in the wire.

We know that the twisting moment equation from that torsional shear stress equation will be

$\tau_1 = \frac{8WD}{\pi d^3}$ ....(1.1)

In addition to the torsional shear stress induced in the wire, the following stresses also act on the wire: Direct shear stress due to the load *W*, and Stress due to curvature of wire.

$\tau_2 = \frac{4W}{\pi d^3}$ ....(1.2)

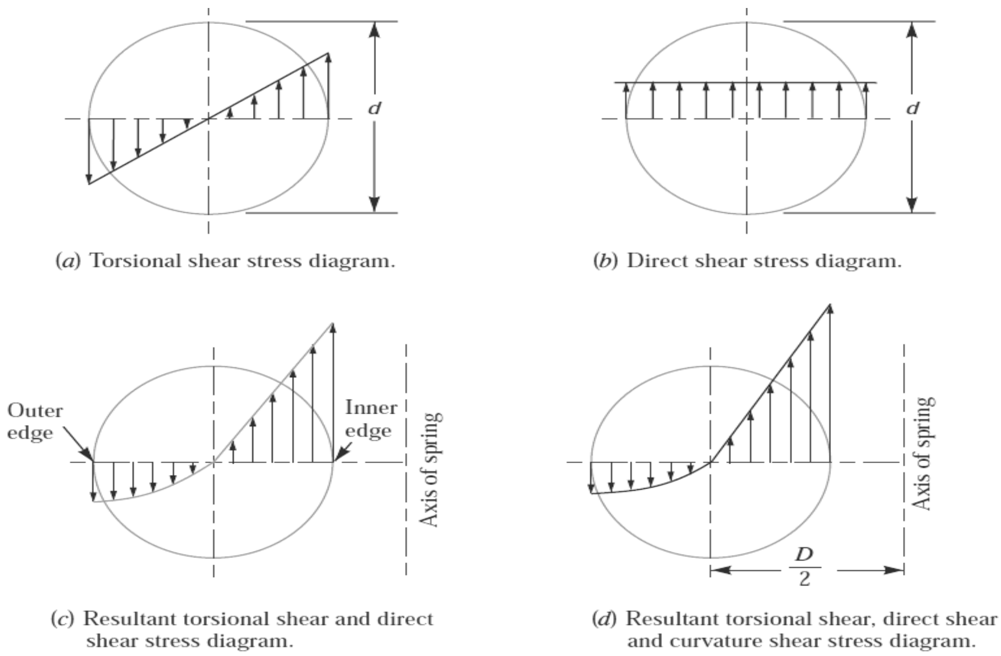

Fig.3: Superposition of stresses in a helical spring[18].

The resultant shear stress induced in the wire,

$$\tau = \left(\frac{8WD}{\pi d^3}\right) \pm \left(\frac{4W}{\pi d^3}\right) \quad ....(1.3)$$

The positive sign is used for the inner edge of the wire and negative sign is used for the outer edge of the wire. Since the stress is maximum at the inner edge of the wire, therefore Maximum shear stress induced in the wire,

$$\tau = K \times \left(\frac{8WD}{\pi d^3}\right) \quad ....(1.4)$$

Effects of both direct shear as well as curvature of the wire, a Wahl's stress factor (K) introduced by A.M. Wahl

$$\tau_{max} = \frac{8WD}{\pi d^3}\left(\frac{4C-1}{4C-4} + \frac{0.615}{C}\right) \quad ....(1.5)$$

$$\tau_{\min} = \frac{8\mathrm{WD}}{\pi \mathrm{d}^3}\left(\frac{4C-1}{4C-4} - \frac{0.615}{C}\right) \quad ....(1.6)$$

Equations (1.5) and (1.6) are usually used by the design engineer for coil springs when neglecting the curvature[8]. Also, since the equations were derived by over simplification, the larger the pitch angle, the more error that will result. The equations require the design engineer to input the coil diameter, design height, design load, spring rate, etc. The equation able to compute the optimum possible shape and dimension of the coil. After this step, for more accurate stress distribution.

