Experimental and FEA for Stress, Fatigue Life and Optimum Weight of LCV Leaf Spring

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Abstract

In this paper, a leaf spring with auxiliary spring is tested for its fatigue life and stiffness. The existing design is with both multi-leaf type springs whereas the modified design consists of auxiliary parabolic spring to have a increased fatigue life by reducing stress levels. The leaf spring is being tested for its targeted life of $1x10^5$ and $5x10^4$ fatigue cycles for main and auxiliary leaf springs respectively. All analytical calculations for the said leaf spring for its stiffness and fatigue life has been done by using SAE manual. Also, FEA for fatigue life and stiffness has been done by using Pro-Mechanica software. The experimental investigation is carried out on a leaf spring test rig with a maximum load of 12730 kg allowing maximum deflection of 146mm and maximum stresses up to $100kg/mm^2$. To increase the fatigue life of a leaf spring, leaves of the spring tension side is shot peened. Now in new leaf spring, main leaf spring consists of 9 leaves whereas auxiliary parabolic leaf spring consists of 3 leaves. The factor of safety for leaf spring is between the ranges 1.2 to 1.5. By using parabolic leaf spring on auxiliary pack, the weight of the leaf spring has been reduced by 43 Kg i.e. from 177 Kg (Existing) to 134 Kg (New) and approximately 24% weight is reduced per leaf spring. All the results i.e. analytical, FEA and experimental are compared in results and discussion

Keywords — *Leaf spring, main spring, auxiliary spring, FEA, test rig, weight reduction and parabolic leaf spring.*

I. INTRODUCTION

The leaf spring should absorb the vertical vibrations and impacts due to road irregularities by means of variations in the spring deflection so that the potential energy is stored in spring as strain energy and then released slowly. So, increasing the energy storage capability of a leaf spring ensures a more compliant suspension system. Leaf springs are widely used on automobiles like trucks, buses and light commercial vehicles. Leaf springs are perhaps the simplest and least expensive of all suspensions. While compliant the vertical direction, the leaf is relatively stiff in lateral and longitudinal directions, thereby reacting the various forces between the sprung and unsprung masses. Now-a-days customer becomes money oriented, and after purchasing a vehicle customer loads the vehicle not at rated loads as suggested by the manufacturer, whereas they are overloading the vehicle beyond the vehicle's rated capacity. Due to this, leaf springs on the vehicle are failing during running of the vehicle prior to its targeted life (i.e.1x105 cycles min). To overcome this, we have studied the failed spring and we observed that customer is overloading the vehicle up to 30% to 40% than its rated capacity, and thus failure occurred. In the present scenario, weight reduction has been the main focus of automobile manufactures. The suspension leaf spring is one of the potential items for weight reduction in automobiles as it accounts for ten to twenty precent of the unsprung weight, which is considered to be the mass not supported by the leaf spring. The introduction of parabolic type leaf spring made it possible to reduce the weight of the conventional multi-leaf spring without any reduction on the load carrying capacity and stiffness. Parabolic type leaf spring is having fatigue life of $2x10^5$ cycles whereas multi-leaf spring is having a fatigue of $1x10^5$ cycles.

