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Design, Simulation, and Fatigue Life Prediction of Leaf Spring for Light Passenger Vehicle Using Graphical Methodology

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ABSTRACT

Weight reductions have become the main primary focus of automobile manufacturer today. The suspension leaf spring is one of the potential items for weight reduction in automobiles as it leads to the reduction of unstrung weight of automobile.Since the experimentation process of fatigue life prediction of leaf spring is time consuming and heavy budget process rarely available. So design engineer working in field of leaf spring always face challenges to formulate alternative method to predict fatigue life and weight reduction. This work introduces improved techniques over existing method for prediction of fatigue life. Here weight reduction approach is by reducing thickness of leaf spring and keeping all dimensions constant and checking its effect on fatigue life, deflection and stress.

Keywords— **Fatigue, graphical method, leaf spring, weight reduction**

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I. INTRODUCTION

A Reduced weight while increasing or maintaining strength of product is getting to be highly important research issue in this modern world. Weight reduction has been the main focus of auto industries in the present scenario. When it comes to R&D for automotive materials most effort goes into developing and using materials to make cars lighter. In spite of this, cars have considerably grown in weight over the last three decades because of increased safety requirements and comfort specifications. It is an enormous challenge to bend this curve and effectively reduce weight in order to meet future emission regulation. Studies indicate that 10% mass reduction relates to a 3% to 7% benefit in fuel consumption depending on the type of car and the drive cycle used. On average a weight reduction of 100kg delivers -10gr CO2/km. and also weight reduction concept has been most important in automobile suspensions system such as leaf spring.Leaf spring is one of the important components of suspension system and it is widely used in automobiles. As we know that the weight of leaf spring is un-sprung weight of automobile. The elements whose weight is not transmitted to the suspension spring are called the unstrung elements of the automobile. This includes wheel assembly, axles, and part of the weight of suspension leaf spring and shock absorbers. Leaf spring contributes considerable amount of weight to the vehicle and need to be stronger enough. We will be focusing on reducing weight of leaf spring and increasing or maintaining the fatigue strength of Leaf spring for light commercial vehicle for Enhanced Mechanical properties to improve the performance over a life. The constant cross section design of leaf springs will be employed to take advantages of ease of design analysis and its manufacturing process. [8]The cost of materials constitutes nearly 60-70% 0f the vehicle's cost and contributes to the better quality and performance of the vehicle. Thus is becomes a potential unit to weight reduction. Weight reduction can be achieved by choosing better material and optimum design etc.

II. LITERATURE SURVEY

MouleeswaranSenthil Kumar et.al, 2007 Author has discussed about the leaf spring of light passenger vehicles and they selected Eglass/ epoxy as the spring material.

Author says that many attempts have been made to substitute more economic resins for the epoxy but all attempts to use polyester or vinyl ester resins have been unsuccessful to date. The leaf spring of light passenger vehicles has to be designed in such a way that its natural frequency is maintained to avoid resonance condition with respect to road frequency to provide good ride comfort. The road irregularities usually have the maximum frequency of 12 Hz [6].Their results states that conventional multi leaf spring weighs about 13.5 kg whereas the E-glass/Epoxy multi leaf spring weighs only 4.3 kg. Thus the weight reduction of 68.15 % is achieved. Besides the reduction of weight, the fatigue life of composite leaf spring is predicted to be higher than that of steel leaf spring. This research work was carried out as a part of the research project sponsored by Defence Research and Development Organization (DRDO), India.[6]

C.K. Clarke et.al, 2005: Author has focused well on metallurgical aspects of leaf spring failure and researcher have used scanning electron microscope (SEM) was used to examine the fracture of leaf spring. And he 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.[2].According to him Fracture of the spring occurred at the formed forward eye, as shown in Fig. 1. Comparison of the eye with unbroken springs revealed that it had somewhat unwrapped prior to the failure.

