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# Design & Analysis of Multi Steel Leaf Spring

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**ABSTRACT**

**In order to economize energy, weight reduction has been the main focus of automobile manufacturer in the present scenario. Weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. The scope of this project is to design, analyze & manufacture a hybrid composite multi leaf spring for a multi utility vehicle. The objective is to compare the load carrying capacity, stiffness & weight of a Hybrid composite leaf spring with the present conventional steel multi leaf set-up. The primary design considerations are deflection, maximum stress induced & fatigue life. In automobile sector leaf spring which is used in a suspension system can be replaceable by a novel concept of hybrid fiber metal composite material hence by combining the mechanical properties of composite fiber and metal to resist high mechanical loads and thereby increasing higher fuel economy and decrease the overall weight of the vehicle. Experimental test rig (endurance test rig) has been used for fatigue analysis of hybrid fiber-metal composite leaf spring. This method provides means to determine the deflection, stress and strain for different loading conditions. The model of leaf spring has been prepared to carry out Finite Element Analysis. The best possible composite mixture and the steel material will be selected for manufacturing and tested to the failure. Thus we can avoid spring failures and achieve higher success rate by introducing this concept.**

*Keywords-* **Fiber laminated composite leaf spring, Fatigue, FEA, Hybrid metal composite leaf spring.**

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## I. INTRODUCTION

Leaf springs are mainly used in suspension systems to absorb shock loads in automobiles like light motor vehicles, heavy duty trucks and in rail systems. It carries lateral loads, longitudinal loads, side loads, brake torque, driving torque. Originally called 'laminated' or 'carriage spring', a leaf spring is a simple form of spring commonly used for the suspension in wheeled vehicles .It is also one of the oldest forms of springing, dating back to medieval times. Sometimes referred to as a semi-elliptical spring or cart spring, it takes the form of a slender arc-shaped length of spring steel of rectangular cross-section. The center of the arc provides location for the axle, while tie holes are provided at either end for attaching to the vehicle body. For passenger vehicles, a leaf spring can be made from several leaves stacked on top of each other in several layers, often with progressively shorter leaves. A leaf spring can either be attached directly to the frame at both ends or attached directly at one end, usually the front, with the other end attached to a shackle, a short swinging arm. The shackle takes up the tendency of the leaf spring to elongate when compressed and thus makes for softer springiness. Some springs terminated in a concave end, called a spoon end (seldom used now), to carry a swiveling member.[1][2].
Leaf springs can serve locating and to some extent damping as well as springing functions. While the interleaf friction provides a damping action, it is not well controlled and results in stiction in the motion of the suspension. For this reason manufacturers have experimented with composite leaf springs.
The suspension leaf spring is one of the potential items for weight reduction in automobile as it accounts for 10-20% of the un-sprung weight. The introduction of composites helps

 

in designing a better suspension system with better ride quality if it can be achieved without much increase in cost and decrease in quality and reliability.[2] The relationship of the specific strain energy can be expressed as it is well known that springs, are designed to absorb and store energy and then release it slowly. Ability to store and absorb more amount of strain energy ensures the comfortable suspension system. Hence, the strain energy of the material becomes a major factor in designing the springs. The relationship of the specific strain energy can be expressed as,

$U = \sigma^2 / 2\rho E$

Where 'σ' is the strength,

'ρ' is the density &

'E' is the Young's Modulus of the spring material.

It can be easily observed that material having lower modulus and density will have a greater specific strain energy capacity. The introduction of composite materials has made it possible to reduce the weight of the leaf spring without reduction of load carrying capacity and stiffness due to more elastic strain energy storage capacity and high strength to weight ratio.This achieves the vehicle with more fuel efficiency and improved riding qualities.[1]

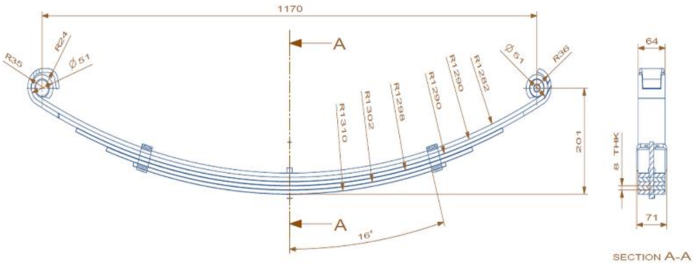


Fig.1 Conventional Leaf spring.