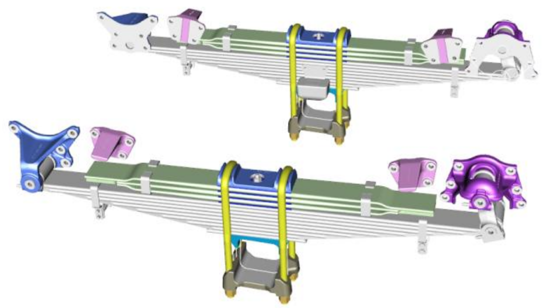

Fig 1: A typical view of a Rear Suspension System

II. LITERATURE REVIEW

T.V.N Ashok Kumar et al [1] Investigation of composite leaf spring in the early 60's failed to yield the production facility because of inconsistent fatigue performance and absence of strong need for mass reduction. Researches in the area of automobile components have been receiving considerable attention now. Particularly the automobile manufacturers and parts makers have been attempting to reduce the weight of the vehicles in recent years. Emphasis of vehicles weight reduction justified taking a new look at composite springs. Studies are made to demonstrate viability and potential of composite materials in automotive structural application. Recent developments have been achieved in the field of materials improvement and quality assured for composite leaf springs based on microstructure mechanism. All these literature report that the cost of composite; leaf spring is higher than that of steel leaf spring. Hence an attempt has been made to fabricate the composite leaf spring with the same cost as that of steel leaf spring. Material properties and design of composite structures are reported in many literatures. Very little information are available in connection with finite element analysis of leaf spring in the literature, than too in 2D analysis of leaf spring. At the same time, the literature available regarding experimental stress analyses are more.

Ravi Kumar V. R. et al [2] Many industrial visits shows that steel leaf springs are manufactured by EN45, EN45A, 60Si7, EN47, 50Cr4V2,55SiCr7 and 50CrMoCV4 etc. These materials are widely used for production of the parabolic leaf springs and conventional multi leaf springs. Conventional (steel) leaf springs use excess of material making them considerably heavy. Automobile manufacturers and parts makers have been attempting to reduce the weight of the vehicles in recent years. Emphasis of vehicles weight reduction in 1978 justified taking a new look at composite springs. This can be improved by introducing composite materials in place of steel in the conventional spring. Most commonly the conventional multi leaf springs are made of several steel plates of different lengths stacked together. So when they are subjected to loading, due to the deflection of consecutive leaves, we can observe the friction between the two leaves. This friction will cause the fatigue failure of steel (conventional) leaf spring. Commonly, when springs are made with number of leaves, it will carry nearly 20% of unstrung weight. For the above reasons, mono leaf composite spring will be a better option to replace the conventional steel multi leaf spring.

Mahajan A. M. et al [3] 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 traveling over the bumps etc. The leaf springs are more affected due to fatigue loads, as they are a part of the unsprung mass of the automobile.

Mr. V K Aher et al [4] Predicts about the fatigue life of a semi-elliptical leaf spring along with stress and deflection calculations. 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. This present work describes static and fatigue analysis of a modified steel leaf spring of a light commercial vehicle (LCV). 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.

Prof. N.P.Dhoshi et al [5] This is about the leaf springs used in tractor trailer without much economical and technical consideration. In the present work improvement areas where one can improve the product quality while keeping the minimum cost. In the present work analytical and Finite element method has been implemented to modify the existing leaf spring with consider the dynamic load effect. One of the important areas where one can improve the product quality while keeping the cost low is the design aspect. One can design the product in such a way that its performance increases while the customer has to pay less as compared to the same product of other companies. Material and manufacturing process are selected upon on the cost and strength factor whereas the design method is selected on the basis of mass production. FEM and ANSYS software ensures a healthy approach of designing the leaf spring thus epitomizing the traits that are essential for the manufacturing. They concluded that the project highlights the need of FEM analysis in industries ranging from small scale to large one, as this will reduce cost also it will improve accuracy.

III. OBJECTIVES

- To reduce overall weight of the spring by using parabolic type auxiliary spring pack and without compromising in load carrying capacity and stiffness.
- To increase the fatigue life by using parabolic type leaf spring.
- To reduce an irritating noise between leaves during working of the leaf spring.
- To reduce chassis height by using parabolic type spring.
- To reduce total vehicle weight by using parabolic type leaf spring.
- To decrease rusting of leaves by avoiding interleaf contact.
- To increase comfort level by using parabolic type leaf spring, as it is having thicker central portion and gradually reducing upto the eye.

IV. DESIGN CALCULATIONS

Vehicle specifications-

Max. Permissible FAW (Kg)	5510
Max. Permissible RAW (Kg)	10200
Max. Payload (Kg)	9780

SAE formulae for leaf spring calculation
Stiffness or load rate,
$k = P/f = 32E\sum I \cdot SF / L3$
where,
k = Stiffness (kg/mm)
P = Load (kg),
f = Deflection (mm),
E = Modulus of elasticity (kg/mm^2),
I = Moment of inertia (mm4),
L = Spring span (mm), and
SF = Stiffening factor.
Stress from load,
$S = L.t.P / 8. \sum I$
where,
S = Stress (kg/mm^2),
E = Modulus of elasticity (kg/mm^2),
t = Leaf thickness (mm),
f = Deflection (mm),
L = Spring span (mm), and
SF = Stiffening factor.

