# Static, Modal and Fatigue Life Prediction through CAE for a Leaf Spring used in Light Commercial Vehicle

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**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 analyze static, modal and predict the fatigue life of steel leaf spring along with analytical stress and deflection calculations. This present work describes static, modal and fatigue analysis of a existing leaf spring and modifying existing steel leaf spring by reducing no of graduated leaves and increasing thickness. 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 fatigue life is carried out by MS fatigue. The pre processing of the modified model is done by using HYPERMESH software.***

**Keywords:** leaf spring, static analysis of analysis of leaf spring fatigue life, fatigue analysis, modal analysis, light commercial vehicles

## 1. Introduction

A spring is defined as an elastic machine element, which deflects under the action of load and returns to its original shape when the load is removed.

The large vehicles need a good suspension system that can be deliver a good ride and handling. At the same time, that component had an excellent fatigue life. Fatigue is one of the major issues in automotive component. 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 leaf spring was analyzed over its full range from 1KN to 10 KN. Bending stress and deflection and mode shapes are the target results. Finally, fatigue life of the steel leaf spring is also predicted.

## 2. Material Properties

The material used for the leaf spring is Manganese Silicon Steel. The standard properties of the steel are given below:

Young's modulus: $2.07\times10^{5}$ N/mm$^2$
Poisson's ratio: 0.3
Density: $0.78\times10^{-6}$ Kg/mm$^3$

**Table 1:** Design Specification of Existing Leaf Spring

| *Sr. No* | *Design Parameter* | *Value* |
|---|---|---|
| 1 | Total Length of the spring (Eye to Eye) (mm) | 1340 |
| 2 | Free Camber (At no load condition) (mm) | 96 |
| 3 | No. of full length leave | 01 |
| 4 | No. of graduated leaves including master leaf | 07 |
| 5 | Thickness of leaf t (mm) | 07 |
| 6 | Width of leaf spring b (mm) | 60 |
| 7 | Maximum Load given on spring (N) | 10000 |
| 8 | Young's Modulus of the spring(N/mm$^2$) | 207000 |

| | | |
|---|---|---|
| 9 | Mass density(kg/mm$^3$) | 0.78×10$^{-6}$ |
| 10 | Yield stress(N/mm$^2$) | 1680 |

Maximum deflection at peak load if P=1000KN

Analytical calculations for existing leaf spring

Maximum deflection at peak load if P =1000N

if P =1000N

$$\delta = \frac{12PL^3}{Ebt^3(3n_f + 2n_g)}$$

=12×(1000/2)×670$^3$/ 2.07× 10$^5$× 60× 7$^3$( 3×1+2×7)

δ = 24.92mm

Maximum stress at peak load.

$$(\sigma_b)_{max} = \frac{18PL}{(3n_f + 2n_g)bt^2}$$

= 18× (1000/2)×670/(( 3×1+2×7) ×60× 7$^{2))}$

$(\sigma_b)_{max}$ = 120.65Mpa

Maximum Stiffness

$$K = \frac{load}{deflection}$$

= (1000/2)/ 24.92

K = 20.0682 N/mm.

**Table 2:** Analytical Calculation of Deflection And Bending Stress For Existing Leaf Spring

| *Sr no* | *load in N* | *Deflection (δ)mm* | *Bending stress(N/mm$^2$)* |
|---|---|---|---|
| 1 | 1000 | 24.92 | 120.65 |
| 2 | 2000 | 45.84 | 241.3 |
| 3 | 3000 | 70.76 | 361.94 |
| 4 | 4000 | 90.67 | 482.6 |
| 5 | 5000 | 111.59 | 603.24 |
| 6 | 6000 | 131.51 | 723.89 |
| 7 | 7000 | 151.43 | 844.53 |
| 8 | 8000 | 172.35 | 965.17 |
| 9 | 9000 | 193.26 | 1085.83 |
| 10 | 10000 | 213.76 | 1206.49 |

Modeling of Leaf Spring

The leaf spring assembly contains number of parts like leaf, center bolt, rebound clamps and bushing. To avoid the complexity, here only leaves are modeled. To create 3D model CATIA V5R18 modeling software was used. This 3D model then imported to HYPERMESH 10 for pre-processing work.

