Review on Helical Compression Spring

Mr. A.G.Hejib, Prof. R.L.Mankar

***Abstract*-The helical compression spring used in suspension system of two wheeler is belonging to the medium segment of the Indian automotive market. The detailed assessment of the problem of two wheeler suspension system is studied. Failure analysis of broken coil springs is valuable both for the short and long term agenda of car manufacturer and parts suppliers. Several case studies of suspension spring failures are studied. The failures presented range from the very basic including insufficient load carrying capacity, raw material defects such as excessive inclusion levels, manufacturing defects such as delayed quench cracking, failures due to complex stress usage and chemically induced failure. FEA of stress distributions around typical failure initiation sites are also studied.**

***Keywords* – helical compression spring, two wheeler, raw material, paint.**

I. INTRODUCTION

A. Suspension system

Suspension system consists of a spring and a damper. The energy of road shock cause the spring to oscillate. These oscillations are restricted to a reasonable level by the damper which is more commonly called a shock absorber. The vehicle suspension system is responsible for the vehicle control, Driving comfort and safety as the suspension carries the vehicle body and transmit all the forces between the rod and the body.

B. Spring

A spring is defined as an elastic machine element that deflects under the action of the load and returns to its original shape when the load is removed. It can take any shape and form depending upon the application.

C. Helical spring

The helical springs are made up of a wire coiled in the form of helix and are primarily intended for compressive or tensile loads. The cross-section of wire from which the spring is made may be circular, square or rectangular. The two forms of helical springs are compression helical spring and tension helical spring. The most popular type of spring is helical compression spring. There are two basic types of helical compression spring Compression spring and Extension spring. In helical compression spring, the external force tends to shorten the spring. The external force acts along the axis of the spring and induces torsion shear stress in the spring wire. It should be noted that although the spring is under compression, the wire of helical compression spring is not subjected to compression stress. Also the wire is not subjected to tensile stress although the spring is under tension. In both cases, torsion shear stresses are induced in the spring wire. The helical spring sometimes classified as closely coiled helical spring and open coiled helical spring.

II. LITERATURE REVIEW

A. History

Helical compression spring made up of spring steel often have yield strength which enables them to return to their original form after significant force was applied. These springs were widely used in auto industry. They connect the wheel to the body elastically and store the energy to absorb and smooth out shocks that were received by the wheel from road irregularities and transmitted to the body. A large variety of springs operate under frequently varying loads and deflections. These springs were failed by fracture due to tensile stresses since it would be difficult to conceive of cracking due to compressive stresses. The torsional stresses which occurred in helical coil springs could be resolved into principal tensile and compression components and these tensile components could also cause cracking. During the manufacturing of spring, great stresses and plastic strains were induced. Once the process is terminated, these permanent strains generate residual stresses that limit spring fatigue life and performance during service.

B. Review of papers

B.Ravi Kumar et al. (2002) studied a failed helical spring used in coke oven batteries for the cause of failure. The spring had four active coils used for expansion or contraction in the coke oven battery. Visual examination of general features indicated the fracture took place in fourth active coil from bottom. The surface of the spring was covered with a thick layer of weakly adhering corrosion product. Chemical analysis of spring material was done. X-Ray diffraction (XRD) phase analysis of the corrosion product indicated Fe_3S_4, Fe_9S_{10}, Feocl.NH_3 and iron oxide. The fracture surface was cut and cleaned. Macrofactography of the fracture surface was conducted using a stereomicroscope. A bench mark was found on the failed surface. The virgin and failed surface sample show the hardness values of 44Rc and 47 Rc. Residual stresses in virgin and failed spring were -273 MPA along wire length and -338MPA along circumferential direction of spring wire and -23MPA along wire length and 43 MPA along circumferential direction of spring wire. The decrease in the stress may due to removal of compressed surface layer by extensive corrosion.The failure analysis is divided into Part I and Part II. In part I, material related aspect of failure were looked. From the results of chemical analysis, microstructural and hardness it was found that the material conforms to spring manufacturer's specification. No microstructural degradation or presence of inclusions had been noticed. The absence of both of these factors indicates that there was no loss in fatigue resistance of the material. In part II the service/environment conditions were considered. Failure by fatigue occurs over a time period. Such failure was not related to service overload failures. The result of microstructure and hardness did not show any degradation that could be correlated to high temperature during service. The presence of a highly porous corrosion product on the spring surface had considered. This indicates the existence of a corrosive environment at the plant.[1]

