Performance Analysis of Steel Leaf Spring With Crack

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***Abstract*— Leaf Spring is one of the oldest forms of suspension units employed in automobiles. To meet the needs of natural resource conservation and energy economy, automobile manufacturers have been attempting to reduce the weight of vehicles in recent years. Extensive research has been made in this area by researchers and engineer so as to reduce the weight of the suspension unit still satisfying the demand of Smooth and safe ride quality. Researchers and engineers are working on applying various design and material combination to satisfy the design criteria and reduce the weight of the unit. The design failure occurs either during service or after its life is completed. The failure in service occurs either due to extreme conditions or due to manufacturing defects. This Failure can be catastrophic. One of these failures is due to Cracks in leaf Springs. These cracks are present either on surface or beneath. These are in very minute size. During Service this crack expands and when it reach surface the component may fail catastrophically over the period of time during service. An effort has been made to analyze the effect of Crack on the Stress generation in a Leaf Spring. Also, modal analysis will be performed to analyze the effect of crack on the natural frequency of the leaf spring. The case is analyzed analytically, using simulation in ANSYS and the results will be validated by experimental testing on UTM for Leaf Spring with and without Crack. The Maximum bending stress is calculated for Leaf spring.**

Keywords— Bending Stress, Crack, Leaf Spring, Modal analysis

I. INTRODUCTION

TO decrease the weight of vehicles in recent years is the basic needs of industry .The suspension spring is one of most important system in automobile which reduces the vibration and absorb jerk during riding. Steel have been vigorously developed for many applications. Other advantages steel are: (a) the possibility of reducing noise, vibrations and ride harshness due to their high damping factors, which means lower maintenance costs; and (c) lower tooling costs, which has favorable impact on the manufacturing costs. Springs are crucial suspension elements in cars; need to reduce the vertical vibrations due to road regularities. Where the function of the springs for an automobile industry are to maintain good control and passenger comfort. Behavior of leaf spring is nonlinear; whose weight is high, and change in solid axle angle due to weight transfer. This lead to over steer and directional instability under such condition it is very difficult for driver to control vehicle. Like this some defect of metallic leaf spring observe so considering automobile development and importance of relative aspects. Where graphite and carbon fiber demonstrate better performance over steel material, however due to cost and availability limits usage on wide scale. The present work is restricted to leaf spring. Many papers were devoted to find spring geometry. In this work, stress-strain study and modal analysis of Leaf spring is being done with and without Crack.

II. LITERATURE REVIEW

N. K. Mukhopadhyay et al. in his paper carried out failure analysis of a leaf spring where hardness and tensile testing, and residual stress evaluation by X-ray diffraction studied. Where the cracks have been attributed to an improper quenching process. It shows that some of these quench cracks have propagated by a fatigue mode which is confirmed by the presence of beach marks on the fracture surface. Where observation of inter granular cracking and presence of FeS sort of grain boundary might have facilitated crack growth and led to failure. It is suggested that quenching should be carried out by recommended procedures guided by the thickness of the component and the composition of the steel.

Peiyong Qin et al. [2002] in his paper studied leaf spring design mainly based on simplified equations and by the trial-and-error methods. These simplified equations of the models were limited to the three-link mechanism and beam theory. Where paper presents detailed finite element modeling and analysis of a two-stage multi-leaf spring, a leaf spring assembly, and a Hotchkiss suspension is using ABAQUS. Due to non-linearity from large deformation, interleaf contact, and friction was included. The stresses and strains under different loads were analyzed.

C.K.Clarke et. al. [2005] in this paper presented the observation about the accident sequence of a rear leaf spring on an Sports utility vehicle in terms of fractured surface analysis and residual- strength estimates. The fractured specimen was checked using Stereomicroscopy, revealed a step in the fracture surface at this location, with deep secondary cracking along the mid plane. Impact of secondary cracks along mid plane of the leaf spring on the strength and leading to failure were evaluated. Failure analysis concluded that sulfur segregation lead to weakening of spring. It was cracked some time in advance and prior cracking in the leaf spring was extensive enough to reduce the strength of the spring to the point where normal dirt road forces were adequate to produce rupture.

Gulur Siddaramanna et al. [2006] said in this paper presented a low cost fabrication for complete mono composite leaf spring leaf spring with bonded end joints. They also did a general study on the analysis and design. Single leaf with variable thickness and width for constant cross sectional area of unidirectional glass fiber reinforced plastic (GFRP) with similar mechanical and geometrical properties to the multileaf spring, was designed, fabricated by the hand lay-up technique and tested. Comparison of the steel spring and the composite spring has stresses that are much lower, the natural frequency is higher.

Agawarn et al. [2006] said in this paper to improve fatigue strength of materials by creating residual stress field by the shot peening. Fatigue strength of shot peened leaf springs has been determined from laboratory. Fatigue strength of EN45A leaf spring of steel specimen is with the help of experiments as a function of shot peening in the conditions used for full-scale leaf springs testing in industries.

E. Mahdi et al. [2006] said paper study on composites material to challenge in vehicle suspension. The changes can be achieved by employing a new material. In this paper, performance of woven roving wrapped composite springs has been predicted by analytically and experimentally. The results showed that the ellipticity ratio increases the spring rate and failure loads.

Senthil Kumar et al. [2007] in this paper discussed regarding static and fatigue analysis of leaf spring which is made by glass fiber reinforced. The dimensions of an existing conventional steel leaf spring a LMV are taken and are verified by design. Due to this load carrying capacity and weight of composite leaf spring are compared with that of steel leaf spring analytically and experimentally. Fatigue life of both leaf spring is predicted. Compared to steel spring, the composite leaf spring is found to less stress, high stiffness and high natural frequency than that of existing steel leaf spring.