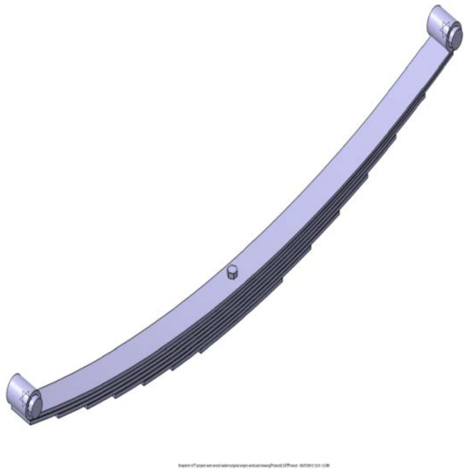

**Figure 1:** Cad Modeling

## 3. Selection of Elements Type

Selecting element type for FEA model is the most important decision in analysis, because element should represent the actual behavior of component. In the present analysis two elements have been used for meshing the leaf spring. They are 4 noded CQUAD element and is 3 noded CTRIA . Each element is described in detail below.

1) Input Summary
   Degrees of Freedom: Ux; Uy; Uz; RotX; RotY; RotZ.
   Real Constants: Thickness
   Material Properties: Young's modulus ; poisons ratio; density
   For element configuration 103 3- noded tria

2) Input Summary
   Degrees of Freedom: Ux; Uy; Uz; RotX; RotY; RotZ.
   Real Constants: Thickness
   Material Properties: Young's modulus ; poisons ratio; density

Meshing of leaf spring

Element used for leaf spring meshing is 4 noded CQUAD and 3 noded CTRIA element. Element size for meshing is about 4 mm. This size of element is sufficient to obtain the accurate results.

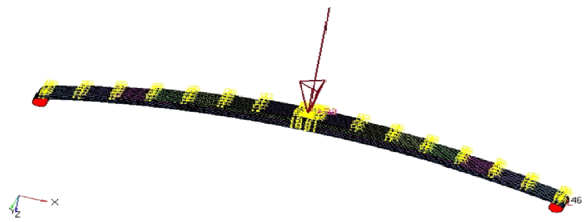

**Figure 2:** Meshing of Model

Essential BCs are those that directly affect the degrees of freedom, and are imposed on the left-hand side vector d. 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.