Fig. 1: The broken halves of the spring have been placed together in a manner exaggerating the opening of the eye before rupture [2].They finally concluded that presence of sulphur segregation at the mid-plane weakened the spring. According to him spring was cracked for some time in advance of the accident and prior cracking in the spring was extensive enough to reduce the strength of the spring to the point where normal dirt road forces were adequate to produce rupture. [2]

Vinkel Kumar Arora et.al, 2014: Author has very efficiently used various fatigue life prediction approaches. He have used four alternative methods of fatigue life assessment firstly by Firstly by SAE spring design manual approach the fatigue test stroke is established and by the intersection of maximum and initial stress the fatigue life is predicted. The second method constitutes a graphical method based on modified Goodman's criteria.

The third method fatigue life assessment is based on analytical technique. The fourth method consists of computer aided engineering tools. The CAD model of the leaf spring has been prepared in solid works and analysed using ANSYS. Using CAE tools, ideal type of contact and meshing elements have been proposed. The method which provides fatigue life closer to experimental value and consumes less time is suggested. [9]

III. MATERIAL and DESIGN PARAMETERS of LEAF SPRING

The material used for leaf springs usually a plain carbon steel having 0.90 to 1.0% carbon. The leaf is heat treated after the forming process. The heat treatment of spring steel produces greater strength and therefore greater load capacity, greater range of deflection and better fatigue properties [11]

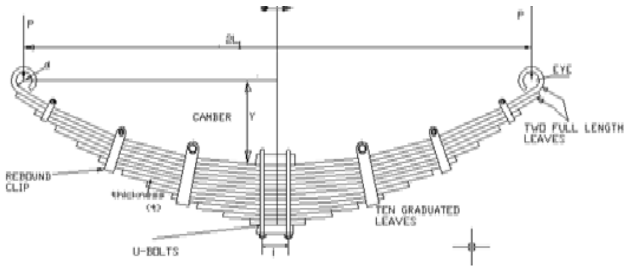

Fig. 2: Leaf spring

Metallurgical test:To check chemical composition of our leaf spring (raw material) we conducted Chemical Analysis by Wet test Method IS-228-1997 at FAN services Ambad, Nashik

Table 1: Chemical composition

C %	Mn %	Si %	S %	P %	Ni %	Cr %	Mo %
0.51	**0.72**	**0.28**	**0.022**	**0.018**	**Nil**	**0.65**	**Nil**

Note: Chemically leaf spring material conforms to SUP-9 specification.

Table-2: Material Properties of SUP-9. [9]

Parameter	**Value**
Material selected – Steel	65Si7/ Sup-9
Ultimate tensile strength,(Sut), MPa	1272
Yield tensile strength,(Sy), MPa	1081.2
Young's modulus E (N/mm2)	200124
BHN	380–432
Poisson's ratio, (μ)	0.266
Density,(ρ), kg/mm^3	0.00000785

Design parameters of multi leaf spring:

Table-2: Design parameters

Notation	**Parameter**	**Value**
n_f	**Number of extra full-length leaves**	**1**
n_g	**Number of graduated length leaves including master leaf**	**7**
n	**Total number of leaves**	**8**
b	**Width of each leaf (mm)**	**70**
L	**Length of the cantilever or half the length of semi-elliptic spring (mm)**	**610**
y	**Camber**	**130**

t	**Thickness of each leaf (mm)**	**Set 'A' 7 mm Set 'B' 11 mm**
P	**force applied at the end of the spring (N)**	

Note : We have considered one extra set of leaf spring for case study which is having all parameters same only there is difference in their thickness i.e. Set A and Set B

.

Deflection and stress of the spring is can be determined by equation (a) and (b) [13]

Deflection $$\delta = \frac{12PL^3}{Ebt^3(3n_f + 2n_g)} \quad \ldots\ldots \text{(a)}$$

Stress $$\sigma = \frac{6pL}{nbt^2} \quad \ldots\ldots \text{(b)}$$

IV. EXPERIMENTAL TESTING OF MULTI LEAF SPRING.

The process of experimental fatigue life prediction of leaf springs is a time consuming, heavy budget process and rarely available process i.e. for the fatigue life of 100000 cycles, the experimental procedure will consume approximately 2-3 days. So for validation purpose we conduct static load deflection test on UTM.

