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Failure Analysis of Automotive Suspension System (Leaf & Helical Spring): A Review

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Abstract: *The Suspension system is one of the most important components of any automotive system. This is effect performance of vehicle and comfort condition of rider or driver. Their premature failure may cause economical loss as well as may be dangerous for life of passengers. Lots of works have been done in this area for the failure analysis. In this paper review is presented on the analysis, investigations, design and study done by various researchers in the area of automotive suspension system. A number of analytical and experimental techniques are available for the fatigue analysis of the vehicle suspension system. Review includes different fatigue analysis techniques of a vehicle suspension system. Significance of this paper is that analysis of Flat spring is also presented along with Helical Spring. Review includes different fatigue analysis techniques adopted by researchers to do failure analysis of an automotive suspension system.*

Keywords: *Suspension system, Leaf spring, Helical Suspension system, Fem, Failure Analysis*

1. INTRODUCTION

In transportation vehicles, an important part of the passenger's comfort and ride comfort is the vibration to which he is subjected. Information concerning the response of passengers to a vehicle vibration environment has become increasingly important for use in the development of new transportation systems. While under design of a new system with regard to allowed vibration levels can cause it to be uncomfortable and hence unacceptable to the traveling public, overdesign (where vibrations that would normally not affect the passenger's perception of comfort significantly are eliminated) can result in excessive system cost. Indeed, in many cases system cost is very strongly related to the ride quality criteria that may be imposed upon the designer. This study is an attempt to relate ride comfort on road vehicle to measured riding vibrations in order to evaluate some design criteria presently in use and to develop better criteria for vehicle ride comfort design. A number of articles are available on the research work done by the various researchers in the area of flat spring. Modeling, Analysis & experimental works are reported in this literature. Few of them are summarized here. This paper presents a candid comment on few significant work in the area of helical and leaf spring.

2. FAILURE ANALYSIS OF LEAF SPRING

Leaf springs are very popular in the heavy vehicles. They are subjected to fluctuating load. Sometime road condition and loading conditions are unusual leads to failure. Few works on suspension system are presented below.

Mahmood M. S and Davood R. [1] have worked on design, analysis and optimization of leaf spring .Their work was in the direction to replace steel leaf spring with an optimized composite one. They presented a spring with minimum weight that is capable of carrying given static external forces without failure. The four-leaf steel spring is analyzed by using ANSYS V5.4 software. The finite element results showing stresses and deflections verified the existing analytical and experimental solutions. Result shows that stresses in the composite leaf spring are much lower than that of the steel leaf spring. Compared to the steel leaf spring the optimized composite leaf spring without eye units weights nearly 80% less than the steel spring. The natural frequency of composite leaf spring is higher than that of the steel leaf spring and is far enough from the road frequency to avoid the resonance.

Abdul K. et. al. [2] has investigated failure Leaf spring for light truck. Three groups of light truck are considered Simulation resembles to constrained condition when mounting on the vehicle, where each leaf in the system can be idealized in to a diamond shape. The finite element method was applied as a method of analysis to examine the stress distribution for each leaf. The number of cases studied equal 24 cases. He concluded the magnitude of stress in lower side surface for all leaves of spring is more than stress in upper side surface.

Santhosh K. et.al.[3] Havepresented work on design and analysis of composite leaf spring. This work deals with the replacement of conventional steel leaf spring with a Mono Composite leaf spring using E-Glass/Epoxy. The leaf spring was modeled in Pro/E and the analysis was done using

ANSYS Metaphysics. From results they observed that the composite leaf spring weighed only 39.4% of the steel leaf spring for the analyzed stresses. So from result they proved that weight reduction obtained by using composite leaf spring as compared to steel was 60.48 %, and it was also proved that all the stresses in the leaf spring were well within the allowable limits and with good factor of safety. It was found that the longitudinal orientations of fibers in the laminate offered good strength to the leaf spring.