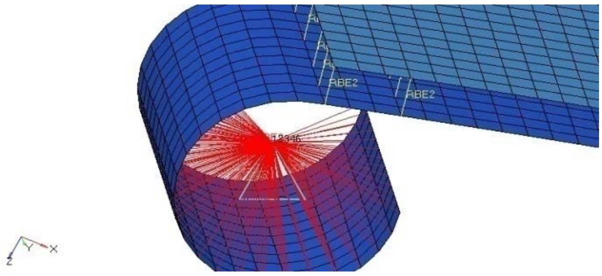


**Figure 3:** Representation of Pivoted Boundary Condition at Front Eye as shown below

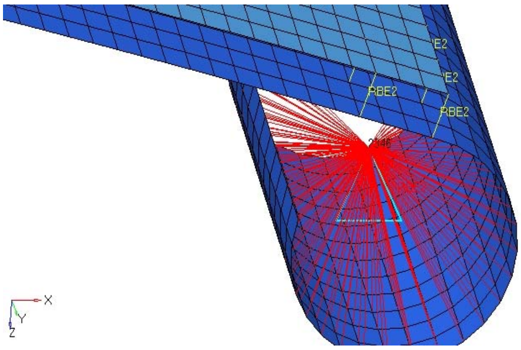


**Figure 4:** Representation of Pivoted Boundary Condition at Rear

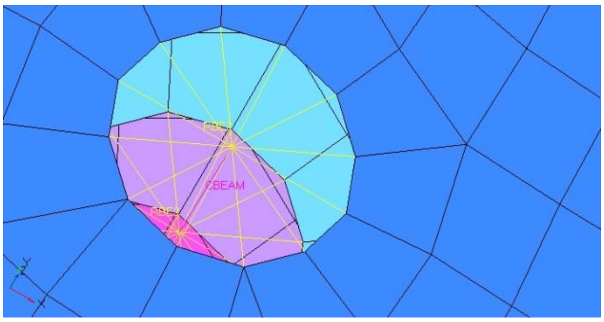


**Figure 5:** Representation of Meshing at the Center Of Bolt

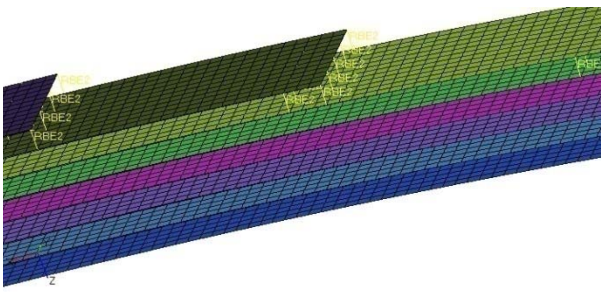


**Figure 6:** Representation of meshing on contact between leaves

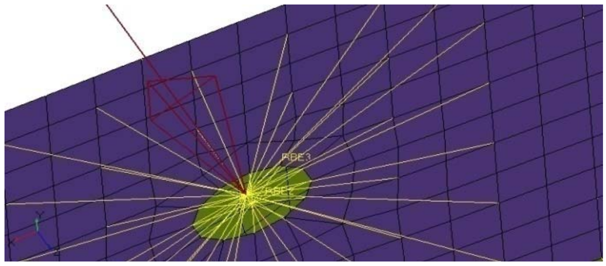


**Figure 7:** Representation of Force Vector

## 4. Non-Linear Static Stress Analysis

Static analysis deals with the conditions of the equilibrium of the bodies acted upon by forces. A static analysis can either be linear or non-linear. All types of non-linearity are allowed such as large deformations, plasticity, creep, stress stiffening, contact elements etc.

A static analysis calculates the effects of steady loading conditions on the structure, while ignoring inertia and damping effects such as those carried by time varying loads. A static analysis is used to determine the displacements, stresses, strains and forces in structures and components caused by loads that do not induce significant inertia and damping effects. A static analysis can however include steady inertia loads such as gravity, spinning and time varying loads.

In static analysis, loading and response conditions assumed that is the loads and structure responses are assumed to vary slowly w.r.t. time. The kind of loading that can be applied in static analysis includes

1. External applied forces, pressures and moments
2. Steady state inertial forces such as gravity and spinning
3. Imposed non-zero displacements

A static analysis result of structural displacements, stresses, strains and forces in structures for components caused by loads will give a clear idea about whether the structure or component will under withstand for the applied maximum forces. If the stress values obtained in this analysis crosses the allowable values it will result in the failure of the structure in the static condition itself. To avoid such failure, analysis is necessary.

Non-Linear Static Stress Analysis of Existing Leaf Spring

To observe load deflection characteristics of existing leaf spring non-linear static stress analysis was done. For analysis work NASTRAN 2005 used. In table 1 comparison of analytically calculated values of deflection and values obtained from simulation were done; only 0.4% variation was observed. In table 2 comparisons of analytically calculated values of bending stress and values obtained from simulation were done; about 4.3% variation was observed.