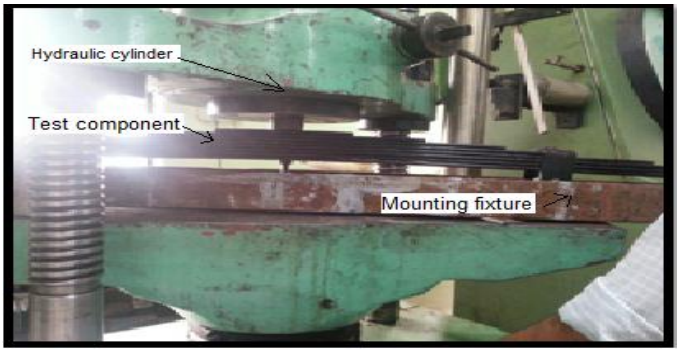

Fig. 3: Testing of leaf spring on UTM in fully laden condition.

The steel leaf springs are tested by using UTM having special arrangement to hold the spring as per practical approach. The spring is loaded at center from zero to prescribe maximum deflection and back to zero. The load is applied at the center of leaf spring and vertical defection of spring center is recorded in the load interval.

V. MODELLING& FINITE ELEMENT ANALYSIS

*CAD MODELLING:*The CAD modeling of the convectional steel leaf spring structure is performed by using Catia V5 R 19 software in part design workbench. Catia is having special tools which can help to generate surface design to construct typical surfacing, which are later converted into solid models. Solid model of all parts of leaf spring structure are thenassembled to make a complete structure

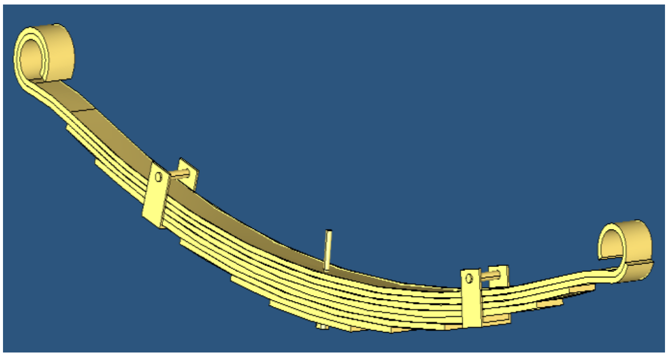

Fig. 4: CAD Model of Multi leaf spring.

Analysis using Hyper-mesh:

A stress deflection is performed using finite element analysis (FEA) the complete procedure of analysis has been done using Hyper-mesh software. The general process of FEA is divided into 3 main phase's processer, Solution and Postprocessor.

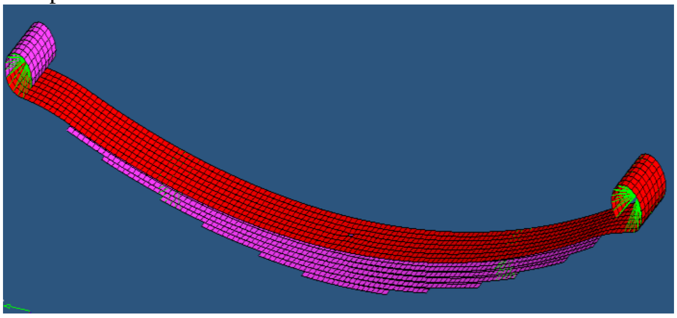

Fig.5: Meshing of Leaf spring Assembly.

