Static And Fatigue Analysis Of Multi Leaf Spring Used In The Suspension System Of LCV

Mr. V. K. Aher *, Mr. P. M. Sonawane **
*(Asst. Prof. Pimpri Chinchwad College of Engineering, University of Pune, India)
** (Asst. Prof. Sinhgad Academy of Engineering, University of Pune, India)

ABSTRACT

The leaf spring is widely used in automobiles and one of the components of suspension system. It needs to have excellent fatigue life. As a general rule, the leaf spring must be regarded as a safety component as failure could lead to severe accidents. The purpose of this paper is to predict the fatigue life of semi-elliptical steel leaf spring along with analytical stress and deflection calculations. This present work describes static and fatigue analysis of a modified steel leaf spring of a light commercial vehicle (LCV). The dimensions of a modified leaf spring of a LCV are taken and are verified by design calculations. The non-linear static analysis of 2D model of the leaf spring is performed using NASTRAN solver and compared with analytical results. The pre processing of the modified model is done by using HYPERMESH software. The stiffness of the modified leaf spring is studied by plotting load versus deflection curve for working range loads. The simulation results are compared with analytical results. The fatigue life of the leaf spring is also predicted using MSC Fatigue software.

Keywords - multi leaf spring, fatigue life, non- linear static analysis, simulation

1. Introduction

The vehicles need a good suspension system that can deliver a good ride and handling. At the same time, the component must have an excellent fatigue life. Fatigue is one of the major issues in automotive components. It must withstand numerous numbers of cycles before it can fail, or never fail at all during the service period. Leaf spring is widely used in automobiles and one of the components of suspension system. It consists of one or more leaves. As a general rule, the leaf spring must be regarded as a safety component as failure could lead to severe accidents. The leaf springs may carry loads, brake torque, driving torque, etc. in addition to shocks . The multi-leaf spring is made of several steel plates of different lengths stacked together. During normal operation, the spring compresses to absorb road shock. The leaf springs bend and slide on each other allowing suspension movement. Fatigue failure is the predominant mode of in-service failure of many automobile components. This is due to the fact that the automobile components are subjected to variety of fatigue loads like shocks caused due to road irregularities traced by the road wheels, the sudden loads due to the wheel travelling over the bumps etc. The leaf springs are more affected due to fatigue loads, as they are a part of the unstrung mass of the automobile.

The aim of the project undertaken was to increase the load carrying capacity and life cycles by modifying the existing multi-leaf spring of a light commercial vehicle (LCV). In this paper, only the work of the modified seven-leaf steel spring is presented. The leaf spring was analysed over its full range from 1kN to 10 kN. Bending stress and deflection are the target results. Finally, fatigue life of the steel leaf spring is also predicted.

2. Literature Review

In the paper, 'Premature fracture in automobile leaf springs' by J.J.Fuentes , H.J. Aguilar , J.A. Rodríguez , E.J. Herrera , the origin of premature fracture in leaf springs used in Venezuelan buses is studied. To this end, common failure analysis procedures, including examining the leaf spring history, visual inspection of fractured specimens, characterization of various properties and simulation tests on real components, were used. It is concluded that fracture occurred by a mechanism of mechanical fatigue, initiated at the region of the central hole, which suffered the highest tensile stress levels. Several factors (poor design, low quality material and defected fabrication) have combined to facilitate failure. Preventive measures to lengthen the service life of leaf springs are suggested [1].

The paper by C.K. Clarke and G.E. Borowski on 'Evaluation of a Leaf Spring Failure' gives the determination of the point of failure during an accident sequence of a rear leaf spring in a sport utility vehicle is presented in terms of fracture surface analysis and residual-strength estimates. Marks at the scene of the accident pointed to two possibilities for the point of failure: marks in the roadway at the start of the accident sequence and a rock strike near the end of the sequence. Evidence from rust and chemical contamination on the fracture pointed to the spring having been cracked in half prior to the accident. Extensive woody fracture and secondary cracking at the mid plane of the spring was evidence for segregation and weakness in the spring. Stress estimates for the effect of both the weakness and prior cracking on the residual strength of the spring revealed reductions in strength of the spring that could produce fracture at the start of the accident sequence.