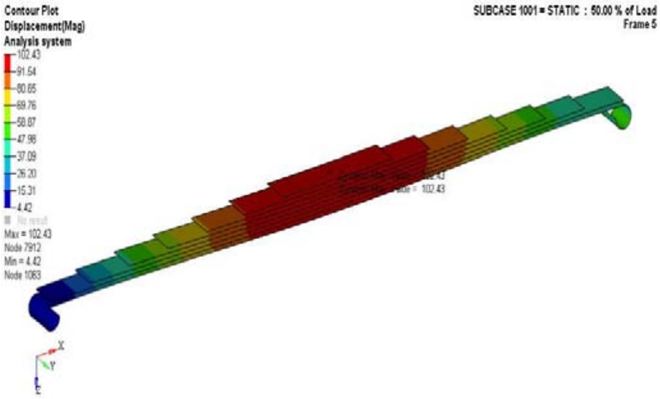


**Figure 8:** Deflection at 5KN Load

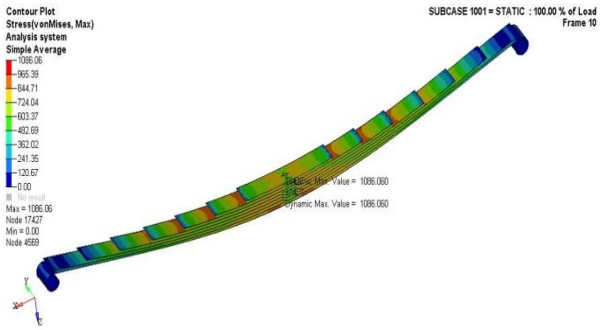


**Figure 9:** Deflection at 10KN Load

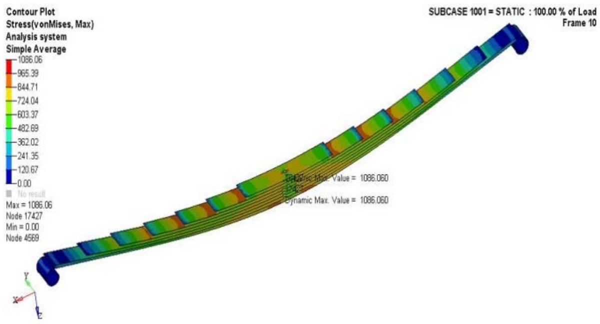


**Figure 10:** Von Mises Stress countor at 10kN load

**Table 3:** Comparison of analytical and simulation deflection of existing spring

| *Load(N)* | *Deflection (mm) analytical* | *Deflection (mm) simulated* |
|---|---|---|
| 1000 | 24.92 | 20.49 |
| 2000 | 49.84 | 40.97 |
| 3000 | 74.76 | 61.46 |
| 4000 | 99.67 | 81.94 |
| 5000 | 124.59 | 102.43 |
| 6000 | 149.51 | 122.91 |
| 7000 | 174.43 | 143.40 |
| 8000 | 199.35 | 163.88 |
| 9000 | 193.26 | 184.37 |
| 10000 | 213.76 | 204.85 |

**Table 4:** Comparison of analytical and simulation bending stress for existing spring

| *Load(N)* | *Deflection (mm) analytical* | *Deflection (mm) simulated* |
|---|---|---|
| 1000 | 24.92 | 20.49 |
| 2000 | 49.84 | 40.97 |
| 3000 | 74.76 | 61.46 |
| 4000 | 99.67 | 81.94 |
| 5000 | 124.59 | 102.43 |
| 6000 | 149.51 | 122.91 |
| 7000 | 174.43 | 143.40 |
| 8000 | 199.35 | 163.88 |
| 9000 | 193.26 | 184.37 |
| 10000 | 213.76 | 204.85 |

## 5. Modal analysis

If system is given some initial disturbance, then it will vibrate at some frequency known as its natural frequency. The lowest natural frequency is referred as fundamental frequency and it has lowest potential and strain energy.

The goal of modal analysis is to find out natural frequencies and mode shapes to ensure that the system does not have resonant frequency near the operating frequency or in the range of operating frequency.

In this work the modal analysis was carried out using NASTRAN as solver. The post processing is carried out in HYPERVIEW.

There are corresponding mode shapes which describe the displacement of system due to vibration. Mode shapes are also known as Eigen vector normal modes characteristic vector or latent vectors.

To see the modal characteristic of existing leaf spring modal analysis was done using NASTRAN 2005. Table 5 Shows the first ten modal frequencies; in which the fundamental frequency for given spring is 8.80Hz.

**Table 5:** Natural Frequency (Hz) of existing leaf spring

| *Sr no* | *Mode Number* | *Frequency in Hz* |
|---|---|---|
| 1 | Mode 1 ( bending mode ) | 8.80 |
| 2 | Mode 2(twisting mode) | 33.95 |
| 3 | Mode 3(lateral mode) | 50.55 |
| 4 | Mode 4 | 59.99 |
| 5 | Mode 5 | 81.52 |
| 6 | Mode 6 | 89.07 |
| 7 | Mode 7 | 113.60 |
| 8 | Mode 8 | 120.60 |
| 9 | Mode 9 | 137.10 |
| 10 | Mode 10 | 167.60 |