Existing spring stiffness and stress values-
K_{Main} = 44 kg/mm
SF = 1.193
S_{Design} = 39.53 kg/mm^2
S_{Max} = 82.87 kg/mm^2
Factor of Safety = 1.3
K_{Aux} = 60.46 kg/mm
SF = 1.2
S_{Design} = 24.07 kg/mm^2
S_{Max} = 92.01 kg/mm^2
Factor of Safety = 1.2

Optimized spring stiffness and stress values-
K_{Main} = 45.15 kg/mm
SF = 1.167
S_{Design} = 50.37 kg/mm^2
S_{Max} = 86.51 kg/mm^2
Factor of Safety = 1.2
$k_{Assy.}$ = 62.11 kg/mm
Design stress,
S_{Design} = 10.06 kg/mm^2
Max. stress,
$S_{Max.}$ = 71.44 kg/mm^2
Factor of Safety = 1.5

As Max. stress value in main spring and auxiliary spring are less than yield stress 110 kg/mm^2 hence, the design is safe.

Fatigue Life Existing leaf spring (Ref. SAE spring manual)
Main spring- 80000 cycles
Auxiliary spring- 55000 cycles

Fatigue Life optimized leaf spring (Ref. SAE spring manual)
Main spring- 68000 cycles
Auxiliary spring- 80000 cycles

Comparison between existing and optimized leaf spring

Design Parameter	Existing Design	Optimized design
Main spring pack type	Multileaf	Multileaf
Auxiliary spring type	Multileaf	Parabolic
Number of leaves (Main pack)	11	9
Number of leaves (Auxiliary pack)	7	3
Leaf spring camber (Main pack)	115	100
Leaf spring camber (Auxiliary pack)	40.5	140
Stiffness of main pack	44 Kg/mm	45.15 Kg/mm
Stiffness of auxiliary pack	60.46 Kg/mm	62.11 Kg/mm
Spring span main pack	1500 mm	1500 mm
Spring span auxiliary pack	1140 mm	1050 mm
Centre bolt size	M16 mm x 1.5 mm x 275 mm	M16 mm x 1.5 mm x 215 mm
Rivet size (Main and Auxiliary pack)	Dia. 10 mm x Length 22 mm	Dia. 12 mm x Length 22 mm
Spacer Plate	Yes	Yes
Material of leaf spring assembly	JIS SUP 11A	JIS SUP 11A
Rated Load on leaf spring	4575 Kg	4575 Kg
Weight of leaf spring assembly	177	134

V. FINITE ELEMENT ANALYSIS

FEA of new leaf spring
Following are the steps for doing finite element analysis of a leaf spring-

- Pre-processing
- Processing, and
- Post-processing

A. Pre-processing:

After modeling in pro-e and assembling individual leaf one over the other, the model is converted into IGES format and then imported in the Pro-Mechanica workbench for doing analysis of a leaf spring. The below fig. shows the meshed model of the leaf spring.

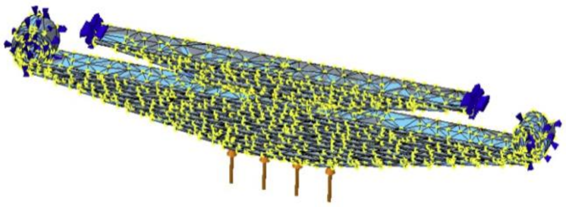

Fig 2: Meshed model of existing spring

Meshing details of existing spring:

No of Elements	4812
No of Nodes	17083
Analysis	Non-linear Static
Element type	Tetrahedral element