Deflection of spring

we know $\theta = \frac{Tl}{GJ}$

Axial deflection of the spring, $\delta = \theta \times D/2$

$$\delta = \frac{8WC^3 n}{Gd} \quad ....(1.7)$$

and the stiffness of the spring or spring rate,

$$\frac{W}{\delta} = \frac{Gd}{8C^3 n} \quad ....(1.8)$$

B. Fatigue Failure

In many application ,force acting on the spring is not constant, it varies with respect to time. the spring is subjected to fluctuating load design on two criteria design for infinite life and design for finite life. Consider spring is subjected to fluctuating force which change in magnitude from $W_{max.}$ to W_{min}. in load cycle. Mean force W_m and force amplitude

$$W_m = \frac{1}{2}(W_{max} + W_{min}) \quad ....(2.1)$$

$$W_a = \frac{1}{2}(W_{max} - W_{min}) \quad ....(2.2)$$

Torsional endurance limits of spring steels are given by Zimmerli. He discovered the fact that the size, material and tensile strength have no effect on the endurance limits (infinite life only) of spring steels in sizes under 10mm(3/8 inches). For all the spring steels in table the corrected values of torsional endurance limit can be taken as: 310 Mpa (45.0 kpsi) for un peened springs, 465 Mpa (67.5 kpsi) for peened springs.

The mean stress $\tau_m = K_s\left(\frac{8W_m D}{\pi d^3}\right)$ ....(2.3)

where K_s is shear stress correction factor.

For torsional stress amplitude

$$\tau_a = K\left(\frac{8W_a D}{\pi d^3}\right) \quad ......(2.4)$$

where K is Wahl factor.

By using values of τ_m and τ_a fatigue diagram of spring is drawn as abscissa and ordinate respectively. With help of Soderberg and Goodman lines fatigue analysis is carried out.

III. LITERATURE REVIEW

Some papers are discussed about the various types of helical compression springs used in the suspension system of automobiles. Also different modes of failure, performance enhancement modification and fatigue stress analysis.

M. T. Todinov had given results of helical compression spring with a large coil radius to wire radius ratio, in which highly stressed region at outer surface of the helix rather than inside. The fatigue crack origin was positioned on the outer surface of the helix at which principal tensile stress maximum amplitude was calculated for the duration of cyclic loading; according to the author fatigue design must be based on the range of the maximum principal tensile stress of the spring[1].

Kotaro watanabe, Tamura Masashi, Yamaya Ken and Takahiko Kunoh, a new type rectangular wire helical spring was manufactured by the authors and it was used as suspension springs for rally cars and the stress was checked by FEM analysis theory on the twisting part. The spring characteristic of the suspension helper spring in a body was clear by this work. Essential manufacturing equipment and its procedure was proposed for newly made spring[2].

B. Ravi kumar, Swapan K. Das, and D.K. Bhattacharya, author was analyzed the failure of a helical compression spring used in coke oven batteries surface corrosion. It was analyzed by X-ray diffraction (XRD) and scanning electron microscope - energy dispersive spectroscopy (SEM–EDS). They had used various testing procedure as chemical, surface corrosion product, fracture surface analysis. Author found main source of failure of the helical compression springs was failed due to corrosion fatigue by loss of surface residual compressive stress[3].

Dammak Fakhreddine, Mohamed Taktak, Said Abid, Abderrazek Dhieb and Mohamed Haddar, Here author used two nodes finite element with six degrees of freedom per node which was capable to model the total behavior of a helical spring. Spring undergoes different static and dynamic loads. For its analysis diiferent methods like FEM, Stiffness matrix method were used[4].

