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Fatigue analysis and design for multi leaf spring of a passenger car

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ABSTRACT

The suspension system of an automotive includes components that are required to withstand harsh working conditions while performing its function of absorbing shocks. For addressing a good ride & control function, the design phase becomes crucial in the development cycle of the product. Leaf spring assumes an important position for determining the characteristics stress of the suspension. Mono leaf & Multi leaves could be the elementary choices for the design process. The material for the leaf although its geometry of the spring plays a key role in determining the fatigue life of the same. This work undertakes research for alternative material available during the design phase. The fatigue life for the spring is assumed through the use of analytical methodology of problem solving i.e. CAE software.
Mathematical treatment is offered for calculating the fatigue life. Validation is effected through physical experimentation at the sponsoring company. The structural behavior of the material is ascertained through testing for the performance characteristic for the spring. It is estimated that the spring will have improved life with this alternative material EN 47 through analytical & mathematical techniques.

Keywords— ***Fatigue life, Leaf Spring, Material change for leaf spring***

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I. INTRODUCTION

Springs are mainly used in the industry as members absorbing shock energy as well as for restoring the initial position of a part upon displacement for initiating a given function. In our case, the latter is prominent. Every powered-vehicle including a four-wheeler / Light Commercial Vehicle (LCV) has a provision for a suspension system which is crucial to the comfort of the passengers and for preventing damage to the goods being carried over the roadways. Since this function is directly related to comfort of the passengers and the also the goods-carrier for fragile materials or materials prone to spillage, it is desired that the suspension system should continue to function in the best manner over the lifespan of the vehicle (typically 15 to 20 years). The number of shocks experienced by the vehicle along with its nature and magnitude influence the fatigue life of the Leaf Spring in the suspension system. Besides, any malfunction or failure of the Spring may evoke secondary claims and may affect the good-will of the customer

In order to conserve natural resources and 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 suspension leaf spring is one of the potential items for weight reduction in automobile as it accounts for ten to twenty percent of the unsprung weight. This helps in achieving the vehicle with improved riding qualities. It is well known that springs, are designed to absorb and store energy and then release it. Hence, the strain energy of the material becomes a major

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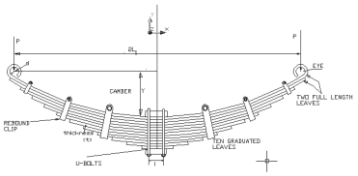
factor in designing the springs.It can be easily observed that material having lower modulus and density will have a greater specific strain energy capacity. The introduction of composite materials was made it possible to reduce the weight of the leaf spring without any reduction on load carrying capacity and stiffness. Since; the composite materials have more elastic strain energy storage capacity and high strength-to-weight ratio as compared to steel. To carry more weight, often the spring is composed of several



leaves, stacked up. It's possible to make the spring rate get stiffer as the suspension compresses. More leaves in a multi-leaf spring, curved so the spring rate gets progressively higher is one way.

II. PROBLEM STATEMENT

To analyse the leaf spring of the suspension system of a Passenger Car (Van) that could withstand one million cycles of peak loading by simulating the spring vis-à-vis the real-time environment as the vehicle is being utilized for transportation. Generally, for such typical applications, each leaf spring is expected to support a load of about 400kg (~4000N) i.e. applicable for each wheel. As such, the peak load experienced is 400 kg with deflection of the spring at 0~40mm at the hook end with 2~4 secs for a typical complete cycle of loading. This would be reviewed and updated during the course of study. The suspension system of a vehicle, here the Passenger Car (Van), has a series of leaf springs bound together as an assembly behaving like a unified component. The hooks are

Sr.	Description of physical region	No. of failures	% failure
1	Deformity/twist in excess of 5 degrees over the individual length of the leaf..	226	37.1
2	Deformity/ Twist in excess of 3 degrees over the assembly.	188	30.9
3	Hair cracks or high order visual deformity.	106	17.4
4	Breakage due to crack/ Signs of Catastrophic failure	89	14.6
	Total	609	

connected to the pivotal points of the chassis at both the ends. The entire weight of the chassis along with the other components of the vehicle over the chassis is borne by the leaf-

Spring typically, there are four leaf springs, each positioned near the axle end at each wheel. While the wheel rolls along the road, the leaf springs absorbs the shock energy due to the unevenness of the road profile or any inconsistencies or discontinuities it path (bump sand pot-holes). The spring is subjected to cyclic loading due to these undulations with a maximum expected frequency of usage at about 500 cycles for peak loading a day. Considering the design life of this vehicle at 15 years, the spring should withstand acyclic loading for tension and compression for about 3.0 million (30 lac) times.