## II. LITERATURE REVIEW

### *A. Analysis and Optimization of Leaf Spring [1]*

The method of the finite element analysis is used in number of studies. The analysis and optimization study includes FEA to study the four steel leaf spring of rear suspension system of light vehicles. The authors verified the FEA results showing stresses and deflection with existing analytical and experimental solutions. The study was conducted with the objectives of obtaining minimum weight spring that should be capable of carrying given static external forces without failure. While designing constraints were used viz. stresses as per Tsai-Wu failure criteria and displacement. The study had recorded the results as an optimum spring width decreases hyperbolically and thickness increases linearly from spring eye toward axle seat. While comparing the composites leaf spring with steel spring, the optimized composite spring had stresses that were much lower. The natural frequency recorded is higher and spring weight without eye is 80% lower.

### *B. Design Optimization of Composite Leaf Spring [2]*

In this study the Genetic Algorithm for design of the composite leaf spring is used. We have seen that the suspension system of automobile remarkably affects the vehicle behavior. The vehicle behavior is measured in term of vibrational characteristics including ride comfort, directional stability etc. leaf spring are having their higher common use in automobiles. These springs are subjected to millions of varying stress cycles leading to fatigue type failure. This is better to replace the steel spring by composite spring which will be going to contribute in weight reduction. There are different method are used for design optimization and most of study using mathematical programming technique and analysis. In this study artificial genetic algorithm is used.The results showed that 75.6% reduction in weight is achieved when a seven leaf steel springs was replaced by a single composite leaf spring by keeping identical design and optimization parameters were selected.

### *C. Fatigue Life Prediction of Parabolic Leaf Spring [3]*

During working condition the parabolic leaf spring undergoes repeated cyclic loading. For this reason the fatigue assessment of parabolic leaf spring has got significance. In this study the simulation of the fatigue life of parabolic leaf spring design with variable loading amplitude. VAL signals were gathered by performing measurements from various road conditions. However the fatigue life of spring is predicted using FE stress-strain model with VAL signal as load input.The results indicated that life of spring is lowest on rough road followed by curve mountain road and smooth highway road respectively. The VAL has provided more realistic estimation as compared to laboratory method of traditional. The approach used for parabolic leaf spring fatigue life analysis is described with flow diagram in fig.1

### *D. Fatigue Life Comparison of Steel and Composite Leaf Spring [4]*

To enhance the vehicle performance and to reduce $CO_2$ emissions conventional steel leaf spring should be replaced by lighter one. The lightweight, better performance and high mechanical spring giving great potential for manufacturing springs that are made up of fiber reinforced composite materials with polymer based composite matrix. The FEA method was used for stress analysis in similar approach to that of steel leaf spring since composite materials are anisotropic materials. It is difficult to understand material structure and to follow correct way different fiber orientation conditions are used. The material properties considered for this study are of carbon fiber reinforced epoxy materials.The conclusion had drawn from this study is the performance of springs made up of composite materials reinforced by long fibers is better than that of the steel and glass fiber reinforced epoxy material used for leaf spring.

### *E. Evaluation of Multi-Leaf Hybrid Spring [5]*

The basic beam theory approach with uniform thickness and width yields reasonable results. However there is need to used FEA for complex leaf spring system such as hybrid steel composite design. In this study the contact type modelling is being compared with non-contact type modelling. A non-linear finite element analysis model of multi-hybrid system is shown in fig 2. This system comprises of number of multi-leaf springs as one spring. One advantage of this method is computational time is less and important disadvantage is simple beam effect. A non-linear contact FEA model is modelled as per the same method above. The expected advantage is with this method greater curacy for solution, reflecting the mechanics of multi-leaf spring system, capturing the deflection characteristics etc. The possible disadvantage for this solution is more computational time than the previous methods.