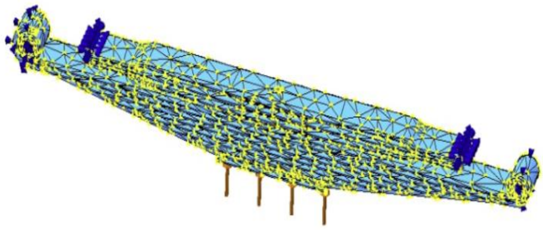

Fig 3: Meshed model of optimized spring

Meshing details optimized spring:

No of Elements	4812
No of Nodes	17083
Analysis	Non-linear Static
Element type	Tetrahedral element

Mechanical properties:

Density (x 1000 kg/m^3)	7.7 - 8.03
Poisson's Ratio	0.27 – 0.30
Tensile Strength(Kg/mm^2)	125
Yield Strength (Kg/mm^2)	110
Elongation (%)	15
Reduction in Area (%)	53
Hardness (HB)	335

B. Processing:

After pre-processing, Loads & boundary conditions are applied as below - One eye is fixed, i.e. only ovement in Z-direction. Second eye i.e. at shackle end is constrained by pin joint and movement in direction X and Z is kept free. Load of 14228 kg and 12247 Kg are applied at the bottom of leaf spring for existing and optimized springs respectively.

C. Post-processing:

After successful completion of the run, results can be viewed in the result window.Total deformation and stresses due to application of load can be viewed as well as animation of deformation can be seen.Two following important results are observed in case of leaf spring are-

Von-Mises stresses
Total deformation under applied load

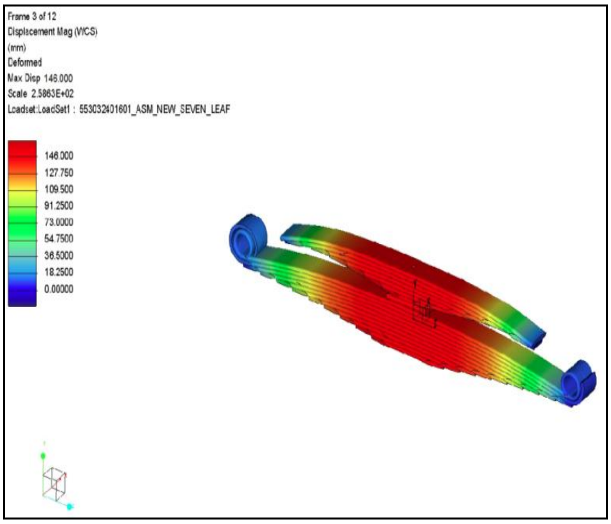

Fig 4: Total deformation in existing leaf spring

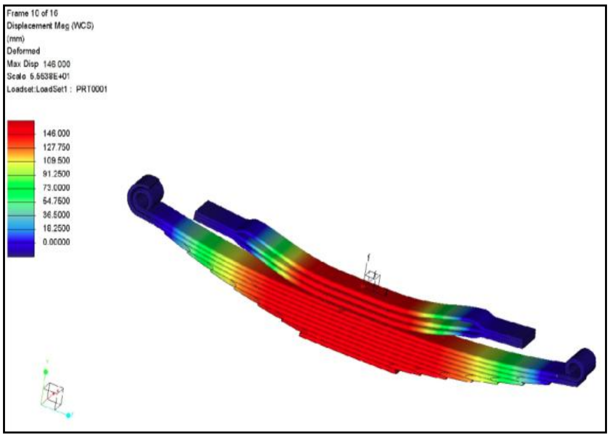

Fig 5: Total deformation in optimized leaf spring

The above fig.4 and 5 shows total deformation of leaf spring under the load of 12730 kg is 146mm.