1.2.1 Warranty Claims (received till 31-Mar-2014)

Product/ Component Name and No. - Leaf Spring. Model No.AT2132
Period of assessment (for data) - April 2012 to Mar 2013
Total number of vehicles released to the market during the period - 40,000 units approx.

Objectives of project work.

• Benchmark the performance for the existing leaf spring using FEA or Mathematical modelling.
• Propose alternative design upon evaluating the results for the benchmark study.
• Assess the behaviour of the alternative design with respect to the conventional steel spring with similar design specifications.
• To conduct experimental results from testing the leaf springs under static or dynamic stress and deflection.
• The alloy steel leaf spring could be modified with variants either in the mass or the geometry or the boundary conditions to effect an alternative design

Design calculations of Benchmark leaf spring.

$\sigma max = 440$ MPa
$\sigma min = 0$ MPa
a) Amplitude Stress
$\sigma a = (\sigma max - \sigma min) / 2$
$= (440 – 0)/2$
$\sigma a = 220$ MPa
b) Mean Stress
$\sigma m = (\sigma max + \sigma min) / 2$
$= (440 + 0)/2$
$\sigma m = 220$ MPa
For MS
Yield strength, Sy = 338.8 MPa
Ultimate strength, Sut = 621 MPa
Fatigue endurance strength, Se' = 0.5 σut
= 0.5X621
Se' = 310.5 MPa

- Endurance limit

Se = ka kb kc kd ke kf Se'
= 0.8*1*1*1*1*1*310.5
Se = 248.4 MPa

- From modified Goodman line

$\sigma a/Se + \sigma m/Sut = 1/n$
$(220/248.4) + (220/621) = 1/n$
n = 0.81

3.2 Fatigue Strength

Modified Goodman line
$Sf = \sigma a/(1 – (\sigma m/Sut))$

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= 220/ (1 – (220/621))
Sf = 340.7 MPa
Finite Life
N = (Sf / a)1/b
a = (f Sut)2 / Se
Where f = 0.84
a = (0.84x621)2/248.4
a= 1095.4
b = - [log (f Sut) / Se]/3
= - [log (0.84x621/248.4)]/3
b = - 0.107
N = (340.7/1095.4)-1/0.107
N = 54981 Cycles

III. FINITE ELEMENT ANALYSIS

Modelling

CATIA, developed by Dassault Systems is one of the leading CAD/CAM/CAE packages. Being a solid modelling tool, it not only unites the 3D parametric features with 2D tools, but also addresses every design through manufacturing process. Besides providing an insight into the design content, the package promotes collaboration between companies and provides them an edge over their competitors.

In addition in creating a solid models, sheet metal components and assemblies 2D drawing view can also be generated in the drafting workbenches of CATIA. drawing view that can be generated includes orthographic, section, auxiliary, isometric and detail views. it can also generate model dimension and create reference dimension in the drawing views. The bidirectionally associative nature of this software ensures that the modifications made in the model are reflected in the drawing views and vice-versa.

CATIA stands for **Computer Aided Three Dimensional Interactive Application**

CATIA V5 Provides three basic platforms : P1,P2,P3 P1 is for small and medium sized process oriented companies that wish to grow towards the large scale digitized product definition.P2 stands for advanced design engineering companies that require product, process and P3 for high end design applications and is basically for automotive and aerospace industries where high quality surfacing or class A surfacing is used.

The subject of interpretability offered by CATIA V5 includes receiving legacy data from the other CAD systems and from its own product data management modules. The real benefit is that links remain associative. As a result any change made to external data gets notified and the model can be updated quickly.

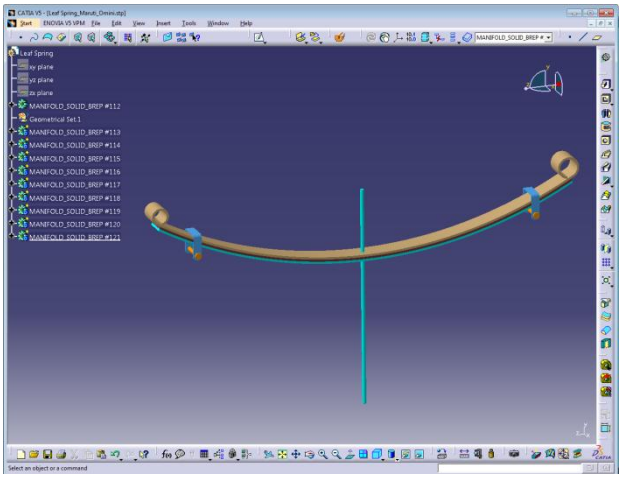

Fig.2 Modelling of leaf spring

IV. MESHING

Finite Element Mesh Generation:

A finite element mesh is a positioning of a given subset of the three-dimensional space by elementary geometrical elements of various shapes. The mesh generation is performed in the bottom-up flow i.e., lines are discretized first; the mesh of the lines is then used to mesh the surfaces; then the mesh of the surfaces is used to mesh the volumes. In this process, the mesh of an entity is only constrained by the mesh of its boundary. For example, in three dimensions, the triangles discretizing a surface will be forced to be faces of tetrahedra in the final 3D mesh only if the surface is part of the boundary of a volume. This automatically assures the conformity of the mesh. Every meshing step is constrained by a “size field” (sometimes called “characteristic length field”), which Gmsh 2.7 prescribes the desired size of the elements in the mesh. This size field can be uniform or specified by values associated with points in the geometry.

Fig. **3** meshing

There are three leaves including master leaf are having surface to surface contact.

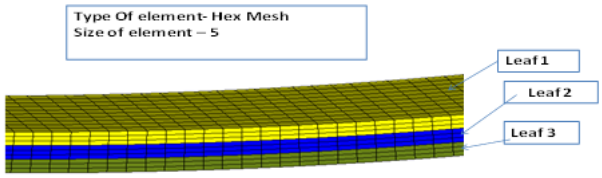

Fig.4 Meshing of three leaves

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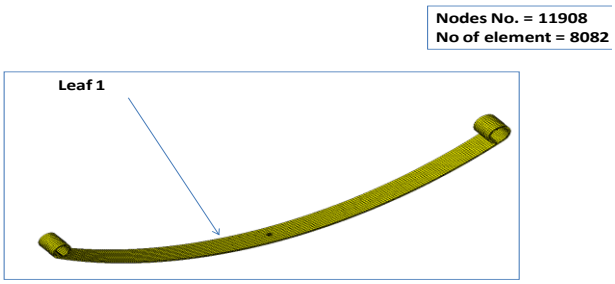


Fig.**5** Meshing of leaf 1

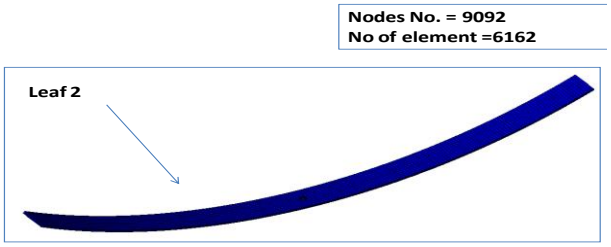


Fig 6 Meshing of leaf 2

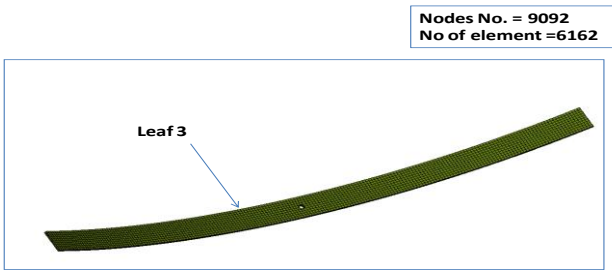


Fig.7 Meshing of leaf 3

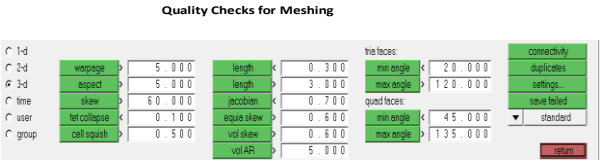
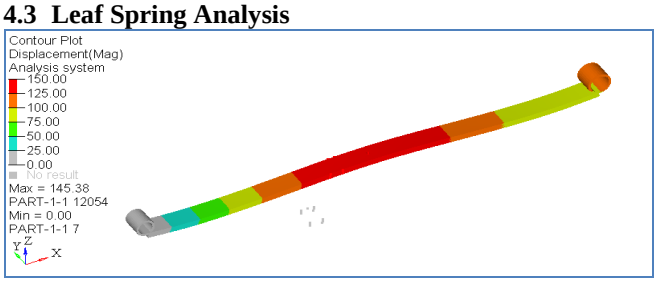