## III. PROBLEM STATEMENT & OBJECTIVES

### A. *Problem Statement*

Many attempts have been made in the past to replace the conventional steel multi leaf setup by composite leaf spring. The noted problems are:

1) To replace the traditional steel leaf springs which are quite heavy with corrosive properties leading to fatigue failure.

2) To reduce the building up of foreign materials in between the individual leaves.

3) To resist high mechanical loads, to maximize the strength and improve shock absorbing properties of the leaf spring. Thereby decreasing the overall weight of the vehicle and increasing higher fuel economy.

### B. *Objectives*

1) Replacement of 'Conventional steel leaf spring' with novel concept of 'Hybrid fiber-metal composite leaf spring' for weight reduction.

2) To find the best composite material which has a high strength to weight ratio and can withstand higher load; most appropriate material out of (E-glass/Carbon fiber).

3) Analytical& Finite Element analysis investigation of both Steel and Hybrid fiber-metal leaf spring.

4) Fabrication & Testing of Hybrid fiber-metal composite leaf spring using the Endurance testing rig.

Comparative study of Analytical, FEM& Experimental results.

## III. SPECIFICATION AND MATERIAL PROPERTIES OF STEEL LEAF SPRING

TABLE I

| Parameters of Steel leaf spring | Value |
|---|---|
| No of Leaves, N | 5. |
| Width, W | 63mm. |
| Thickness of leaves, t | 8mm. |
| Length between eye centres, L | 1170mm. |
| Length of front cantilever, a | 585mm. |
| Length of rear cantilever, b | 585mm. |
| Eye Diameter, D | 51mm. |
| Metal to metal clearance, $x_c$ | 161mm. |
| No of full length leaves | 2. |
| Gross vehicle weight of Bolero Maxx | 2620Kg. |

TABLE II

| Material Properties of EN45A | Value |
|---|---|
| Density, ρ | 7850 Kg/m$^3$ |
| Young's modulus, E | 2.1*10$^5$ MPa. |
| Poisson's ratio, μ | 0.266. |
| Ultimate Tensile Strength, $S_{ut}$ | 1272 MPa. |
| Yield Tensile Strength, $S_{yt}$ | 1158 MPa. |
| Coefficient of Friction | 0.2 |

The parameters and material properties of steel leaf are listed in Table I & Table II respectively.

## IV. BOUNDARY CONDITIONS OF STEEL LEAF SPRING

On the axle of the automobile the leaf spring is mounted on the frame of the vehicle. The details of the boundary conditions applied at the eye ends are given below.

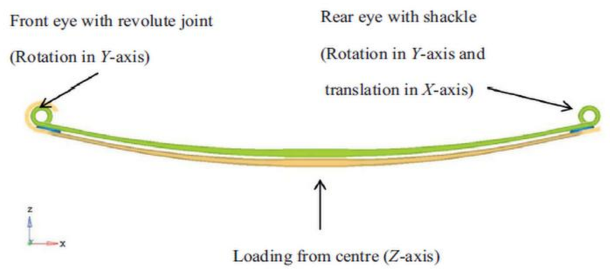


Fig.2 Bounday conditions[3]

TABLE III

| Degree of Freedom Constraints | Rear Eye | Front Eye |
|---|---|---|
| Translation Constrained | Y & Z | X, Y and Z |
| Rotation Constrained | X and Z | X and Z |
| Allowing | Y rotation and Free X translation | Free Y rotation |

## V.DESIGN& ANALYSIS OF STEEL LEAF SPRING

### A. *Analytical Modelling*

Given Data:
Stiffness,K = 65.17N/mm.
Laden weight on each leaf spring, F = 2620/4 = 655Kg.
Factor of Safety, n = 2.