The point of failure of the spring was placed at the start of the accident sequence [2].

'Automobile Compression Composite Elliptic Spring' is studied by G. Goudah, E. Mahdi, A.R. Abu Talib, A.S. Mokhtar and R. Yunus. An automotive suspension system is designed to provide both safety and comfort for the occupants. When a vehicle encounters a road surface irregularity, the tire deforms and the suspension displaces. The result of such disturbance will cause some energy lost which will be dissipated in the tires and the shock absorber while the remainder of the energy is stored in the coil spring. In this paper, Finite element models were developed to optimize the material and geometry of the composite elliptical spring based on the spring rate, log life and shear stress. The influence of ellipticity ratio on performance of woven roving wrapped composite elliptical springs was investigated both experimentally and numerically, the study demonstrated that composites elliptical spring can be used for light and heavy trucks with substantial weight saving. The results showed that the ellipticity ratio significantly influenced the design parameters. Composite elliptic spring with ellipticity ratios of a/b= 2 displayed the optimum spring model [3].

'Analytical and experimental studies on Fatigue Life Prediction of steel and composite Multi-leaf Spring for Light Passenger Vehicles Using Life Data Analysis' is carried by Mouleeswaran Senthil Kumar, Sabapathy Vijayarangan. This paper describes static and fatigue analysis of steel leaf spring and composite multi leaf spring made up of glass fibre reinforced polymer using life data analysis. The dimensions of an existing conventional steel leaf spring of a light commercial vehicle are taken and are verified by design calculations. Static analysis of 2-D model of conventional leaf spring is also performed using ANSYS 7.1 and compared with experimental results. Same dimensions of conventional leaf spring are used to fabricate a composite multi leaf spring using E-glass/Epoxy unidirectional laminates. The load carrying capacity, stiffness and weight of composite leaf spring are compared with that of steel leaf spring analytically and experimentally. The design constraints are stresses and deflections. Finite element analysis with full bump load on 3-D model of composite multi leaf spring is done using ANSYS 7.1 and the analytical results are compared with experimental results. Fatigue life of steel leaf spring and composite leaf is also predicted. Compared to steel spring, the composite leaf spring is found to have 67.35 % lesser stress, 64.95 % higher stiffness and 126.98 % higher natural frequency than that of existing steel leaf spring. A weight reduction of 68.15 % is also achieved by using composite leaf spring. It is also concluded that fatigue life of composite is more than that of conventional steel leaf spring [4].

'Design and Analysis of Fiber Reinforce Polymer (FRP) Leaf Spring - A Review' paper by Bhushan B. Deshmukh , Dr. Santosh B. Jaju tells about weight reduction , the main issue in automobile industries. Weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. The introduction of FRP material has made it possible to reduce the weight of spring without any reduction on load carrying capacity. The achievement of weight reduction with adequate improvement of mechanical properties has made composite a very good replacement material for conventional steel. Selection of material is based on cost and strength of material. The composite materials have more elastic strain energy storage capacity and high strength to weight ratio as compared with those of steel, so multi-leaf steel springs are being replaced by mono-leaf composite springs. The paper gives the brief look on the suitability of composite leaf spring on vehicles and their advantages. The objective of the present work is design, analysis and fabrication of mono composite leaf spring. The design constraints are stress and deflections. The finite element analysis is done using ANSYS software. The attempt has been made to fabricate the FRP leaf spring economically than that of conventional leaf spring [5].