L. Del Llano-Vizcaya et al.(2006) examined fatigue and failure analysis of helical compression springs. Chemical composition was determined by a spark emission spectrometer. The spring was fabricated by cold coiling spring had total 9.5 coils, length was 153.6 mm, diameter was 5.7mm. Application of spring was in mining industry equipment. A fatigue testing machine was designed to determine the S-N curve of the helical compression spring. The residual stresses in the spring were measured using X-Ray diffraction equipment. The fatigue lives under constant amplitude axial loading and torsional loading were correlated by coffin- mansoonequations.

$\frac{\Delta\epsilon}{2} = \frac{\epsilon_f}{E}(2N_f)^b + \epsilon_f(2N_f)^C$ for axial loading

$\frac{\Delta\gamma}{2} = \frac{\tau_f}{G}(2N_f)^{b_0} + \gamma_f(2N_f)^{C_0}$For torsional loading

These equations were used for establishing fatigue parameter Vs life relations. The fatigue life prediction is based on the continuum mechanics variables on the physical crack plane called critical plane was proposed by brown and miller for shear fracture material. Wang and brown (WB) replaced normal strain range by normal strain excursion. A shear fracture parameter was proposed by fatmi and socie. The first method of approximation the strain life relationship from monotonic properties was proposed by Manson (M) and later modified by Muralidharan (MM). ANSYS and n code were used in the spring fatigue analysis to estimate the number of cycles to failure at each stress amplitude. [2]

L.DelLiano-Vizcaya et al.(2007) studied the manufacturing process of mechanical spring and observed that tensile residual stresses induces on the inner coil surface while compressive residual stresses were generated on outer coil surface which reduces considerably the spring strength and service life. These unfavorable stresses partially eliminated by heat treatment. In this process the spring is heated uniformly below the material transformation temperature. An experimental investigation had been conducted to access the stress relief influence. S-N curve was determined for spring treated under different conditions (temperature and time) on testing machine. Next stress relief effect on spring relaxation induced by cyclic loading was evaluated and residual stresses were measured to analyze the effect of heat treatment. It was observed that fatigue limit depends on the residual stress field. Before heat treatment tensile residual stress 312MPA and after heat treatment stresses were 100 to 300MPa.[3]

Y.Prawoto, M.Ikeda et al. (2008)discussed about automotive suspension coil springs, their fundamental stress distribution, materials characteristics, manufacturing and common failures. It was observed that first automobile coil spring was on the model T (ford) in 1910. Coil material used had 500 MPa design stress level. Today it may be around 1200 MPa. In the case study of failure reasons of helical compression spring raw material defect was observed. It may be due to entry of foreign particles in the raw material called as inclusion. Classified into larger and smaller one. Next surface imperfection could occur as small hardening cracks, tool marks, scale embedded to the base material during cold drawing by the raw material. Poor shot peened surface also classified as surface imperfection. Decarburization may be described as a metallurgical process in which the surface of metal is depleted of carbon, by heating above the lower critical temperature or by chemical action. Corrosions were more common cause of spring breakage. The analysis results of above cases were as follows i) none – No stress concentration. Von mises stress = 1715MPa, max. Principal stress = 1200MPa. ii) Inclusion – stress concentration observed in this area 2069, 1922 MPa. iii) Imperfection – stress concentration observed at crack location 4195, 2670 MPaiv) corrosion – observed at bottom edge of corrosion surface 3453, 3286MPa. V) Decarburization- on decarburized layer, stress reached the yield point, plastic deformation occurred. [4]

Xian etal. (2012) presented the action and requirements of variable stiffness coil spring, constrained nonlinear optimization mathematics model of variable stiffness coil spring was established. Using a certain front suspension stiffness of helical spring as an example, spring wire diameter d, lap number n and spring index C were design variables, spring wire shear stress is less than the allowable shear stress for constant spring KP was as large as possible and spring – mass was minimum for objective function. Then using optimization toolbox to optimize design and calculate. The results show that the multi-objective mathematical optimization model was simple and accurate. The quantity and efficiency were improved. This optimization was not only applied to variable pitch coil spring but also apply to other springs.[5]