#### 1) *Case 1:*

Design Load,
P = n*g*F
= 2*9.81*655
**P = 12851.1 N = 12900 N (approx.).**

Stiffening Factor, SF = 1.1 (for Passenger vehicles from Spring Design manual)[8]
From SAE Spring Design manual the moment of inertia of master leaf spring (for W = 63mm & t = 8 mm) is 2588 mm$^4$.[8]

Length Ratio,
$Y = \frac{b}{a} = \frac{585}{585} = 1.$
So, it's a symmetrical semi elliptic case.

Total Moment of Inertia,
$\sum I = (K*L^3)/ (32*E*S.F)$
$= (65.17*1170^3)/ (32*2.1*10^5*1.1)$
**$\sum I$ = 14120.281 mm$^4$.**

Stress in Leaf Spring
S = (L*t*P) / (8*∑I)
= (1170*8*12900) / (8*14120.28)
**S = 1068.88 MPa.**

Load rate
$k = (32*E*\sum I*SF) / L^3$
$= (32*2.1*10^5*14120.28*1.1) / 1170^3$
**k = 65.16 N/mm.**

Deflection,
δ = P/k
= 12900/65.16
**δ = 197.97mm.**

*2) Case 2:*

For load = 655Kg;
= 655*10 = 6550N.
Length Ratio,
$Y = \frac{b}{a} = \frac{585}{585} = 1.$
So, it's a symmetrical semi elliptic case.

Total Moment of Inertia,
$\sum I = (K*L^3)/ (32*E*S.F)$
$= (65.17*1170^3)/ (32*2.1*10^5*1.1)$
**$\sum I$ = 14120.281 mm$^4$.**

Stress in Leaf Spring
S = (L*t*P) / (8*∑I)
= (1170*8*6550) / (8*14120.28)
**S = 542.73 MPa.**

Load rate
$k = (32*E*\sum I*SF) / L^3$
$= (32*2.1*10^5*14120.28*1.1) / 1170^3$
**k = 65.16 N/mm.**

Deflection,
δ = P/k
= 6550/59.72
**δ = 109.67mm.**
Referringthe formulas from SAE Spring Design manual. The stress calculated for a load of 6550N is 542.73 N/mm$^2$ and deflection is 109.67mm.

But the master leaf remains of steel of thickness = 8mm. Moment of Inertia of master Leaf = 2588 mm$^4$ (standard gauge from SAE Spring Design manual) [8]
Inertia required for single composite leaf = 14120.281-2588 = 11532.281mm$^4$.

$$I_{composite} = 11532.281 = \frac{(w \times t^3)}{12} = \frac{(63 \times t^3)}{12}$$

**t = 12.99mm ~ 13mm.**
Thickness of master leaf = 8mm.
Thickness of composite leaf = 13mm.

*B. CAD Model*

A standard leaf spring setup is designed as per the data available and modelled in software CATIA V5.

Fig.3 Multi View of the CAD model.

*C. Finite Element Modelling*

Stress analysis is to be performed using finite element method. The software used is "ALTAIR HYPERMESH v11". In the finite element modelling the material used for Leaf spring analysis is Structural Steel which is Isotropic in nature. The element type used is "C3D8R". It's an 8 noded Hexagonal mesh element, per node it has three degrees of freedom. Element size taken is 5.

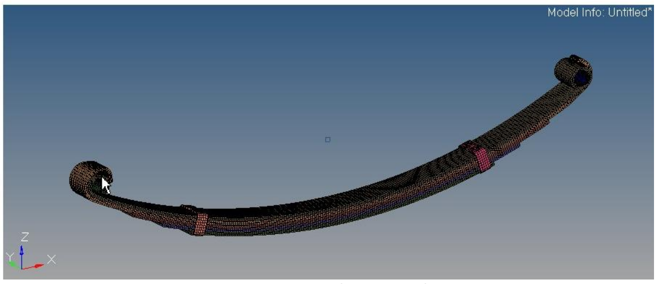


Fig.4 Meshed model of Steel leaf spring.