Fatigue life prediction is based on knowledge of both the number of cycles the part will experience at any given stress level during that life cycle and another influential environmental and use factors. The local strain-life method can be used pro-actively for a component during early design stage [6]. Fatigue failure always starts with crack-growth. The crack can initiate from the surface or at a depth below the surface depending on the materials processing conditions [7]. Fatigue crack contact under cyclic tensile loading was observed in Elbers work. This simple observation and crack-closure concept began to explain many crack-growth characteristic .Research on fatigue continue and in 2008, Fuentes et al. did a study which is subjected to leaf spring failure. They make a conclusion, i.e. the premature failure in the studied leaf springs which showed the fracture failure on a leaf was the result of mechanical fatigue and it was caused by a combination of design, metallurgical and manufacturing deficiencies.

Fatigue test using constant amplitude loading is a commonly practiced to predict the fatigue life properties of materials. Recently, only fatigue test data or/and fatigue curve under constant amplitude loading have been given in many handbooks of the fatigue and mechanical properties of metals. To get more accurate fatigue life prediction, the actual case condition also needs to be considered. Many models have been developed to predict the fatigue life of components subjected to variable amplitude loading. The earliest of these are based on calculations of the yield zone size ahead of the crack tip and are still widely used [8].

The major reason for carrying out variable amplitude loading test is the fact that a prediction of fatigue life under this complex loading is not possible by any cumulative damage hypothesis [9].In the case of parabolic spring, this was representing by different road surface and driving condition of the vehicle. Using constant amplitude loading, test were performed in controlled condition. But in VAL, lot of parameter need to be consider like cycle range and sampling frequency. Traditionally, fatigue life at variable amplitude is predicted by using material properties from constant amplitude laboratory test together with the Palmgren-Miner damage accumulation hypothesis [10].

There is the demand for spring excellent in sag resistance and fatigue properties, along with the increase in loaded stress on the springs. Strengthening for spring material would be effective in improving fatigue property, from the point of fatigue limits. However, when a spring material is strengthened, the defect sensitivity of the spring tends to be high, and that sometimes makes the fatigue life of the spring shorten [11]. The objective of the study carried by F.N.Ahmad Refngah, S.Abdullah, for their paper 'Life Assessment of a Parabolic Spring Under Cyclic Strain Loading' is to simulate the variable amplitude loading for the fatigue life analysis. Service loading of parabolic spring has been collected using data acquisition system. The finite element method (FEM) was performed on the spring model to observe the distribution stress and damage. The experimental works has been done in order to validate the FEM result [12].

3. Finite Element Modelling of The Leaf Spring

Multi leaf spring was modeled using commercial software and all the specifications were accordingly followed the relevant drawing standard. The spring geometry consists of master leaves and graduated leaves. As a preliminary study here, several assumptions have been made i.e. the chosen material was homogeneous, the frictional effect has not been taken into account, shackle and bush was not modeled, to reduce the complexity of simulation. Shackle and bushing only presented by boundary condition . The whole assembly is pre-processed in ALTAIR HYPERMESH v10. The iges file is imported to HYPERMESH, wherein finite element modelling is executed. A finite element model is the complete idealization of the entire structural problem including the node location, the element, physical and material properties, loads and boundary conditions. The purpose of the finite element modelling is to make a model that behaves mathematically as being modeled and creates appropriate input files for different finite element solvers.

Figure 1 Finite element model of the leaf spring with boundary conditions

Here meshing of spring is done by isomeshing with quadrilateral plate elements. Global-edge-length is 4mm. The CQUAD4 is used for modelling plates, shells and membranes. The CQUAD4 can represent in-plane, bending and transverse shear behavior, depending upon data provided on the PSHELL property entry. The CQUAD4 element is a quadrilateral flat plate connecting four grid points. At some junctions, the triangular elements are also introduced to make the frame to behave like stiffeners at those parts.