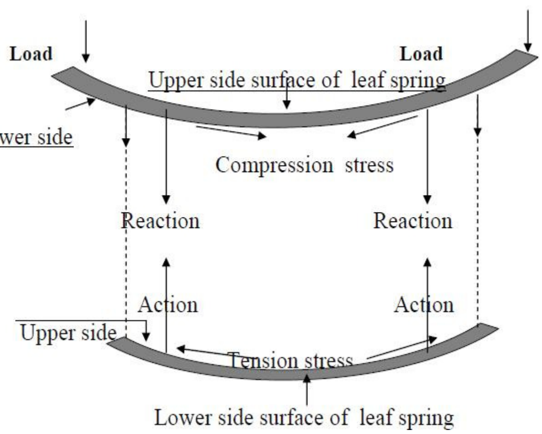

Fig. 1. Stressed Leaf Spring

Pankaj S. et.al [4] theyhavestudied on design and analysis of composite leaf spring for light vehicles. Main objective of this work is to compare the stresses and weight saving of composite leaf spring with that of steel leaf spring. Here the three materials selected which is glass fiber reinforced polymer (E-glass/epoxy), carbon epoxy and graphite epoxy is used against conventional steel. From the result, among the three composite leaf springs, only graphite/epoxy composite leaf spring has higher stresses than the steel leaf spring. From results its proved that composite mono leaf spring reduces the weight by 81.22% for E-Glass/Epoxy, 91.95% for Graphite/Epoxy, and 90.51 % for Carbon/Epoxy over steel leaf spring.

Claudio R. A.andet. al., [5] havepresented in their paper fatigue life calculation using total fatigue life predictive methods which are normally used for notched geometries, gave conservative results for almost all of the situations herein studied. These are found to be too pessimistic in predicting the shot peening effect. Results are much better if stress or strain energy density is averaged over a critical distance, when shot peening is considered.

Malaga and et.al. [6]Have presented work on design optimization of leaf spring. The automobile industry has shown increased interest in the replacement of steel spring with composite leaf spring. Main purpose of this paper is to replace the multi-leaf steel spring by mono composite leaf spring for the same load carrying capacity and stiffness. Three different composite materials have been used for analysis of mono-composite leaf spring. They are E-glass/epoxy, Graphite/epoxy and carbon/epoxy. Static and model analysis has been performed. From results it is concluded that E-glass/epoxy has lower stresses among using three materials. So they suggested E-glass/epoxy composite material for replacement of steel leaf spring.

Prahaladet.al.[7] They have worked on Design improvements of leaf Spring of BEML Tatra 815 VVNC 8 X 8 Truck. Main objective of this work is increase the PL carrying capacity of BEML Tatra by 5000 kg. By incorporating the necessary changes in suspension system(Leaf Spring) of the vehicle. The distribution of gross vehicle weight (GVW) on the front and rear tandem axles are Front axle weight is 2 x 6500 kg, Rear axle weight is 2 x 7500 kg, Gross vehicle weight is 28,000kg. Here they do some changes in design so they distributed weight of Fifth wheel load (FWL) on the front and rear tandem axle is Front axle weight is 2 x 6750 kg, Rear axle weight is 2 x 9750 kg,Gross vehicle weight is 33,000 kg . Results showed that finite element analysis (FEA) on rear leaf spring verifies that, design were adequate. The material 60Cr4V2 is better for design of new leaf spring, which fulfills the requirement.

Qureshi h., [8] they have studied on automobile leaf spring from composite materials. They performed experiment in laboratory & was followed by road test. Field testing to determine ride characteristics were also carried out on a number of GFRP springs which were mounted in place of conventional steel spring on jeep. This test was limited to ride quality and sound observation on different road condition. From result it is observed that GFRP spring were more flexible then steel leaf spring. From test ride they observed that harshness & noise also reduced then steel leaf spring. Compared to the steel spring, the optimized composite spring has stresses that are much lower, the natural frequency is higher and the spring weight without eye units is nearly 80% lower.