The IGES file is imported to hyper-mesh where we can do pre-processing i.e. Finite element modeling. The purpose of FEM is to make a model that behaves mathematically as being and create appropriate input file for different finite element solvers. We meshed the model in hyper-mesh which is well shown in Fig. 5. Rigid body element node is connected to remaining nodes on surface of eye. so that all nodes on eye follows path or action as per master node which is showed in Fig. 6

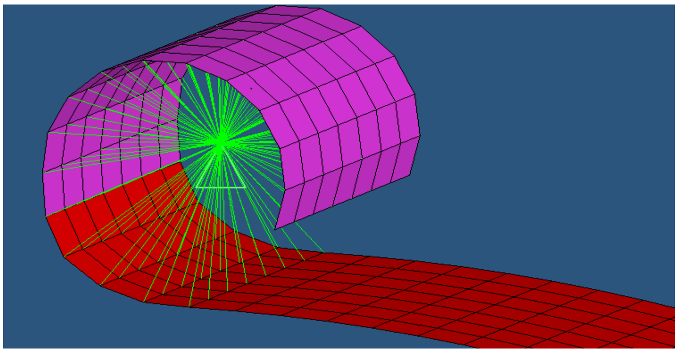

Fig. 6: Boundary Conditions in Hyper-mesh at Eye End

Finite element model of the leaf spring has properties given in table 3.

Table 3: Finite Element Model Properties.

	7 mm thick Leaf spring.	**11 mm thick Leaf spring.**
Number of elements	**3750**	**3750**
Element types	**Mixed**	**Mixed**
Global element	**3**	**3**

size		
Number of nodes	4349	4349

The front eye of the leaf spring was fixed in x, y and z translation and x and z rotation, allowing free y rotation The rear eye was constrained in y and z translation and x and z rotation, allowing free x extension and y rotation Axle load is applied in vertical direction. From zero to prescribed maximum deflection and back to zero.

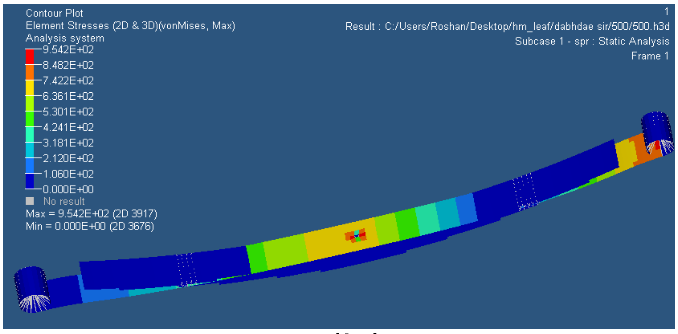

Fig. 7Von- Misses stress of leaf spring

Von- Misses stress of leaf spring is shown in Fig. 7 under the maximum load,since comparative 11 mm thick leaf spring is having large load caring capacity so heavier load is applied on it and since Displacement of the leaf spring is very important as it is directly related to spring rate. The displacement is given in Fig. 8.

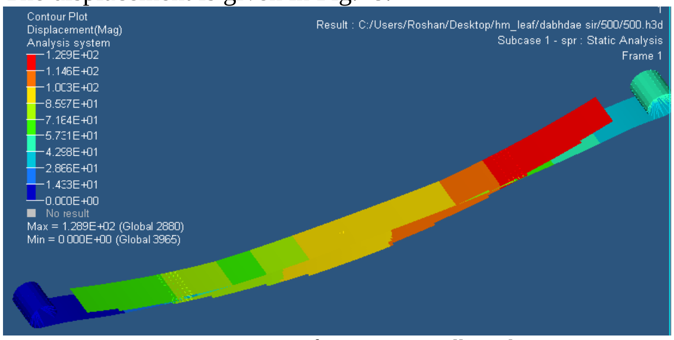

Fig. 8Deformations at Full Load

Table 4: Experimental and FEA results for load, deflection, and bending stresses for 7 mm thick leaf spring.

Load (N)	Deflection (mm)		Stress N/mm2
	Experimental	FEA Result	FEA Result
981	11	14.056	90.63
1962	28	28.12	181.3
2943	44	42.16	271.9
3924	61	56.22	362.5
4905	77	70.28	453.2
5886	92	84.38	543.8
6867	105	98.26	634.4
7848	115	112.44	725.1
8829	118	126.5	815.7
9810	130	140.56	906.3