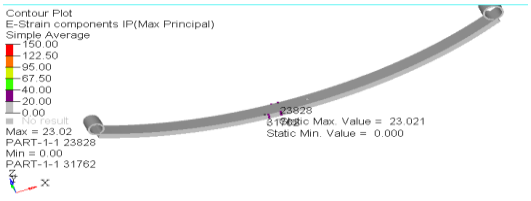
Fig. **8** Quality checks for meshing

In Quality checks standard aspect ratio is 5, the aspect ratio obtained is 3.73 whereas standard warpage is 5 and obtained warpage is 3.73.Quad face standard min. angle is 45 & obtained angle is 60 whereas standard max. angle is 135 & obtained angle is 127.

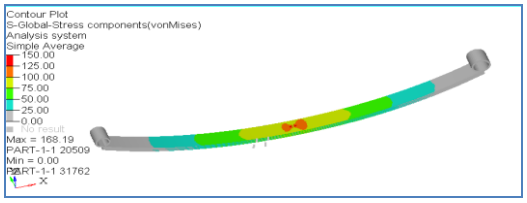
4.3 Leaf Spring Analysis



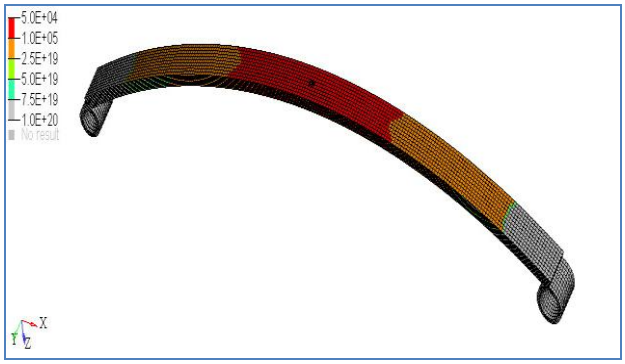
Displacement plot



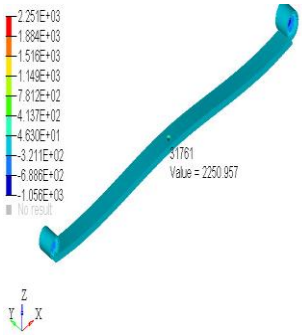
Maximum principal stress



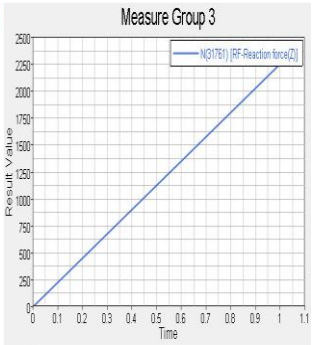
Von Misses stresses



Fatigue analysis of Medium alloy steel



Maximum deflection



Graph of load Vs time Load vs Deflection vs Stress

Sr. No.	Load	Deflection	Stress
1	225 N	0.1*135=13.5 mm	80 MPa
2	394 N	0.175*135 = 23.65 mm	150 MPa
3	563 N	0.25*135 = 33.75 mm	180 MPa
4	816 N	0.3625*135 = 48.93 mm	270 MPa
5	1196 N	0.5312*135 = 71.712 mm	400 MPa
6	1766 N	0.7844*135 = 105.94 mm	580 MPa
7	2250 N	1*135 = 135 mm	750 MPa

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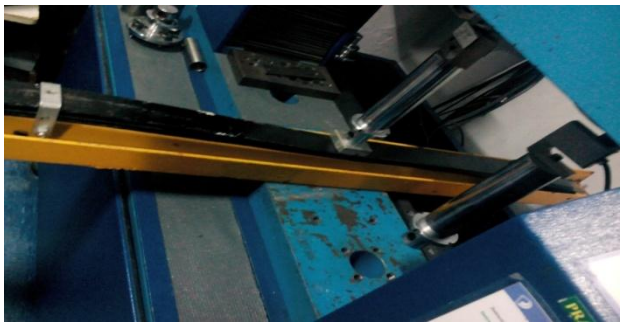
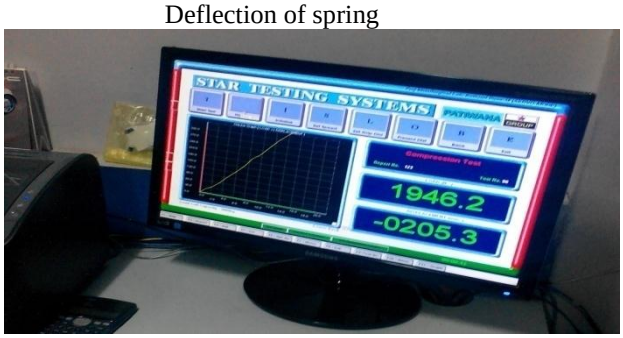
V.EXPERIMENTAL SETUP