Predrag B. et.al. [9] Concluded that fatigue life of acomponent is a very important regarding safety and stability of any dynamically loaded systems. On the base of the fatigue simulations it is clear that the longest fatigue life of the mono-leaf spring is obtained by using the largest transition radius of 115 mm. With this transition radius, the mono-leaf spring may be able to endure at least 50 Million cycles, according to the S/N curve of the un notched longitudinal oriented specimens. Also, by using other S/N curves for the perpendicular specimen orientation as well as for the notched specimens, the fatigue life is longer too.

Krishan K. and Aggarwal M. [10] have carried out on a multi leaf spring having nine leaves used by acommercial vehicle. The finite element modeling and analysis of a multi leaf spring has been carried out. It included two full length leaves in which one is with eyed ends and seven graduated length leaves. The FE model of the leaf spring has been generated in CATIA V5 R17 and imported in ANSYS-11 for finite element analysis. Bending stress and deflection are the targeted results. A comparison of both i.e. experimental and FEA results has been done to conclude. When the leaf spring is fully loaded, a variation of 0.632 % in deflection is observed between the experimental and FEA result, and same in case of half load, which validates the model and analysis.

TABLE 1. Stresses obtained experimentally and from FEM analysis

Parameters	Experiment Results	FEA Results	Variation
Normal Static Load	35000N	35000N	Nil
Deflection	158 mm	157 mm	0.632 %
Spring Rate	221.5 N/mm	222.92 N/mm	0.641 %
Bending	101.8	113.25	10.11 %
Stress	Kgf/mm2	Kgf/mm2	

Clarke C.K and G.E. Borowski [11] have discussed the determination of the point of failure during an accident. Finite-element stress analysis is used to study the existence of tensile stresses at the location of the fracture. A finite-element analysis is carried in finite-element code ALGOR is conducted on the spring eye stress conditions in order to examine the transverse stresses. Residual-strength calculations are made with longitudinal forces. Reduction in strength produced by the old OD crack is also estimated based on published stress-intensity data.

MouleeswaranS.kandSabapathy V. [12]have described in their paper static and fatigue analysis of steel leaf spring and composite multi leaf spring made up of glass fiber reinforced polymer using life dataanalysis. Adopted the analysis model of Hwang and Han

$N = \{B (1 - r)\}^{1/c}$

They found stiffness; natural frequency of composite leaf spring is higher than steel spring It is found that the life of composite leaf spring is much higher than that of steel leaf spring. Also weight of spring is reduced.

Aher V. K. and P. M. Sonawane [13], purpose of this paper have to predict the fatigue life of semi-elliptical steel leaf spring along with analytical stress and deflection calculations by using CAE tools. From the nonlinear static analysis, it is observed that for the leaf spring at 6 kN. Load, the maximum von-Mises stress is 592.43 MPa and at 10 KN it is 1047.34 MPaFrom load Vs deflection curve shows there is linear relationship between the load and deflection. For the validation, the FEA deflections are compared to the analytical. From load Vs deflection curve shows there is linear relationship between the load and deflection.