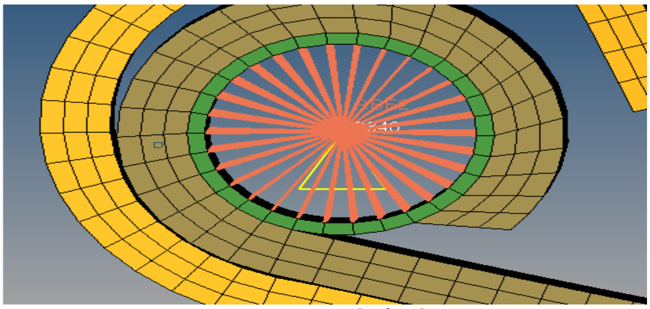

Fig.5 Constraints at leaf ends.

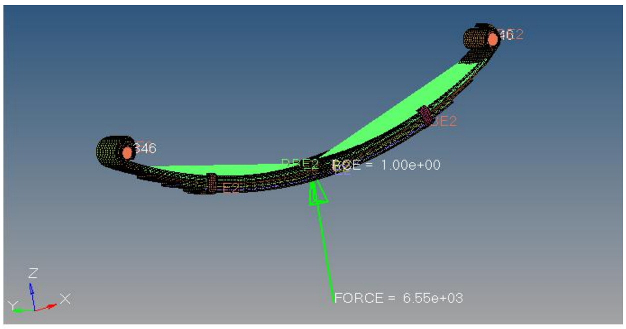


Fig.6 Load and Boundary conditions applied to the Leaf spring.

*1) Static Analysis of Steel Leaf Spring*

The Static loading is done at 6500N. The stress and deflection values for this particular loading is noted. The solver used is “ABAQUS” and the results are viewed in “HYPERVIEW”.The load vs deflection curve for this particular loading is plotted using FEM & Experimental methods and Stiffness is calculated.

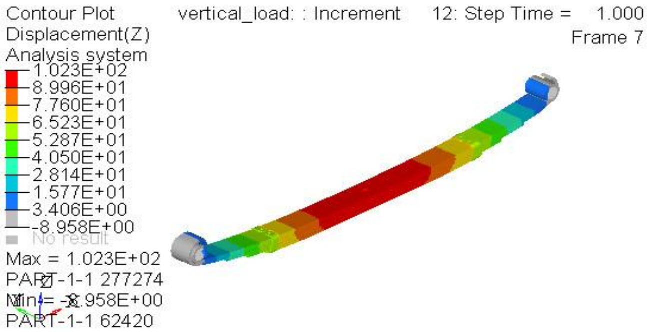


Fig.7 Displacement plot.

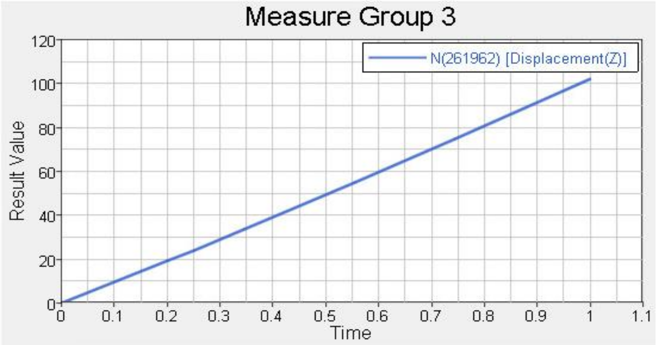


Fig.8 Load vs Displacement plot wrt Time.

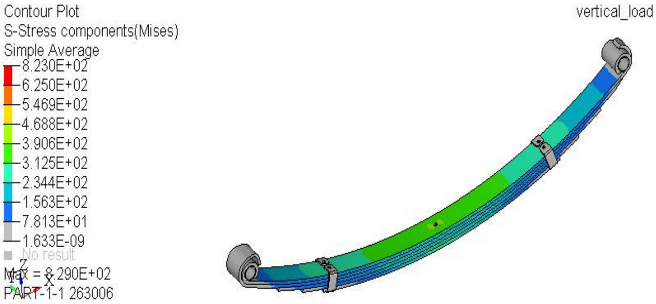


Fig.9 Full leaf assembly Stress plot.