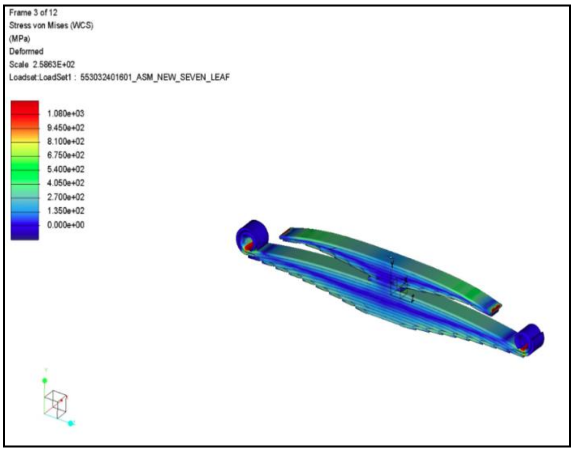

Fig 6: Max. Stress in existing leaf spring

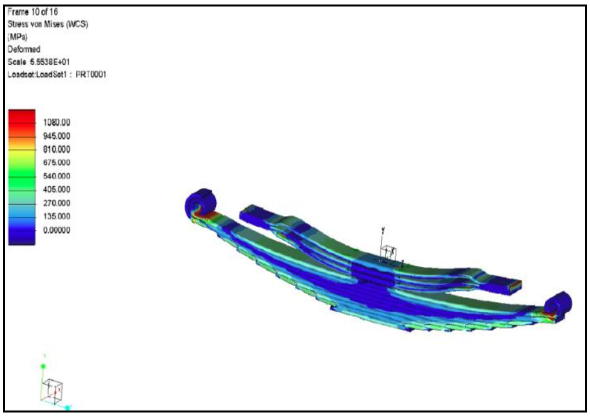

Fig 7: Max. Stress in optimized leaf spring

The above fig.7 and 8 shows stress values in existing and optimized springs for main spring and auxiliary springs i.e. 80.80 kg/mm^2, 88.30 kg/mm2, 84.30 kg/mm^2 and 73.60 kg/mm^2 respectively under maximum deformation of 146mm

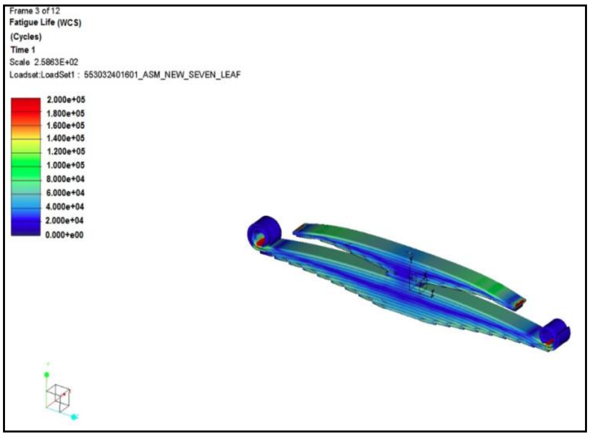

Fig 8: Fatigue life of a existing leaf spring

Fatigue life of main and auxiliary existing leaf spring assembly is 75726 cycles and 54241 cycles against a stress value of 80.80 kg/ mm^2 and 88.30 kg/mm^2.

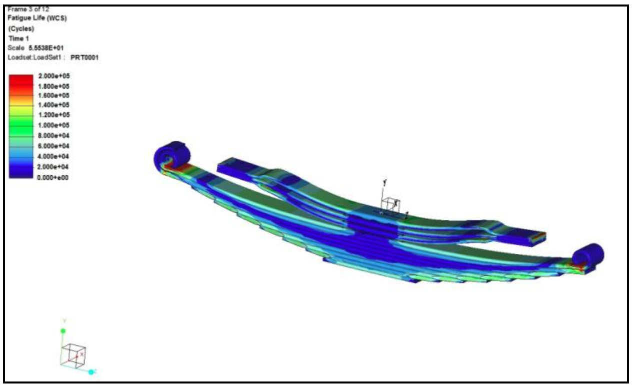

Fig 9: Fatigue life of a existing leaf spring

Fatigue life of main and auxiliary optimized leaf spring assembly is 74064 cycles and 54786 cycles against a stress value of 84.30 kg/ mm^2 and 73.60 kg/mm^2.