L. Del Llano-Vizcaya, C. Rubio-Gonzalez, G. Mesmacque and T. Cervantes-Hernandez,author used a multiaxial fatigue criteria for analysis of helical compression spring. Critical plane approaches, Fatemi–Socie and Wang–Brown, and the Coffin–Manson method based on shear deformation, were used for analysis of fatigue life. ANSYS was used for stress analysis and multiaxial fatigue study by nCode software. Fatigue life good predicted by Fatemi-Socie critical plane approach, Wang-Brown criterion gives more fatigue life[5].

C. Berger, B. Kaiser, in this paper the author achieve the first results of very high cycle fatigue tests on helical compression springs. Si–Cr-alloyed valve spring wire with a wire diameter between 2mm and 5 mm, shot-peened and preset springs tested. The fatigue tests were extended up to 10^8 cycles or even more. The purpose is to evaluate results of fatigue rangein stress cycle up to10^9 . Cycles extended from 10^7 to approximately 10^8 cycles results in a nearly 10% reduction of the fatigue limit, while an increase from 10^7 cycles to $1.2X10^9$ cycles reduces the fatigue limit by approximately 25% for 90% survival probability[6].

L. Del Llano-Vizcaya, C. Rubio-Gonzalez and G. Mesmacque, author had given an experimental exploration been conducted to evaluate the stress relief influence on helical spring fatigue properties. This methodology used in the experimental work and procedures used in the relaxation tests, fatigue tests and residual stress measurements. First S–N curves were used for springs in different condition (times and temperatures) on a testing machine. The inner and outer coil surfaces residual stresses were measuredand analyze effect of heat treatment[7].

Y. Prawoto, M. Ikeda, S.K. Manville and A. Nishikawa, author had given information about an automotive suspension coil springs, its fundamental stress distribution, materials characteristic, manufacturing and common failures. As the stress level was enlarged, material and manufacturing quality became more critical. Here author discussed various case studies of suspension spring failures. Simulation of failure mode were done by finite element analysis and its results study by compairing with results obtained from experimental study[8].

Yuuji Shimatani, Kazuaki Shiozawa, Takehiro Nakada and Takashi Yoshimoto, In this paper author presented two types of specimen which were processed by grinder and cutting tool, both specimens indicate clear duplex S-N curve, collected 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). The existence of almost same size inclusion at crack origin causes fatigue life in very high-cycle regime was almost same between the both specimens[9].

C. Berger, B. Kaiser and C. Berger, In this paper author taken 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. SiCr and SiCrV-alloyed valve spring steel wires and of a stainless steel wire test springs were manufactured of oil hardened and tempered of diameters of 1.6 mm and 3.0 mm with shot peened. Different material spring show signs of different fatigue properties and different failure mechanisms in the VHCF regime. For analysis, fractured test springs were investigated by stereo-microscope, Scanning Electron Microscope (SEM) and by means of metallographic micro sections[10].

B. Pyttel , D. Schwerdt, C. Berger, The paper gives an outline of the present state of research on fatigue strength and failure mechanisms at very high number of cycles. Considering different failure mechanisms, a double S–N curve is recommended to describe fatigue behaviour. Materials are different metals with body-centred cubic steels and quenched and tempered steels but also materials with a face-centred cubic lattice like aluminium alloys and copper. Furthermore design codes have to consider new research results and give recommendations to fatigue design and assessments of components[11].

Brita Pyttel, K.K. Ray, Isabell Brunner, Abhishek Tiwari and S. A. Kaoua, In this paper helical compression springs which 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. Using ABAQUS 6.10 finite element analyses were done. The simulation results demonstrate an oscillatory behavior of stresses along the length at inner side. Shear stresses were asymmetrical along the length of the spring with local maxims at starting of each middle coil. FEA used for further analysis and failure analysis by ABAQUS[12].

Priyanka Ghate , Dr. S. R Shankapal and M. H. Monish Gowda,Currently suspension system carry load in normal operating conditions and maintain the required ride index. In present work, analyze in detail the reason for failure and a single non linear spring had been suggested to improve durability of the primary suspension and in the the essential ride index. By applying the forces obtained from dynamic analysis, failure of the composite spring assembly was analyzed. Numerical analysis stress level of composite set is upto 412Mpa where as newly designed spring reduce it to 160 Mpa and this numerical simulation in ADAMS. For this case ride index was found upto 1.78. Finally author concluded that new spring design able to enhance durability and ride index[13].