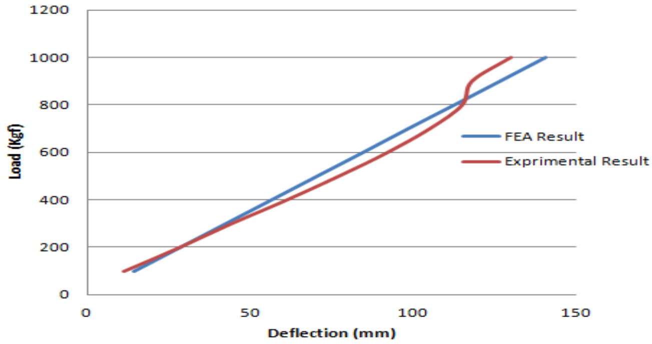

Fig. 8 Comparative result analysis of 7 mm thick leaf spring

Table 5: Experimental, FEA and Analytical results for load, deflection, and bending stresses for 11 mm thick leaf spring

Load (N)	Deflection (mm)		Stress N/mm2
	Experimental result	FEA Result	FEA Result
981	4	4.696	34.01
1962	10	9.736	68.02
2943	15	14.776	102.03
3924	20	19.816	136.04
4905	26	24.856	170.05
5886	31	29.896	204.06
6867	37	34.936	238.07
7848	43	39.976	272.08
8829	49	45.016	306.09
9810	56	50.056	340.1

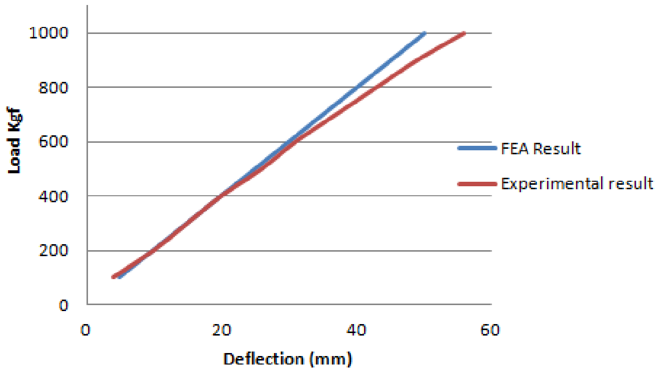

Fig. 9 Comparative result analysis of 11 mm thick leaf spring

I. FATIGUE LIFE ESTIMATION BY GRAPHICAL METHOD.

Since experimental fatigue life prediction of leaf spring is time consuming and heavy budget process. So we have adopted graphical method. This method involves application of Marin equation which involves surface, reliability temperature size, etc factors of particular design shape and material of leaf spring. Here we have adopted this method for material Sup 9 of 7mm thickness and then for 11 mm thickness. Considering the design, material, processing parameters of leaf spring for SUP 9 showed in table (4) which is well explained by Vinkel Kumar Arora et.al, 2014.

Table 6: Parameters of SUP 9 for graphical method

Parameters for graphical method.	Leaf spring set thickness	
	7mm	11 mm

S_{ut}	1272	1272 Mpa
S_y	1081 Mpa	1081 Mpa
$S_e^{'} = 0.5Sut$	636 Mpa	636 Mpa
$\sigma_{\max}$ at 1g	923.9 Mpa	370.5 Mpa
$\sigma_{\min}$ at 0.3g	277.17 Mpa	111.5 Mpa
$S_a = (\sigma_{\max} - \sigma_{\min})/2$	323.36 Mpa	129.67 Mpa
$S_m = (\sigma_{\max} + \sigma_{\min})/2$	600.53 Mpa	240.82 Mpa
K_{load}	1	1
K_{surface}	1	1
$K_{\text{temp} \le 450}$	1	1
$K_{\text{reliability}}$	0.814	0.814
K_{size}	1	0.85
S_e	517.70	432.48

As shown in Fig. 9 alternating vs. mean stress graph of 7 mm and 11 mm thick leaf spring, it is observed that the intersection of the alternating and mean stress lines of 7 mm lies outside the region AC. Hence component is design for finite life. But if we observe the position of 'I' of 11 mm thick leaf spring is within the region AC. so we can say that it is having infinite life for same stress level. To predict the fatigue life we have to take help of S-N curve of Sup-9 material for 7 mm thick leaf spring, which is shown in Fig. 10