TABLE. 1 Specifications of the leaf spring

Material	SAE 5160H
Young's Modulus of the spring (MPa)	20700
Ultimate Tensile Strength (MPa)	1584
Total Length of the spring (Eye to Eye) (mm)	1340
Distance between U bolts (mm)	80
Free Camber (At no load condition) (mm)	96
No. of full length leaves	02
No. of graduated leaves	05
Thickness of each leaf (mm)	8
Width of each leaf spring (mm)	60
Design Load given on the spring (N)	6000
Maximum Load (Metal to Metal Position) (N)	10000

3.1 Representation of Boundary Conditions

To represent the pivoted boundary condition at front eye, a master node was created at the central axis of front eye. This master node was connected to remaining nodes of eye with rigid body element RBE2. At master node all degrees of freedom except rotational DOF about y-axis were constrained. To represent the boundary condition at rear eye, a master node was created at the central axis of rear eye. This master node was connected to remaining nodes of eye with rigid body element RBE2. At master node all degrees of freedom except rotational DOF about y-axis and translation in x were constrained. (Fig.2)

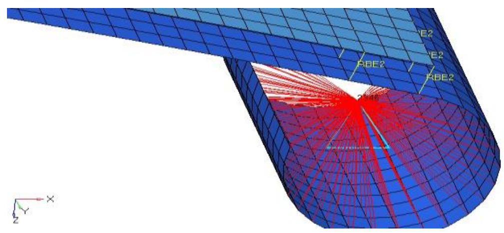

Figure 2 Rigid element at constraint eye end

To represent the central bolt CBEAM element was used. For that nodes on the circumference of hole were connected with the master node created on the central axis by RBE2 elements with all DOFs constrained. After that the master nodes were connected by CBEAM element. As leaves in leaf spring were in contact with each other, means the distance between two leaves should remain constant. There was no penetration of leaves with each other during simulation. To represent this RBE2 elements were used to join nodes on leaves with each other having all DOFs constrained except translation in x and z direction.(Fig.3)

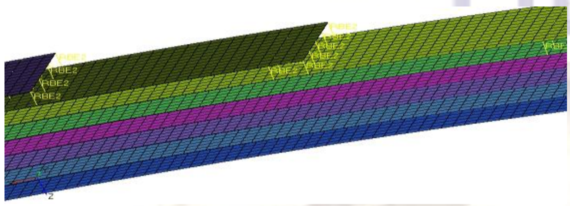

Figure 3 Rigid connection at the end of each leaf

4. Non-linear Static Analysis

The non-linear analysis is done for leaf spring in its horizontal condition by specifying the load in terms of 'Newton' and other dimensions by 'mm'. The constraints applied are multi point constraints. The load is applied uniformly on the frame structure. The analysis file is attached to the solver. After solving the model, the results can be viewed to the desired condition. The results of the analysis are as per the following Fig.4,5,6 and 7.