Tausif M. Mulla, Sunil J. Kadam and Vaibhav S. Kengar, In this work, Three Wheeler Vehicle's front automotive suspension with its elastic performance and stress analysis was discussed. FEA results lead to poor accuracy and obtained from classical spring model. It give relative error of maximum shear stress ranging from 1.5 to 4 per cent to the applied loads, obtained value compared to the analytical value taken from standard textbook data. Shear stress at inner side of every coil was maximum so failure can happen at inner side side except end coil[14].

C. Berger, B. Kaiser, I. Brunner and M. Mahendran, In this paper, Shot peened helical compression springs undergoes fatigue test with the help of a special spring fatigue testing machine at 40Hz. SiCr- and SiCrV-alloyed valve spring steel and stainless steel test springs materials with oil hardened and tempered 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 levels of stress. VHCF-test method used for different wire diameter of spring. Author compared different springs results by there sizes, materials, number of cycles and shot peening conditions. Given outline for further exploration in VHCF-region[15].

Chandrakant Chavan, G.M.Kakandikar and Swapnil S. Kulkarni, To find out the fatigue life of the coil spring in car suspension and recognize areas of improvement over the fatigue life. Finite Element Analysis would be deployed for the structural analysis using NASTRAN or suitable solver while the fatigue life calculated using `MSC Fatigue' or suitable. For this work, experimentation shall be performed for validating the performance parameter as `Stiffness' of the spring. Author purpose was to gain optimized design which is besr suitable for the proper functioning of system. For this work author validate the numerical results with experimental outcomes for improvement of fatigue life[16].

Youli Zhu, Yanli Wang and Yuanlin Huang, This paper analyzed failure of a heavy vehicle suspension compression coil spring at the transition position from the bearing coil to the first active coil in service, while the nominal stress here should always be much less than that at the inside coil position of a fully active coil. Crescent shaped region and beach marks, typical of fatigue failure exposed by Scanning electron microscopy. Due to contact and friction . ZnCaph phosphate layer and painting around the contact zone were damaged and show corrosion and corrosion pits induced local stress concentration. At the edges of the contact zone stress analysis indicated severe stress singularities, which facilitated cycle slip and fatigue crack nucleation. Initial crack was formed, it was the maximum principal tensile stress that forced the crack to propagate along the direction of 45° with the spring wire axis. It is strongly suggested to adopt a non-closed ends design in order to avoid wear and corrosion of the suspension spring[17].

IV. CONCLUSION

The above discussion elaborate that springs used in automobile suspension system, in which essential to do its analysis. Spring analysis includes maximum displacement, stress distribution analysis, and different mode of failure. Spring undergoes different types of loading in its life span. ANSYS, NASTRAN, CATIA, SolidWork, etc. software used for analysis of spring. Analysis of spring includes calculation of fatigue stress, shear stress and maximum displacement. Mean diameter and number of active coil are main parameter of spring calculated by shear stress and deflection equations. For large coil diameter spring initial crack propagate along 45° with the spring wire axis due to the maximum principal tensile stress. For small wire diameter generally crack initiate at inner side of coil except end turns. Shear stress equations gives analytical results. FEM results obtained provides better solution for currently available analysis resources.

REFERENCES

[1] M.T. Todinov, "Maximum principal tensile stress and fatigue crack origin for compression springs", *international journal of mechanical sciences", vol. 41*, 1999,pp. 357-370.

[2] Watanabe Kotaro, Tamura Masashi, Yamaya Ken &Takahiko Kunoh, "Development of a new type suspension spring for rally cars", *journal of materials processing technology, (2001),* pp.132-134.