**Figure 11:** First mode shape (bending mode) of existing leaf spring

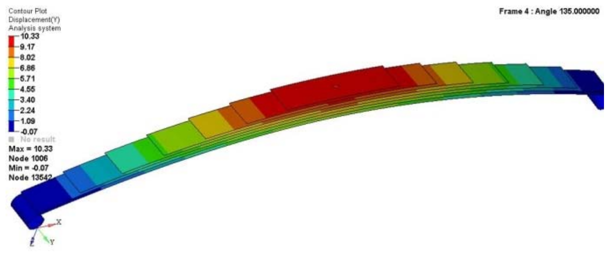

**Figure 12:** Second mode shape (lateral mode) of existing leaf spring

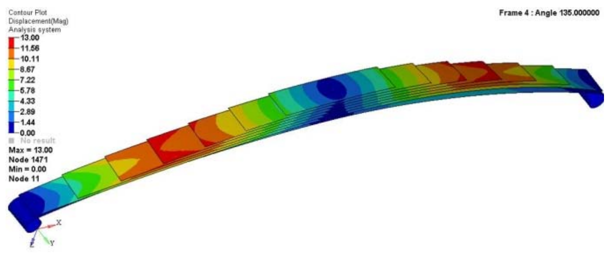

**Figure 13:** Third mode shape (lateral mode) of existing leaf spring

Fatigue Analysis of Leaf Spring

The phenomenon of decreased resistance of material to fluctuating stress is main characteristic of fatigue failure. It is observed that about 80% of failures of mechanical components are due to fatigue.

Fatigue life is defined as the number of stress cycles that the standard specimen can complete without appearance of first fatigue crack

Fatigue Analysis of Existing Leaf Spring

Fatigue analysis of existing leaf spring was done using MSC/Fatigue 2005 solver. And the minimum life obtained from simulation at 10KN load was $3.94\times10^{5}$cycles.

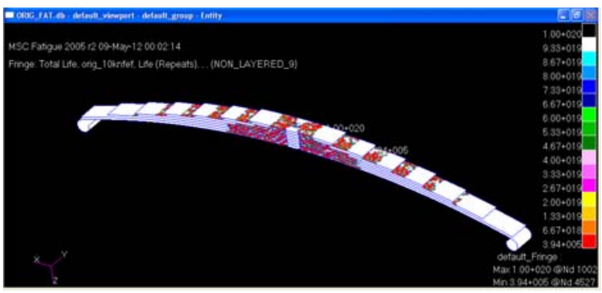

**Figure 14:** Life contour of existing leaf spring

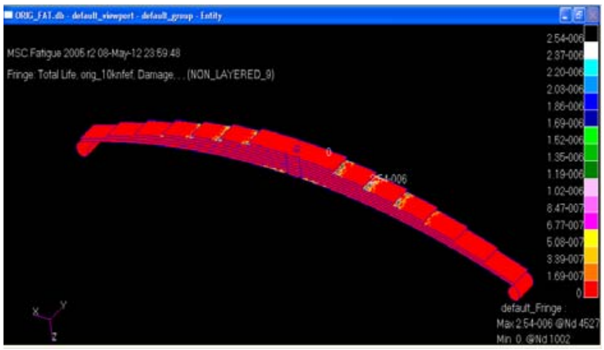

**Figure 15:** Damage contour of existing leaf spring

Design Calculation For Modified Leaf Spring

The specification For modified leaf spring are, No. of graduated leaves including master leaf = 6, and thickness of leaf=8mm, and all other parameter are same from table 1, while designing modifies spring

**Table 6:** Analytical calculation of deflection and bending stress for modified leaf spring

| *Sr no* | *load in N* | *Deflection (δ)mm* | *Bending stress(N/mm²)* |
|---|---|---|---|
| 1 | 1000 | 18.92 | 104.69 |
| 2 | 2000 | 37.84 | 209.38 |
| 3 | 3000 | 56.76 | 314.06 |
| 4 | 4000 | 75.68 | 418.75 |
| 5 | 5000 | 94.60 | 523.44 |
| 6 | 6000 | 113.52 | 628.13 |
| 7 | 7000 | 132.43 | 732.81 |
| 8 | 8000 | 151.35 | 837.50 |
| 9 | 9000 | 170.27 | 942.19 |
| 10 | 10000 | 189.19 | 1046.88 |