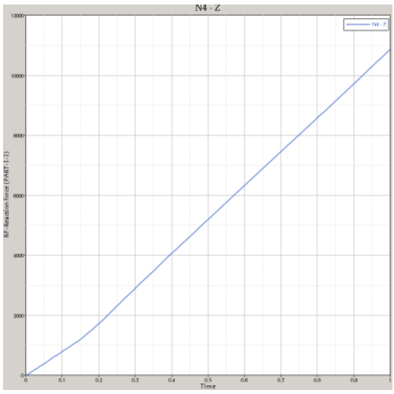

Fig 10: Nodal force vs. time plot at stack centre existing leaf spring

Vertical displacement at stack centre- 146.0mm
Reaction force at stack centre- 18586 kg
Vertical stiffness- 127.3 kg/mm

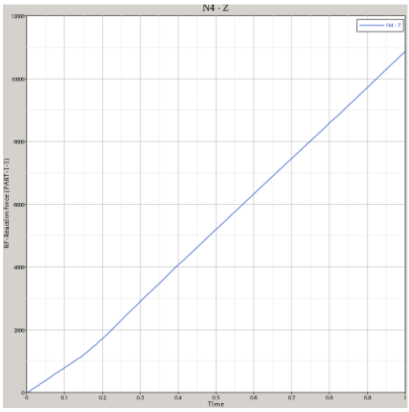

Fig 11: Nodal force vs. time plot at stack center optimized leaf spring

Vertical displacement at stack centre- 146.0mm
Reaction force at stack centre- 18075 kg
Vertical stiffness- 123.8 kg/mm

VI. TESTING AND VALIDATION

The following figures shows subsequent photos of fatigue testing rig, leaf spring at initial stage and leaf spring at final stage (full loaded).

Fig 12: Fatigue testing rig

Fig 13: Leaf spring at initial stage

Fig 14: Leaf spring at final stage (fully loaded)

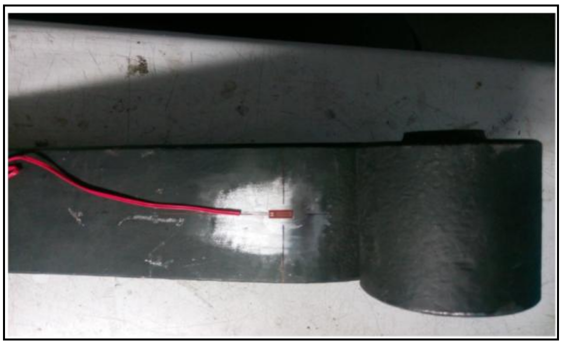

Fig 15: Strain gauging near leaf spring eye

Fig 16: Strain gauging near leaf spring seat

Fig.12 shows Fatigue Testing Rig in which leaf springs are tested for their life. The fatigue or endurance testing is carried out according to IS 1135, the number of samples to be tested should be as agreed between the supplier and purchaser. The fatigue test shall be conducted in deflection. The spring shall be cycled between deflection values corresponding to OC and OB as defined in Fig.10. Typically this can be 0.5 times the rated load to twice the rated load unless otherwise specified. The load at rated load position shall be measured at periodic intervals unless otherwise specified and on completion of the test to determine the change in load.

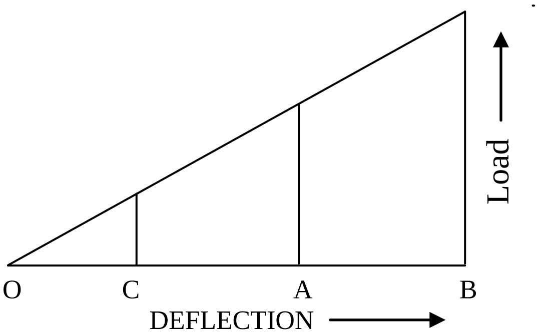

Fig17: Load deflection diagram

OA- Load/Deflection corresponding to rated load;
OB- Load/Deflection corresponding to maximum load experienced under actual vehicle conditions- typically 2g, where 'g' is the load shared by springs under the laden conditions of the vehicle;
OC- Load/Deflection corresponding to

OC = OA – (OB – OA)/2

Leaf spring with auxiliary spring is tested in fatigue testing rig; main spring is tested for a target fatigue life of 100000 cycles while auxiliary spring is tested for a target fatigue life of 50000 cycles. During testing one end of leaf spring is fixed and other end is connected to shackle for length compensation. Load is applied from top at the centre of the leaf spring.