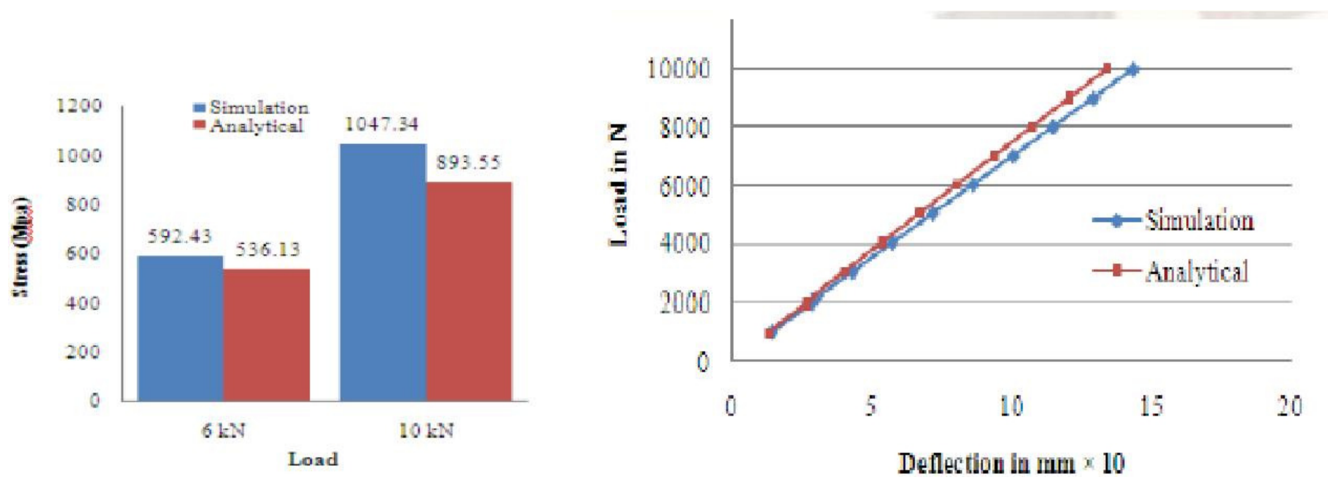

Fig. 2. Analytical and Simulated result

From Modal analysis, the fundamental frequency for the leaf spring is 10.68 Hz observed in vertical bending mode. The subsequent 2nd and 3rd mode shows the lateral and twisting modes. From the fatigue analysis, it is clear that the damage sum is less than 1 hence it is in safe limits and the life predicted for the leaf spring is 1.47×107 cycles.

Mahdi E. A. et. al. [14]havepresented work on light composite elliptic springs for vehicle suspension elliptical springs has been investigated both experimentally and numerically. A series of experiments was conducted for composite elliptical springs with ellipticity ratios (a/b) ranging from one to two. Here they were also presented history of their failure mechanism. Both spring rate and maximum failure increase with increasing wall thickness. In general, this present investigation demonstrated that composites elliptical spring can be used for light and heavy trucks and meet the requirements, together with substantial weight saving. The results showed that the ellipticity ratio significantly influenced the spring rate and failure loads. Composite elliptic spring with ellipticity ratios of a/b 2.0 displayed the highest spring rate.

Charde R. B and D.V. Bhope[15] found for product quality it is necessary to determine the stresses in variouscomponents In first approach the stress analysis is carried out by considering only the graduated leaves and in other approach the stress on master leaf is carried out by considering one extra full length leave. The results of finite element analysis for both approaches are verified experimentally by using strain gauges. The stress are evaluated at varies distances varying from 15mm to 345mm measured from support. So, length of graduated leaves plays a significant role in the stresses on master leaf. It is also observed from table that with the addition of extra full length of leaf the stresses are reduced drastically. Thus to strengthen the leaf spring extra full length leave are recommended.

TABLE 2: Stresses obtained analytically and from FEM analysis

Sr No.	Length mm	Maximum Stress calculated analytically N/mm2	Maximum Stresses By FEM N/mm2	Maximum stress with analysis Experimental Analysis N/mm2
1	15	46.41	50.794	39.48
2	125	35.49	46.59	36.33
3	235	22.38	41.07	32.97
4	345	10.37	27.94	26.25

Dhoshi N.P. et.al. [16].shows the importance of analytical andmicro-analysis. FEM analysis is done in ANSYS 11.0 and the project shows the importance of Stress analysis. On reducing the number of leaf spring from 17 to 13 will further reduce the weight by approximately 6kg and the production cost by nearly 20%.