From Finite element analysis it can be seen that for a load of 6550N the displacement achieved is 102.3mm and Von Mises stress achieved is 546.9 $N/mm^2$.

The stiffness calculated is,

$K = F/\delta$

$= 6550N/ 102.3mm$

$K = 64.02N/mm.$

*2) Dynamic Analysis of Steel Leaf Spring*

For automotive components normal modal analysis plays major role in design approval. To avoid resonance, leaf spring has to be designed with respect to road frequency in such a way that, its natural frequency should be maintained to provide ride comfort. The road irregularities usually have maximum frequency of 12Hz. The mode shapes of Steel leaf spring are shown and frequencies are notes. [1]

The material used is “Steel EN45A”. Materialislinearandelastic,Isotropic andTemperatureindependent (t=0). ModulusofelasticityE= 2.1e5 (N/mm2), Poissonratioν= 0.266, Densityρ= 7.89e-09(tonnes/mm3).

Analysisis performedinthe‘HYPERMESHv11’ and the solver used is “MSC NASTRAN”. The results are viewed in “HYPERVIEW”.

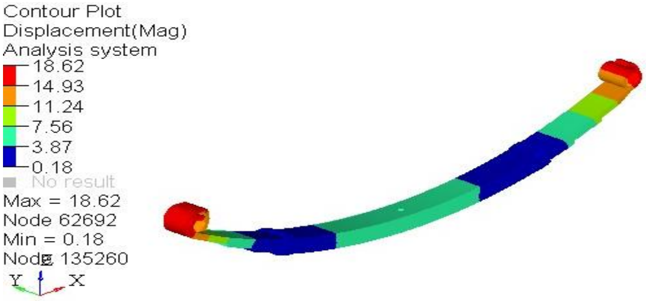


Fig.10 Mode shape 1 - 124.3Hz.

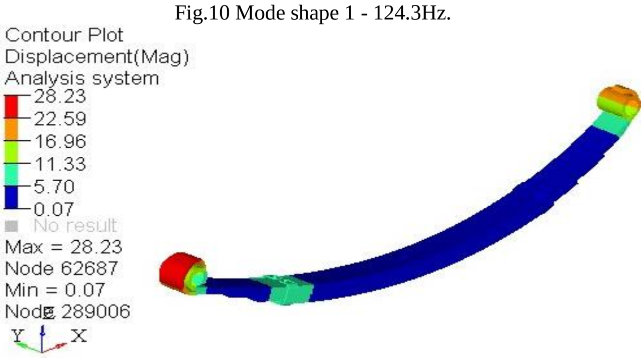


Fig.11 Mode shape 2 - 241.3Hz.

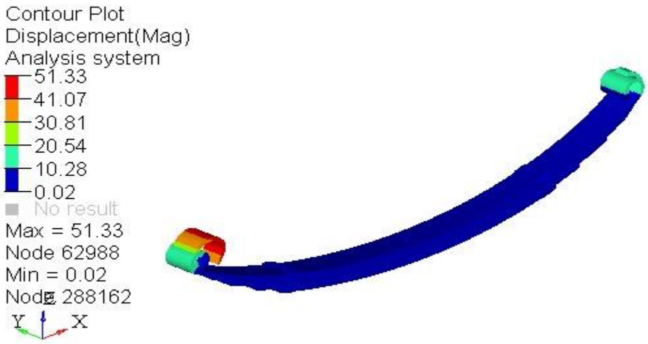


Fig.12 Mode shape 3 - 328.3Hz.

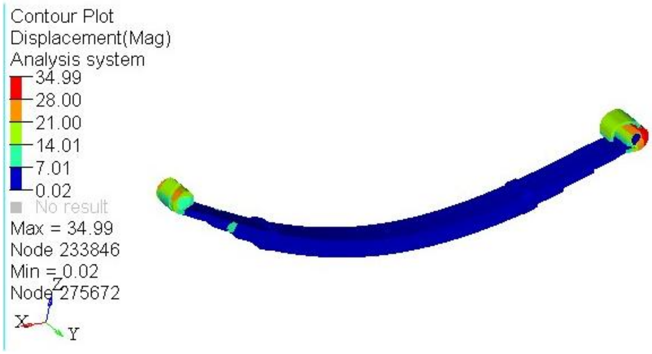


Fig.13 Mode shape 4 - 393.0 Hz.