[3] B. Ravi Kumar, Swapan K. Das, & D.K. Bhattacharya, "Fatigue failure of helical compression spring in coke oven batteries", *engineering failure analysis,vol. 10, (2003),* pp. 291–296.

[4] Fakhreddine Dammak, Mohamed Taktak, Said Abid, Abderrazek Dhieb & Mohamed Haddar, "Finite element method for the stress analysis of isotropic cylindrical helical spring", *journal of mechanics and solids, vol.24, (2005),* pp. 1068-1078.

[5] L. Del Llano-Vizcaya, C. Rubio-Gonzalez, G. Mesmacque & T. Cervantes-Hernandez, "Multiaxial fatigue and failure analysis of helical compression springs", *engineering failure analysis, vol. 13, (2006),* pp.1303-1313.

[6] C. Berger & B. Kaiser, "Results of very high cycle fatigue tests on helical compression springs, *international journal of fatigue", vol. 28, (2006),* pp. 1658-1663.

[7] L. Del Llano-Vizcaya, C. Rubio-Gonzalez & G. Mesmacque, "Stress relief effect on fatigue and relaxation of compression springs", *material and design, vol.28, (2007),* pp.1130-1134.

[8] Y. Prawoto, M. Ikeda, S.K. Manville & A. Nishikawa, "Design and failure modes of automotive suspension springs", *engineering failure analysis, vol.15, (2008),* pp. 1155–1174.

[9] Yuuji Shimatani, Kazuaki Shiozawa, Takehiro Nakada and Takashi Yoshimoto," Effect of surface residual stress and inclusion size on fatigue failure mode of matrix HSS in very high cycle regime", *Procedia engineering, vol.2, (2010),* pp. 873–882.

[10] B. Kaiser, B. Pyttel and C. Berger, "Behavior of helical compression springs made of different materials", *international journal of fatigue, vol. 33, (2011),* pp.23-32

[11] B. Pyttel, D. Schwerdt, C. Berger, "Very high cycle fatigue – Is there a fatigue limit?", *International Journal of Fatigue, vol. 33, (2011)* pp.49–58.

[12] Brita Pyttel, K.K. Ray, Isabell Brunner, Abhishek Tiwari, S. A. Kaoua, "Investigation of probable failure position in helical compression

springs used in fuel injection system of diesel engines", IOSR, *journal of mechanical and civil engineering, vol. 2, issue- 3,(2012),* pp 24-29.

[13] Priyanka Ghate, Dr. S. R Shankapal & M. H. Monish Gowda, "Failure investigation of a freight locomotive suspension spring and redesign of the spring for durability and ride index", *sasTECH vol. 11, issue- 2, (2012).*

[14] Tausif M. Mulla, Sunil J. Kadam &Vaibhav S. Kengar, "Finite element analysis of helical coil compression spring for three wheeler automotive front suspension", *international journal of mechanical and production engineering, vol-1, issue-1, (2012).*

[15] B. Pyttel, I. Brunner, B. Kaiser, C. Berger, M. Mahendran, "Fatigue behavior of helical compression springs at a very high number of cycles– Investigation of various influences", *international journal of fatigue, (2013),* pp. 30-37.

[16] Chandrakant Chavan, G.M.Kakandikar, Swapnil S. Kulkarni, "Analysis for suspension spring to determine and improve its fatigue life using finite element methodology", *international journal of scientific research and management studies (IJSRMS), Vol.1, Issue- 11, (2014),* pp : 352-362

[17] Youli Zhu, Yanli Wang, Yuanlin Huang, "Failure analysis of a helical compression spring for a heavy vehicle's suspension system", *Case studies in engineering failure analysis,Vol. 2, (2014)*, pp.169–173.

[18] R.S. Khurmi, J.K. Gupta, *A Textbook of Machine Design* (Eurasia Publishing House (Pvt.) Ltd. 2005)

[19] Shigley, *Mechanical Engineering Design* (Budynas−Nisbett's, McGraw−Hill Primis, 2006).

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