Manas P. and Narendra Y.[17],They have worked on study of a parabolic leaf spring by finite element method & design of experiments. Main objective of this study was the behavior of parabolic leaf spring, design of experiment has been implemented. For DOE, they selected input parameters such as Eye Distance & Depth of camber. This work is carried out on a mono parabolic leaf spring of a mini loader truck, which has a loading capacity of 1 Tons. The modeling of the leaf spring has been done in CATIA V5 R20. Max Von Mises stress and Max Displacement are the output parameters of this analysis. In DOE Eye Distance & Depth of camber have been varied and their effect on output parameters have been plotted. The variation of bending stress and displacement values are computed. From design of experiments they observed following a) If the camber is increased there is a decrease in the average amount of displacement. They conclude that the optimum setting of dimensions pertaining to parabolic leaf spring can be achieved by studying the various plots obtained from Design of Experiments.

Ashish V. et.al.[18]They have presented work on design & assessment of leaf spring. Main objective of their work was to compare the load carrying capacity, stresses and weight savings of composite leaf spring with that of steel leaf spring. Here the multi leaf spring consist three full length leaves in which one is with eyed ends used by a light commercial vehicle. The Theoretical and CAE results are compared for validation. From results it is proved that the bending stresses are decreased by 25.05% in composite leaf spring means less stress induced with same load carrying conditions. The conventional multi leaf spring weights about 10.27kg whereas the E-glass/Epoxy multi leaf spring weighs only 3.26 kg. Thus the weight reduction of 67.88% is achieved by using composite material rather than using steel material.

Niklas Philipson [19] found the conventional way to model leaf springs is to divide the spring into several rigid links. The models in this paper are designed as generalized force elements where the position, velocity and orientation of the axle mounting give the reaction forces in the chassis attachment positions. The shape of the Figure leaf spring will be determined by the rotations between each link.

Vinkel et.al.[20] the work have carried out on the front end leaf spring of acommercial vehicle. CAE analysis of the leaf spring has been done and the results are compared with the experimental results .When the leaf spring is fully /half loaded, a variation of 1.17% in deflection, time bending stress for fully loaded, is increased by 12.30 %, for half loaded bending stress is increased by 12.02 %. maximum equivalent stress is 172.5 MPa& 86.29 MPa for fully and half loaded leaf spring respectively, which is below the Yield Stress i.e. 250MPa.Therefore the design is safe which is observed among the

3. FAILURE ANALYSIS OF HELICAL SUSPENSION SYSTEM

Helical Suspension Systems are very common in two wheelers. These are also favoritechoice for light and medium weight passenger cars. Few contribution made by various researchers, on failure analysis in this area is presented here.

Michalczyk K. et.al [21]have presented the analysis of elastomeric coating influence on dynamic resonant stresses values in spring 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.

Mulla T., and Kadam S. [22] author have analyzed the elastic behavior and the stress analysis of springs employed in the TWV's front automotive suspension have been presented and discussed in this paper. The results obtained by a fully 3D FE analysis also stress ranging from 1.5 to 4 per cent, with reference to the applied loads, obtained when compared with the values calculated by using simple analytical model which is found in textbooks. In such case residual stress in every coil may be important factor which influence the failure.

Ravi B. k. et al.[23] author was analyzed 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.

James M. et al. [24] 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.

Sid A. et al. [25] have applied FEA for analysis of 3D geometric modeling of a twin helical spring and its finite element to study the spring mechanical behavior under tensile axial loading. The spiraled 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 spiraled 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 behavior. The overall equivalent stress is values 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.