 

*3) Fatigue analysis of Steel Leaf spring*

The main purpose of Finite element based fatigue analysis used for simulation of leaf spring during the design stage of development process is to enable reliable fatigue life calculations. In this the three input parameters namely geometry, materials and loading are regarded as input functions. The work flow of fatigue analysis with finite element method is shown in Fig.4.[3]

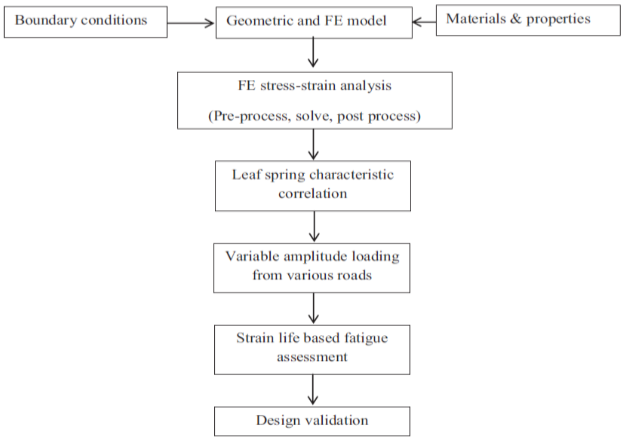


Fig.14 Flowchart for Fatigue analysis.

The software planned for fatigue analysis is FEMFAT /MSC FATIGUE / n-Code.

## VI. EXPERIMENTATION OF STEEL LEAF SPRING

*A. Static Testing*

The steel leaf spring is to be tested by using Universal Testing Machine. It's make is Star testing system, India

Fig.15 Static Testing for Load vs Deflection.

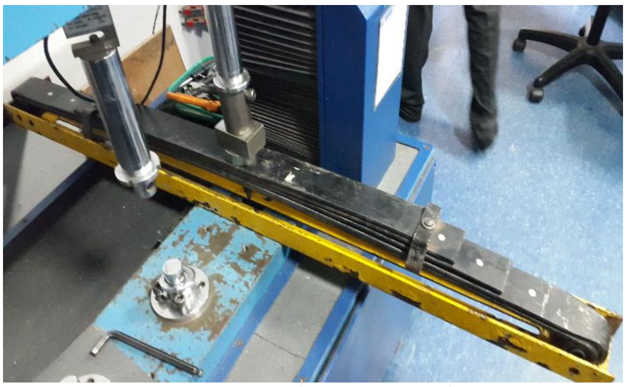

Fig.17 Static Testing for Maximum Deflection.