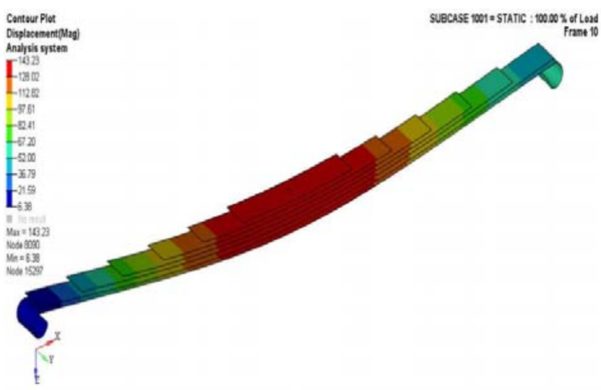

**Figure 16:** Deflection at 10 KN load

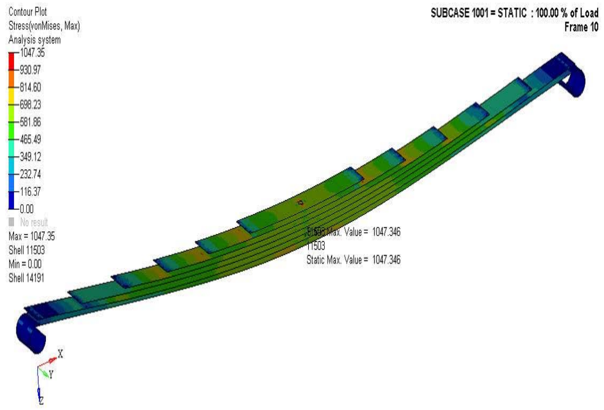


**Figure 17:** Von Mises Stress counter at 10kN load

**Table 7:** Comparison of analytical and simulation deflection for modified leaf spring.

| *Load(N)* | *Deflection (mm) analytical* | *Deflection (mm) simulated* |
|---|---|---|
| 1000 | 18.92 | 14.32 |
| 2000 | 37.84 | 28.65 |
| 3000 | 56.76 | 42.97 |
| 4000 | 75.68 | 57.29 |
| 5000 | 94.60 | 71.61 |
| 6000 | 113.52 | 85.95 |
| 7000 | 132.43 | 100.26 |
| 8000 | 151.35 | 114.58 |
| 9000 | 170.27 | 128.07 |
| 10000 | 189.19 | 143.23 |

**Table 8:** Comparison of analytical and simulation, Bending Stress for Modified Spring.

| *Load(N)* | *Deflection (mm) analytical* | *Deflection (mm) simulated* |
|---|---|---|
| 1000 | 104.69 | 104.70 |
| 2000 | 209.38 | 209.50 |
| 3000 | 314.06 | 314.20 |
| 4000 | 418.75 | 418.90 |
| 5000 | 523.44 | 523.70 |
| 6000 | 628.13 | 628.40 |
| 7000 | 732.81 | 733.10 |
| 8000 | 837.50 | 837.90 |
| 9000 | 942.19 | 942.60 |
| 10000 | 1046.88 | 1047.35 |

Modal Analysis of Modified Leaf Spring

**Table 9:** Natural Frequency (Hz) of Modified Leaf Spring

| *Sr no* | *Mode number* | *Frequency in Hz* |
|---|---|---|
| 1 | Mode 1 ( bending mode ) | 10.68 |
| 2 | Mode 2(twisting mode) | 41.60 |
| 3 | Mode 3(lateral mode) | 61.57 |
| 4 | Mode 4 | 75.41 |
| 5 | Mode 5 | 99.33 |
| 6 | Mode 6 | 108.30 |
| 7 | Mode 7 | 142.9 |
| 8 | Mode 8 | 154.0 |
| 9 | Mode 9 | 166.2 |
| 10 | Mode 10 | 227.6 |