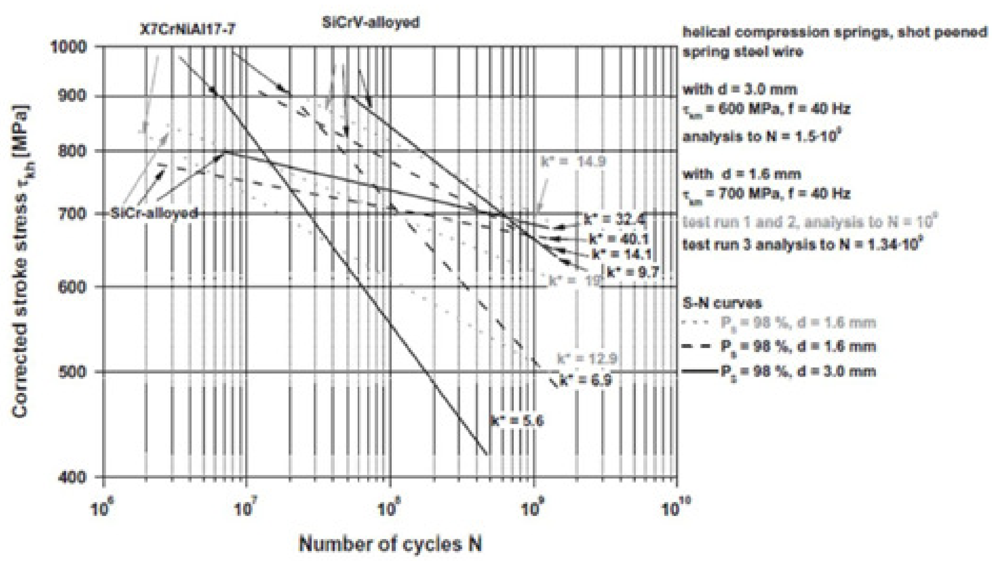

Fig. 3. Analytical and Simulated result

Pyttel B. et al. [26] have conducted Long-term fatigue tests on shot peened helical compression springs 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 micro sections in order to analyze the fracture behavior 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 summarized 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

Wei L. et al. [27] analyzed the very high cycle fatigue (VHCF) properties of newly developed clean spring steel. 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. 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.

Stefanie Stanzl-Tschegg [28] have analyzed to 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.

Penga Y., et al. [29] they have presented 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, parametric modeling 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 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.

Matjaz M. and et al. [30]have analyzed on 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. 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.

Gubeljaka N., et al. [31] authors have analyzed on 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 cause's higher compress stress magnitude and consequently change of loading ratio to more negative value and additionally extended life time of spring.

M. T. Todinov [32] 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.

Touhid Z. et.al. [33] Have presented 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 multi axial 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.

Kotaro watanabe et al.[34] they have presented 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.

Pyttel B. et al. [35]have presented 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 behavior considering different failure mechanisms. Investigated materials are different metals with body-centered cubic lattice like low- or high strength steels and quenched and tempered steels but also materials with a face-centered cubic lattice like aluminium alloys and copper. Recommendations for fatigue design of components are given.

Dammak F. et al. [36] have analyzed and present an efficient two nodes finite element with six degrees of freedom per node, capable to model the total behavior 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.

L. Del Llano et. al. [37] they have 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 n Code 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.

Berger, C.B. et al. [38] they have presented 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 108cycles 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 109cycles, about the mechanisms causing failures and about possible remedies or measures of improvement in another significant work.

GaikwadS. S. and et al.[39]have depicts about how to prevent the accident and to safeguard the occupants from accident, horn system is necessary to be analyzed in context of the maximum safe load of a helical compression spring. In this work, helical compression spring is modeled and static analysis is carried out by using NASTRAN software. It is observed that maximum stress is developed at the inner side of the spring coil.

A.R. González et. al. [40] presented an adjustable-stiffness actuator composed of two antagonistic non-linear spring 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 behavior 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.

4. CONCLUSIONS

This paper presents a candid comment on the research work done in the area of suspension system. Authors have summarized some contributions made by researchers in the area of vehicle suspension system. Work done in the area of Leaf spring as well as in the area of Helical suspension Systems are reported here to enable the researchers to know the direction of research in both type of system in one glance ie. in one paper. From survey it appears that composite materials are attracting researches for development of suspension system. It is also observed that as a case study researcher can do failure analysis of some medium segment car like TATA-Indica, Maruti-Swift etc. Bond graph technique has not been exploited for this purpose very much. So one may apply Bondgraph technique for the analysis and study of failure of suspension system.

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