MohdIzahamZainalAbidin, Jamaludin Mahmud (2013) worked on coil spring made of spring steel often had high yield strength which enables them to return to their original form after a significant force was applied. Specific application of steel spring in automobile was ruled by industrial guideline for example Japanese Industrial standard (JIS), Daewoo Engineering Standard (EDS) and Daihatsu Technical Standards (DTS). To investigate characteristics of a coil spring used in automobile i.e. SUP12 where the analysis approach was done systematically using experimental and numerical methods. The experimental part was intended to verify the SUP12 springs material properties (spring constant, yield strength and tensile strength) were within standard for spring steels, JIS G 4801(1984). The SUP12 underwent tensile testing in accordance to JIS Z 2201(2010). Finite element simulation was performed using HYPERWORKS software to predict the steel spring under displacement condition as per specific customer requirement. The resulting experimental data indicates that the tested SUP12 passed the minimum requirement as per standard. Finite element results show that the spring meets the customer requirement within small deviation. Completion of the study would benefits in development and designing phase of an automotive coil spring where designers fulfill both requirement from industrial and customer's quality need. Also research on how reliable the FE modeling of tensile test as compared to actual testing results. FE model could be improved by including other material properties or refinement of 3D element in term meshing, size. [6]

TsubasaTsuboushi et al. (2014) developed a coil spring with high rectangular cross section ratio. Some robots often had to be made compact as they worked in limited spaces. Coil spring with high rectangular ratio had started to be used as the joint mechanism because they were compact, easy to bent and able to convey strong twist force. In this paper new and inexpensive method was proposed where a stainless steel wire was wound around into the shape of coiled spring and subjected to upset in the spring axis direction. The FEA was conducted for estimation of the work hardening. High work hardening means high yield stress. Based on analysis, a series of experiments were carried out and the formed springs were evaluated in terms of tension, torsion and bending characteristics. It was concluded that the new method of forming coil springs with rectangular cross section with high rectangular ratio was much more cost effective in manufacturing than the conventional machining. Quantitative evaluation was conducted on the performance of the coil spring with high rectangular ratio used as a component of surgical manipulators. The coil spring formed by proposed method have two advantages. Firstly, the coil spring with a cross section of a high rectangular ratio reduce the spring constant, compare to a circular cross section, leading to easiness for controlling the shape of the spring, when it is used in surgical manipulator. Secondly, the work hardening enlarged the elastic limit, leading the safety of the coil spring, compared to the machined coil spring.[7]

Youli Zhu, Yanli Wang et al. (2014)analyzed why a compressive coil spring fractured at the transition position from the bearing coil to the first active coil in service. While the nominal stress should always much less than at the insides coil position of a fully active coil. Visual observation indicated that a wear scar was formed on the first active coil. Scanning electron microscopy examination showed crescent shaped region and bench marks. Zncaph phosphate layer and painting around the contact zone were worn out due to contact and friction and Resulted into corrosion. Corrosion pits induced local stress concentration. Stress analysis indicated severe stress singularities at the edge of the contact zone which facilitate cycle slip and fatigue crack nucleation. Recommendation was also made for improving the fatigue performance of the suspension springs. It was the concurrent act of the wear, corrosion together with stress singularities at the contact zone of the closed end that resulted in fatigue crack initiation. Once the initial crack was formed, it was maximum principal tensile stress that forced the crack to propagate along the direction of 45^0 with spring axis. It was strongly recommended to adopt a non- closed end design in order to avoid wear and corrosion of spring. Solid lubrication film, if possible could be used in closed resistance of the end coils could be done if necessary.[8]

B. Pyttel, B.Kaiser et al.(2014) reported long term fatigue tests on shot peened helical compressive springs were conducted by means of a special spring fatigue testing to machine. Test springs were made up of three different material i.e. oil hardened and tempered SiCr, SiCrV- alloyed valve spring steel, stainless steel. With a special test strategy in a test run, upto 500 springs with a wire diameter of 3mm or 900 springs with wire diameter 1.6mm were tested at different stress level. Analysis was done after test and results were compared. Fractured test springs were examined under optical microscope. Scanning electron microscope used in order to analyze fracture behavior and failure mechanism. For comparing the results for the springs with d= 1.6mm and d= 3mm except the springs made of the stainless steel wire, the fatigue strength of spring with (d = 3mm) is higher than that of (d = 1.6mm). there was no fatigue limit but remarkable decrease in fatigue strength in the region of $10^7 < N < 10^9$ to $1.5x10^9$ for all spring and materials. It is more pronounced for the spring made up of stainless steel wire with 30% decrease per decade or even more in comparison about 10% for the SiCr and SiCrV- alloyed valve spring wire. A second shot peening treatment improved the fatigue strength of springs made of SiCr and SiCrV – alloyed spring steel wire with d= 1.6mm. In most cases springs made of stainless steel wires failed from the subsurface.[9]