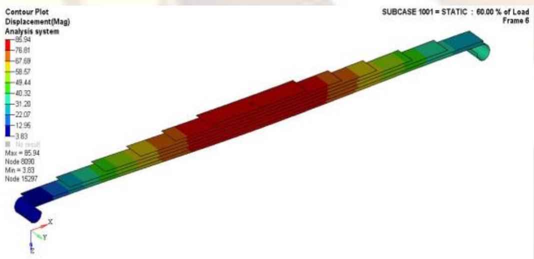

Figure 4 Deflection at design load 6 kN

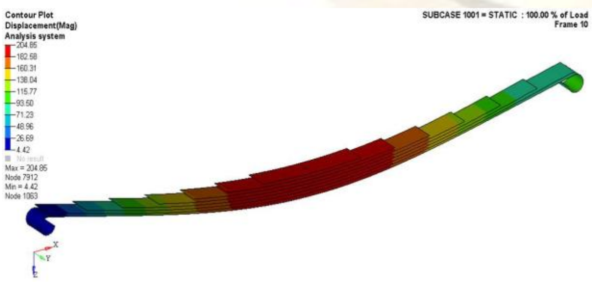

Figure 5 Deflection at maximum load 10 kN

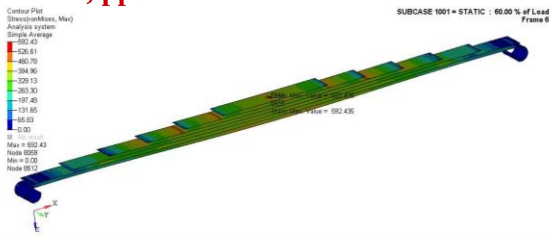

Figure 6 von-Mises stress at design load 6 kN

Figure 7 von-Mises stress at maximum load 10kN

The load vs deflection plot for the leaf spring is linear as shown in the Fig. 8

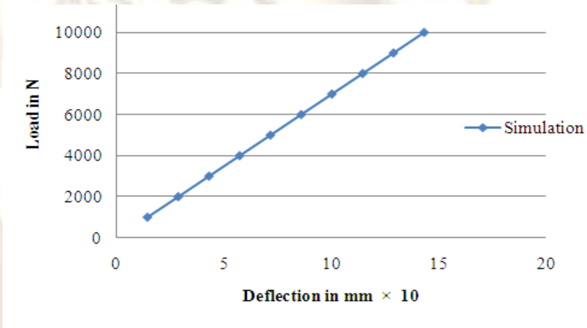

Figure 8 Load Vs Deflection plot for the leaf spring

5. Modal Analysis

The normal modes analysis gives a set of natural frequencies. In this work it obtained initial six frequencies and also the corresponding mode shapes. The fig. 9, 10 & 11 show few of the modes shapes.

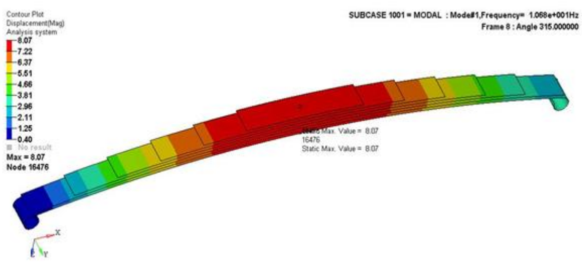

Figure 9 Vertical Bending first fundamental frequency

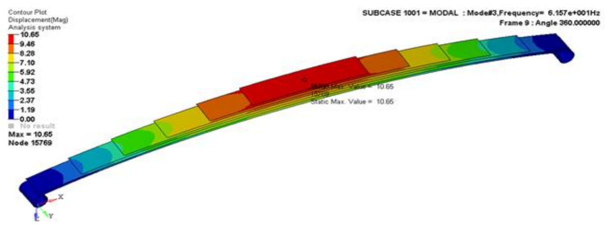

Figure 10 Second mode lateral bending frequency

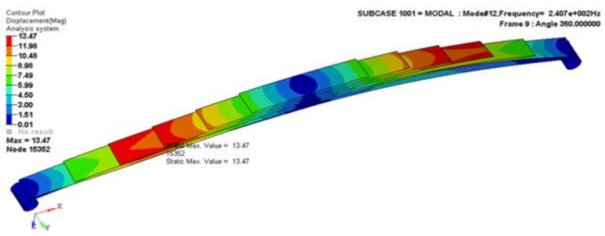

Figure 11 Third mode twisting frequencies

6. FEA-Based Fatigue Simulation

The finite element model from earlier stage was applied with the constant amplitude loading to simulate the actual road loading condition. In this simulation, the Goodman approach has been used. The material that has been used for the simulation of the spring is SAE5160H low carbon alloy steel, which is normally used for the spring fabrication. Ultimate Tensile Strength of the material is 1584 Mpa. The results obtained using MSC Fatigue software for the fatigue analysis are as shown in Fig.12 and Fig.13.