UTM (Universal Testing Machine)



Deflection of spring



Monitor display of load Vs deflection

VI.CONCLUSION

1) When Benchmark material (Medium alloy steel) is considered then fatigue life in terms of number of cycles will be 50,000 cycles.
2) Existing material for the leaf spring is Medium alloy steel, by conducting finite element analysis and by the experimentation it is clear that there may be chances of early failure of leaf spring.
3) After design calculations of existing leaf spring mathematically no. of life cycles are 54,981 cycles.

Future Scope

1) In this project we have considered the material of leaf as Medium alloy steel and changed material is EN47 we can also make use of composite material including Epoxi resin to improve the strength to weight ratio.
2) Modification in leaf spring may be made in following ways
   a. Change Of Material
   b. Change Of Dimensions

REFRENCES

1. M.A. Osipenko, Yu.I. Nyashin, R.N. "*A contact problem in the theory of leaf spring bending*" International Journal of Solids and Structures 40 (2003) 3129–3136

2.A. González Rodríguez a, J.M. Chacón b, A. Donoso c, A.G. González Rodríguez d. *"Design of an adjustable-stiffness spring: Mathematical modeling and simulation, fabrication and experimental validation"*mechanism and machine theory 46 (2011) 1970–1979

3 F.T. Rowland, Manual on Design and Application of Leaf Springs—SAE HS J788, Society of Automotive Engineers (SAE), Warrendale, PA, 1980.

4.N.J. Nigro, S.P. Bhatia, Equivalent one-dimensional system for analysis of taper leaf springs, ASME J. Engrg Ind. 98 (Series B) (1976) 39–42.

5.B.I. Dunaevskii, Calculation of solid beams and flat springs (leaf springs) of varying cross-section, Sov. Engrg. Res. 61 (1981) 36–38.

6.W.F. Milliken, D.L. Milliken, Chassis Design: Principles and Analysis, Society of sAutomotive Engineers (SAE), Warrendale, PA, 2002.

7.G.Rill, N. Kessing, O. Lange, J. Meier, Leaf Spring Modelling for Real Time Applications, Proceedings of International Association of Vehicle System Dynamics (IAVSD) 18th Symposium, Atsugi, Japan, 2003.

8.E. Zahavi, Analysis of a contact problem in leaf springs, Mech. Res. Commun. 19 (1992) 21–27.

9.Q. Li, W. Li, A Contact finite element algorithm for the multileaf spring of vehicle suspension systems, IMEC-E Part D: J. Autom. Engrg. 218 (2004)305–314.

10.M.A. Omar, A.A. Shabana, A. Mikkola, W. Loh, R. Basch, Multibody system modeling of leaf springs, J. Vib. Contr. 10 (2004) 1601–1638.

11.A.A. Shabana, Dynamics of Multibody Systems, Second ed., Cambridge University Press, Cambridge, 1998.

12.J.S. Przemieniecki, Theory of Matrix Structural Analysis, McGraw-Hill, NY, 1968.

Y.A. Khulief, A.A. Shabana, A continuous force model for the impact analysis of flexible multibody systems, Mech. Mach. Theory 22 (1987) 213–224.

13.H.B. Pacejka, Tire and Vehicle Dynamics, Society of Automotive Engineers (SAE), Warrendale, PA, 2002. Vehicle Dynamics Terminology SAE J670e, 1978, Society of Automotive Engineers (SAE).

14.G.Gim, P.E. Nikravesh, An analytical model of pneumatic tires for vehicle dynamic simulations. 3. Validation against experimental data, Int. J.Vehicle Des. 12 (1991) 217–228.

15.J. Klaps, A.J. Day, Steering drift and wheel movement during braking: parameter sensitivity studies, IMEC-E Part D: J. Autom. Engrg. 217 (2003) 1107–1115.

16.L.F. Shampine, M.K. Gordon, Computer Solution of Ordinary Differential Equations, W.H. Freeman, San Francisco, 1975.

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