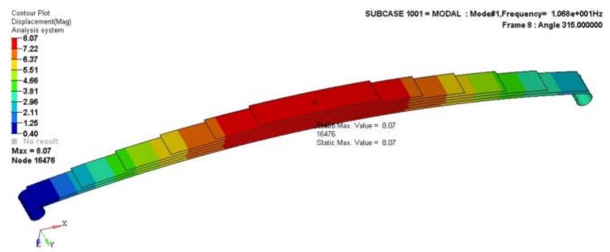


**Figure 17:** First mode shape (bending mode) of modified leaf spring

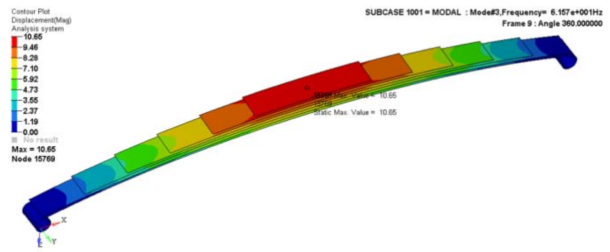


**Figure 18:** Second mode shape (lateral mode) of modified leaf spring

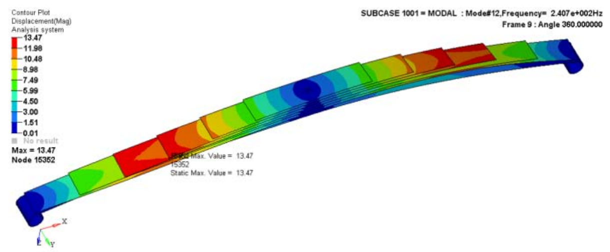


**Figure 19:** Thied mode shape (twisting mode) of modified leaf spring

Fatigue analysis of modified leaf spring

Fatigue analysis of modified leaf spring was done using MSC/Fatigue 2005 solver. And the minimum life obtained from simulation at 10KN load was $1.47\times10^{7}$cycles.

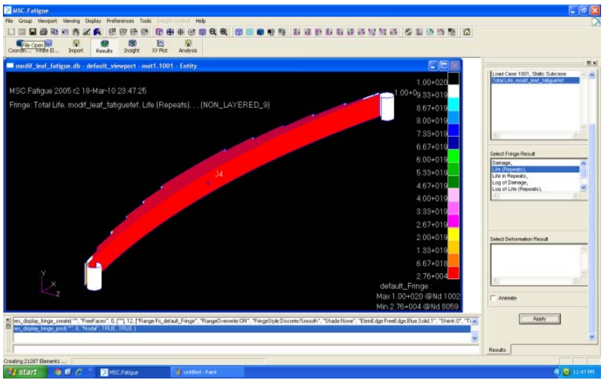

**Figure 20:** Life contour for modified leaf spring

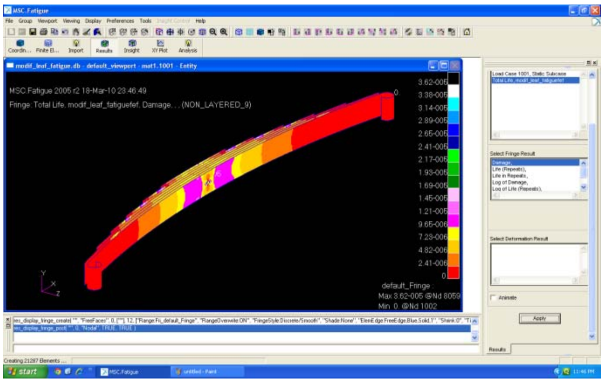

**Figure 21:** Damage contour for modified leaf spring.

## 6. Conclusion

The results offered by the simulation are presented below:

1. At 5kN load the deflection value and bending stress value for existing leaf spring from simulation are 102.43mm and 543.03N/mm$^2$ respectively.
2. At 10kN load the deflection value and bending stress value for existing leaf spring from simulation are204.85mm and 1086.06N/mm$^2$ respectively.
3. At 5kN load the deflection value and bending stress value for modified leaf spring from simulation are 71.61mm and 523.70N/mm$^2$ respectively.
4. At 10kN load the deflection value and bending stress value for modified leaf spring from simulation are 143.23mm and 1047.35N/mm$^2$ respectively.
5. All analytically calculated values of deflection and stresses are closely matching with values obtained from non-linear static stress analysis.
6. From modal analysis it was found that the fundamental bending mode frequency of existing leaf spring is 8.80Hz and for modified leaf spring 10.68Hz.
7. From fatigue simulation the minimum life of existing leaf spring was $3.94 \times 10^5$ cycles and for modified leaf spring $1.47 \times 10^7$ cycles.

## 7. Future scope

This paper work was based on the premise of modifying the physical parameters of the design. The results arrived at along with the conclusion suggests an improvement over the fatigue life through manipulation of the dimensions of the spring. The other areas for study might include the following:

Change in the material –composite material could be utilized for enhancing the performance of the spring (improving the fatigue life)

This study paper hopes to give more information for the manufacturer to improve the fatigue life of the leaf spring. It can help to reduce cost and times in research and development of new product. Recently, manufacturer only rely on fatigue test with constant amplitude loading, and this study will help to understand more the behavior of the leaf spring and the simulation of fatigue life.

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