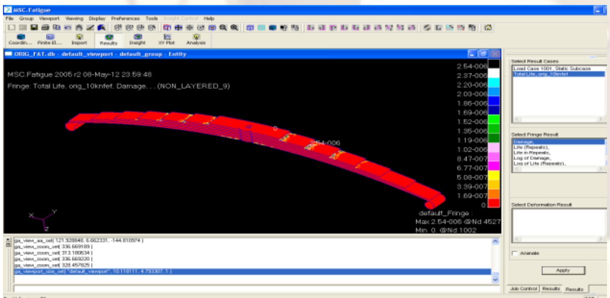

Figure 12 Damage sum location of leaf spring

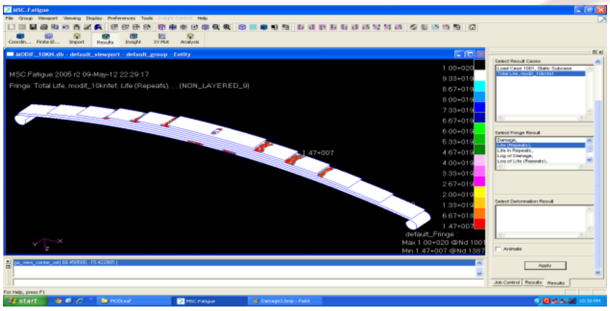

Figure 13 Contour plot of life of the leaf spring

6. Results

i) 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 MPa. For the validation, the FEA stresses are compared to the analytical as shown in the Fig.14.

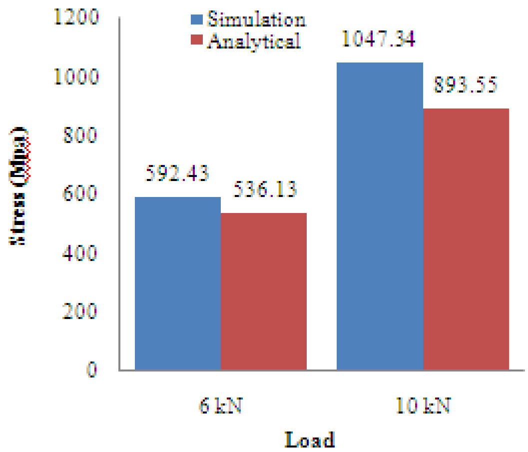

Fig.14 Comparison of the simulation and analytical stresses

ii) From 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 as shown in the Fig.15.

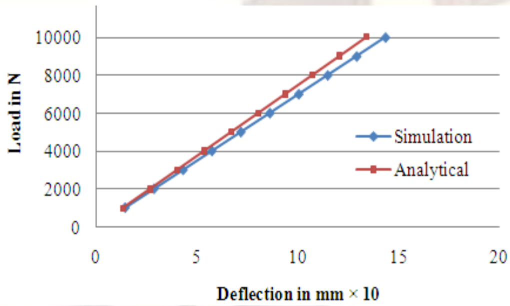

Figure 15 Graph of comparison of simulation and analytical deflections

iii) From Modal analysis, the fundamental frequency for the leaf spring is 10.68 Hz observed in vertical bending mode. The subsequent 2^{nd} and 3^{rd} mode shows the lateral and twisting modes.

iv) 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 1.47×10^{7} cycles.

7. Conclusion

The fatigue life prediction is performed based on finite element analysis and fatigue life simulation method. FEM gives the prediction of critical area from the viewpoint of static loading. The results of non-linear static analysis of 2D model of the leaf spring using the commercial solver and analytical results shows better correlation. The stiffness of the leaf spring is studied by plotting load versus deflection curve for whole working load range which shows the linear relationship. Using the constant amplitude loading, the fatigue damage and life of the spring has been predicted. From the damage contour, the highest damage value is in acceptable range.

This study will help to understand more the behavior of the spring and give information for the manufacturer to improve the fatigue life of the spring using CAE tools. It can help to reduce cost and times in research and development of new product.

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