R. Puff et al. (2014)investigated the effect of the presence of non-metallic inclusions in the early failure of a helical spring subjected to regular design loads during its operation. To understanding the reduction in fatigue strength, an analytical model was used. A two – dimensional (2D) finite element method analysis was developed to evaluate the residual stresses originated around an inclusion located near the material surface, by the application of a shot peening process. A three dimensional (3D) FEM model was developed to study the stress concentration around the inclusion that appears under design loads. Also show that the analytical model developed by Murakami (2002) provided a valid insight on the fatigue strength reduction and that the FEM model may actually provide good qualitative and quantitative data that could help to obtain a better understanding of the process of early failures of spring wires with non-metallic inclusions. The treatment with shot peening with the objective of improving surface fatigue strength by the introduction of residual compressive stresses could also induce the formation of regions with high stress concentration near sharp corners of inclusions, which were favorable points for initiation of cracks. Due to geometry of the inclusion residual tension stresses could be generated at these points. External loads were responsible for high stress concentration regions near the inclusions, since they were close to surface.[10]

P.N.L.Pavani, B.K.Prafulla et al. (2014) implemented wave spring which was precise flat wire compression springs that fit into assemblies that other springs could not since the overall length and operating height of wave spring was lower than those of conventional round wire spring. The wave spring was reduce the part weight and raw material cost. A wave spring was occupied an extremely small area for the amount of work it perform. In this paper, a three dimensional finite element model for shock absorber spring was proposed. 3D model was created using Pro/Engineering. The model was changed by changing the length of the spring. Structural analysis had been conducted on the wave spring by varying the spring material. Structural analysis was done to validate the strength. All results of wave springs were compared with coil spring. Results showed that wave spring possess less deformation and more stresses when compared with coil springs. The proposed FE model was used to analyze the dynamic behavior of wave springs. The stiffness of the spring material increases, total deformation decreases and corresponding stresses was increase. When the deformation decreases the spring back effect was less and the use of dashpot could eliminated and the spring alone could be used as suspension system.[11]

LadislavKosec, Ales Nagode et al. (2015) focused on failed coil spring of rear shock absorber of a motor car during operation. The surface of a spring was protected against corrosion with thick layer ofpaint on polymer basis. Around the fractured surface, protective layer was damaged and removed over a length of several centimeters. In this area, spring had been long exposed to corrosion attack and thus surface heavily corroded and wrinkled. On a minor portion of fracture surface, compact, dark brown rust was visible. From this part, crack gradually propagated due to combination of corrosion attack and cyclic loading.[12]

GoranVukelic, Marino Brcic (2016) focused on analysis of possible causes of failure of coil spring on a specific type of motor vehicle. Visual examination carried out to find the location of fracture. Using optical microscopy evaluation of the basic microstructure of the fractured surface was performed and possible inclusions distinguished. Detailed scanning electron microscopy examined to characterize the fine microstructure of the fractured surface and reveal flaws that served as crack initiation points. Optical emission spectrometer with glow discharge source (GDS) sample simulation was used to determine chemical composition of spring material. Hardness test was performed. Using the results of the performed experimental analysis, possible causes of failure were recognized. Further analysis would include finite element method to determine stress levels in undamaged and damaged coil spring along with numerical estimation of fatigue life.[13]

C. Discussion –

It had seen that helical compression spring undergo the fluctuating loading over the service life. Most of cases, the springs were failed due to corrosion. It was indicated by visual examination, chemical analysis, surface examination. Failure of spring due to improper heat treatment had seen. For this purpose relaxation test, fatigue test, residual stress measurement had done. By changing the material of the spring, analysis had done using experimental and numerical methods. The spring made up of different material and diameter had tested by fatigue testing machine. The fracture springs had examined under optical microscope. FEM analysis had done to evaluate stresses in the helical compression spring which failed early due to presence of non-metallic inclusions. The shape of helical compression spring had changed and the results of experimental and software analysis had compared with conventional one.

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