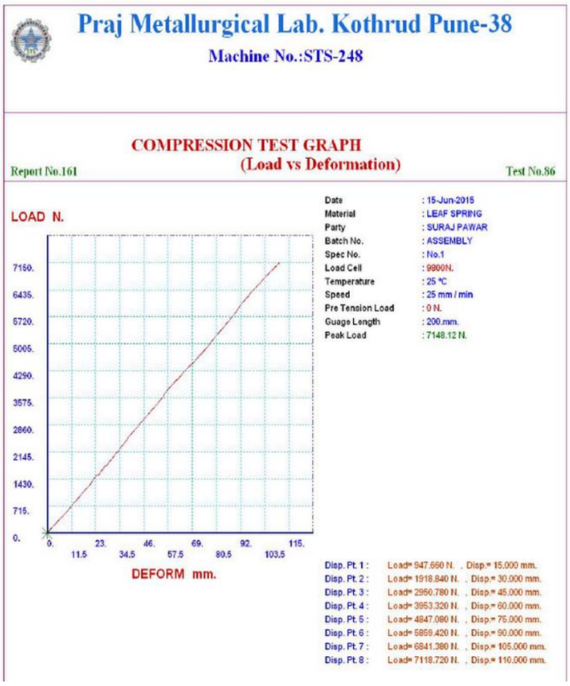


Fig.18 Load vs Deflection Plot

The testing is done at a speed of 25mm/min. The gauge length set is 200mm and results are upto a peak load of 7148.12N. The load is applied at the center of the spring. The vertical deflection is recorded in intervals of 15mm. From the curve it can be seen that the plot is linear. The maximum deflection is seen at 110mm, it is a point where the Steel assembly is perfectly parallel to the C shaped channel.

The deflection at 6550N is 100.5mm.
The stiffness achieved is K = 65.17N/mm.

*A. Fatigue Analysis Using Variable Amplitude Loading Endurance Test Rig.*

This setup is designed to conduct endurance testing of Leaf springs either in one leaf or in cantilever form at set defection. Facility of measurement of load v/s displacement for the spring is also provided.

Capacity – 500kg max.
Displacement – 100mm max.
Length of test spring – 1m max.

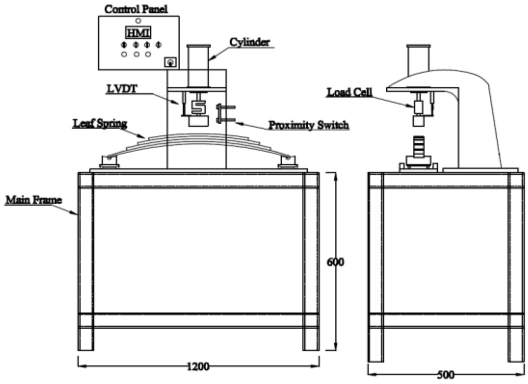


Fig.19 Front & Side view of Experimental setup

 

Fig.20 Photographic Image of the setup

## VII. RESULTS AND DISCUSSION

A Steel leaf spring used in the rear suspension of light passenger cars was analyzed by analytical & finite element analysis. The experimental results verified the analytical and finite element solutions methods under static loading containing the stresses and deflection and stiffness is to be calculated from the above.

TABLE IV

| Material | Static Loading(N) | Maximum Deflection(mm) | | |
|---|---|---|---|---|
| Steel EN45A | 6550N | Analytical | FEM | Experimental |
| | | 109.67 | 102.33 | 100.5 |

TABLE V

| Material | Static Loading(N) | Maximum Von Mises Stress ($N/mm^2$) | |
|---|---|---|---|
| Steel EN45A | 6550N | Analytical | FEM |
| | | 542.73 | 546.9 |

The modal analysis results for the first four natural frequencies is shown in Table VI.

TABLE VI
Natural Frequencies of steel Leaf spring

| Modes | Frequencies (Hz) |
|---|---|
| 1 | 124.3 |
| 2 | 241.3 |
| 3 | 328.3 |
| 4 | 393.0 |

## VIII. FUTURE SCOPE

1. Based on the results determined by Structural Analysis using FEA, the inputs shall be used for conducting Fatigue Analysis using MSC FATIGUE or n-Code as preferred solvers.

2. The Steel Multi Leaf spring will be replaced by equivalent Hybrid fiber metal composite leaf spring for weight reduction.

3. Mathematical treatment could be extended further to include preliminary evaluation for composite materials.

4. The laminates or layers for the Composite material could be considered for its lay or orientation while preparing the model for analysis.

## CONCLUSION

The development of Steel leaf spring having constant cross section and constant width is modelled in CATIA v5.
Software’s used are ALTAIR HYPERMESH as a preprocessor and solvers used are MSC NASTRAN, ABAQUS and the results are viewed in HYPERVIEW.
Comparison of results at a load of 6550N is done hence, from the results we can see that the Analytical,FEM and Experimental results are close in agreement.
Based on the results the development of Hybrid composite leaf spring is to be done to reduce weight, increase stiffness, decrease stresses and increase natural frequencies.

## AKNOWLEDGEMENT

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