VII. RESULTS AND DISCUSSION

From below results between FEA and experimental it is clear that correlation is about 95 to 98% for all stress, stiffness and fatigue life.

Parameter	Existing Design FEA Results	Optimi-zed Design FEA Results	Existing Design Testing Results	Optimi-zed Design Testing Results
Stress (kg/mm^2)	Main-80.80 Aux-88.30	Main-84.30 Aux-73.60	Main-82.14 Aux-90.40	Main-96.54 Aux-72.76
Stiffness (kg/mm)	127.3	123.8	125.2	124.6
Fatigue Life (Cycles)	Main-75726 Aux-54241	Main-74064 Aux-54786	Main-71440 Aux-52407	Main-70203 Aux-57640
Weight	-	-	177	134

CONCLUSION

From above study it is clear that the weight of the leaf spring has been reduced by 43 Kg per spring by maintaining same stiffness and capacity. The stresses are also within material yield limit hence; the design is safe. By using parabolic type leaf spring fatigue life of the spring is increased. In future, we can make both springs of parabolic type thereby weight of the leaf spring will be reduced also, the fatigue life also increased.

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REFERENCES

[1] T.N.V.Ashok Kumar,E.Venkateswara Rao, S.V.Gopal KrishnaDesign and Material Optimization of Heavy Vehicle Leaf Spring IJRMET Vol. 4,Issue Spl – 1, Nov 2013 – April 2014.

[2] Malaga. Anil Kumar, T.N.Charyulu, Ch.Ramesh Design Optimization of Leaf Spring IJERA Vol.2, Issue 6, Nov.-Dec. 2012, pp. 759-756.

[3] Dhiraj K Bhandarkar, Sanjay P. Shekhawat Design, Analysisand Optimization of Leaf Spring IJIRSET Vol. 3, Issue 6, June 2014.

[4] Edward Nikhil Karlus, Rakesh L. Himte, Ram Krishna Rathore Optimization of Mono Parabolic Leaf Spring IJAET Vol. 7, Issue 1, pp.283-291.

[5] Kaveri A. Katake, S. H. Mankar, Samir J. Deshmukh A Review on Design and Optimization of Composite Leaf Spring IJIERE Vol. 2, Special Issue 1 MEPCON 2015.

[6] Yohannes Regassa, R. Srinivasa Moorthy & Ratnam Uppala Failure Analysis of Semi-elliptical Master Leaf Spring of Passenger Car using Finite Element Method GJREM & ME Vol. 13 , Issue 2, Version 1.0 Year 2013.

[7] Ajinkya Mahadev Mahajan, A. P. Shrotri, Swapnil Kulkarni Fatigue Failure Analysis & Validation of Mono Leaf Spring Design IJAERS E-ISSN2249–8974.

[8] Ajay B.K, Mandar Gophane, P.Baskar Design and Analysis of Leaf Spring with Different Arrangements of Composite Leaves with Steel Leaves National Journal on Advances in Building Sciences and Mechanics Vol.6, No.1.

[9] N.S. Mendhe, Dr.S.A. Sonawane, Prof.K.C. Rajapurkar Experimental Study and Optimization of Leaf Spring IJERT Vol. 4 Issue 01 Jan 2015.

[10] Vinkel Kumar Arora, Gian Bhushan, and M.L.Agarwal Fatigue Life Assessment of 65Si7 Leaf Spings: A Comparative Study Hndawi Publshing Corporation International Scholarly Research Notices Vol. 2014, Article ID607272,11Pages.

[11] R.B. Charde, Dr. D.V. Bhope Investigation of Stresses in Master Leaf of Leaf Spring by FEM and its Experimental Verification IJEST Vol.4 No.02 Feb 2012.

[12] S.Rajesh and G.B. Bhaskar Experimental Investigation on Laminated Composite Leaf Springs subjected to Cyclic Loading IJET Vol.6 No.1 Feb-Mar 2014.