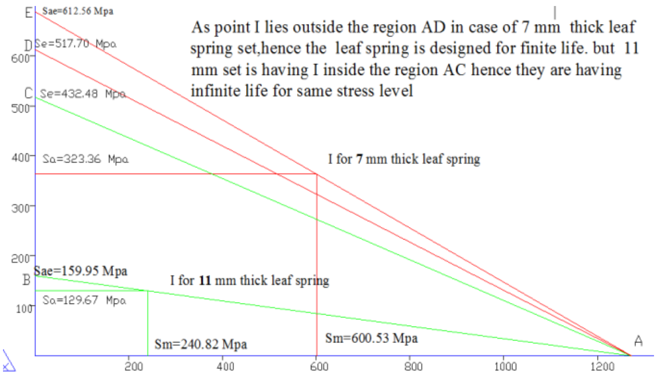

Fig. 9 Alternating stress versus mean stress plot.

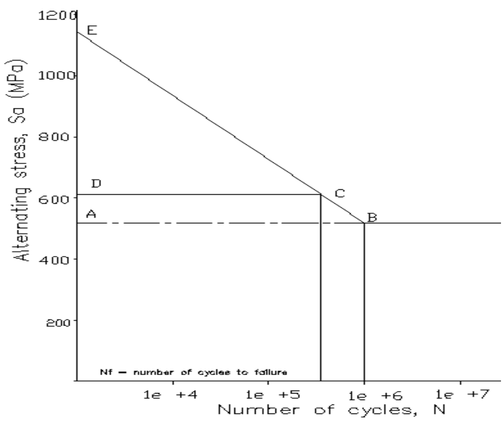

Fig. 10: Alternating stress versus number of cycles of 7 mm thick leaf spring

Point D shows the endurance limit, which is 517Mpa. Line CB shows equivalent alternating stress. Point B shows intersection of alternating stress which will give the number of cycle that can be sustained for prescribes stress level.

Triangle ABC is having similarity with triangle ADE

Hence, $AC/AE = CB/DE$

$AC = \log A - \log C = 0.27,$

$AE = \log A - \log E = 0.344,$

$DE = \log D - \log E = \log 10^6 - \log 10^3 = 3$

$$CB = \frac{0.27 \times 3}{0.344} = 2.35$$

Total $CB = 3 + 2.35 = 5.35$

Number of cycles = $10^{5.35}$ =223872.11 cycles to failure.

Table 7: Fatigue life of leaf spring at different thickness

Leaf spring set of thickness.	Fatigue life of spring
7 mm	223872.11
11 mm	1.38038×10^9

VI. Conclusions:

The sup-9 Leaf spring model is considered for determining stress, deflection by experimental, analytical and CAE (using Hyper-mesh) approach

The following conclusion is made.

1. When the leaf spring is loaded up to its extreme limit, a variation not exceeds 10 % in deflection is observed at various loads between experimental and FEA for both models which validates the model and analysis.
2. And it is observed that resulting design and stimulated stress are much below the strength properties of the material satisfying maximum stress failure criterion
3. For same stress level the 11 mm thick leaf spring is having 74.22 % less deflection than 7 mm thick leaf spring.
4. Because of larger area the 11 mm thick leaf spring is having 59.94 % less stress than 7 mm thick leaf spring.
5. By reducing thickness from 11 mm to 7 mm 36.37 % weight reduction is observed.
6. For same stress level 7mm thick leaf spring is having 223872 fatigue life cycles which is finite life but for 11 mm leaf spring cross finite life.
7. This work will help researcher to deciding optimum thickness which will help to reduce weight of vehicle.

For achieving improved ride characteristics, increased fuel efficiency and material saving we can use better material giving better fatigue life or we can reduce thickness less than existing thickness of spring, up to the thickness which will be satisfying the required stress, deflection and fatigue life. Though reduction of material for each spring is less but we know that vehicles are manufactured in tonnages and for each vehicle 4 springs are needed means almost this will give definitely large reduction in material cost. And another think is study of effect of change in thickness on fatigue life.

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