Prawoto et al. [2008] said in this paper automotive suspension coil springs and their fundamental stress distribution. Failure of coil's perform due to improper than the coil springs are used in lower stress. Failures presented range from the very basic including insufficient load carrying capacity, raw material defects.

Fuentes et al. [2009] said in this paper the origin of premature fracture of leaf springs is due to common failure analysis procedures. From this concluded that fracture occurred by a mechanism initiated at the central hole which is suffered the highest tensile strength.

WenyiPeng et al. [2010] said in this paper the analyzed the fracture of 60Si2Mn spring flat steels during punching by use of the microscope and a Charpy impact tester. Results show that the fracture of 60Si2Mn spring during cold-punching is due to the non-homogenization. Collapsing fracture is characteristic with cleavage and pearlites.

Nenad Gubeljak et al. [2010] said in this paper performed analysis and several investigations shows the fatigue threshold for very high cycle fatigue depends. The stress loading limit regarding to inclusion size R=-1 in form of S-N curves. Experimental results of S-N curve by model.

M. M. Patunkar et al. [2011] discussed in this paper present the leaf springs is the oldest suspension components frequently used in commercial vehicles. Literature survey shows the leaf springs are designed as a generalized force elements. There is an increasing interest in the automobile industry for replacement of steel spring with composite leaf spring because of high strength to weight ratio. Analysis of the composite material becomes equally important to study the behavior of Composite Leaf Spring. Objective of this modeling and analysis of composite mono leaf spring and compare with results.

Kumar Krishan et al. [2012] discussed that multi leaf spring having nine leaves generally used in a commercial vehicle. FEA analysis carried out for this leaf spring it includes two full length leaves in which one is with eyed ends and seven graduated length leaves. Where material used for leaf spring is SUP9.

III. OBJECTIVE

The main objectives of the project is

1) To determine stress for steel Leaf spring without Crack by taking steel leaf spring of Light duty vehicle with specific dimension and applying static load on leaf spring gradually.

2) To determine effect of crack on stress and Natural Frequency for steel leaf spring with Crack depth by taking steel leaf spring of Light duty vehicle with specific dimension and applying static load on leaf spring gradually.

3) Conducting Modal analysis on leaf spring with and without cracks. The results obtained can be used for comparison purpose of leaf springs.

IV. ANALYTICAL SOLUTION

A. Material properties and physical parameters of steel leaf spring. The material used for steel leaf springs is usually plain carbon steel having 0.90 to 1.0 % carbon. The leaves are heat treated once the forming process is completed. The heat treatment of spring steel produces greater strength & therefore greater load capacity, greater range of deflection & better fatigue properties.

According to Indian standards, the recommended materials are

1) For automobiles– 50 Cr1, 50 Cr1V23, and 55 Si 2Mn 90 all used in hardened & tempered state.
2) For rail road springs – C 55 (Water- hardened), C75 (Oil – hardened), 40 Si 2Mn 90 (Water – hardened) & 55 Si 2 Mn 90 (Oil – hardened)

In this project testing & analysis is done for steel leaf spring of material EN 45.

Table 4.1: Leaf Spring Dimensions

Parameter	EN 45
1) St. length in mm	945mm
2) Leaf thickness in mm	8mm
3) Leaf width in mm	45 mm
4) Camber in mm	125 mm

Table 4.2: Material Properties.

Parameter	EN 45
1) UTSS	1158 N/mm2
2) Tensile Strength	1034 N/mm2
3) Young's modulus	207 GPa
4) Poisson's ratio	0.3
5) Density	7850 Kg/m3

4.1 Analytical Calculation

We know that for leaf spring Bending Stress is calculated by using Flexural formula as below. At the load of 186 N Bending stress value is calculated as follows,

Bending stress, $\sigma = 6\,w\,L / bt2$

$= 6 \times (186) \times (545) / (50 \times 8^2)$

$= 818.81137\ N/mm^2$

Calculating the Theoretical Values of bending Stress.

4.2 Computer algorithm for bending stress and defection by using C language

```
#include <math.h>
#include <conio.h>
#include <stdio.h>
void main()
{
float W,L,E,b,t,Z,D,I,Y,X;
clrscr();
printf("\n Enter the value of load W : ");
scanf("%f",& W);
printf("\n Enter the value of length L : ");
scanf("%f",& L);
printf("\n Enter the value of width b : ");
scanf("%f",& b);
printf("\n Enter the value of thickness t : ");
scanf("%f",& t);
printf("\n Enter the value of Maximum Deflection D : ");
scanf("%f",& D);
printf("\n Enter the value of Young's Modulus E : ");
scanf("%f",& E);
printf("\n Enter the value of Yield Stress X : ");
scanf("%f",& X);
I=((b*(t*t*t))/12);
printf("\n Moment of Inertia =%f",I);
Z=((W*(L*L*L))/(3*E*I));
printf("\n Deflection due to applied load =%f",Z);
if(Z>D)
{
printf("\n Material is fail due to deflection. ");
}
else
{
printf("\n Leaf spring is safe from deflection point of view. ");
}
Y=((6*W*L)/(b*(t*t)));
printf("\n Stress due to applied load is =%f",Y);
if(Y>X)
{
printf("\n Material is fail due to Stress. ");
}
else
{
printf("\n Leaf spring is safe from stress point of view. ");
}
getch();
}
```

Output:-

```
EN 45
Enter the value of load W : 801.97
Enter the value of length L : 545
Enter the value of width b : 50
Enter the value of thickness t : 8
Enter the value of Maximum Deflection D : 125
Enter the value of Young's Modulus E : 2.07e5
Enter the value of Yield Stress X : 1034
Moment of Inertia =2133.333252
Deflection due to applied load =97.993507
Leaf spring is safe from deflection point of view.
Stress due to applied load is =819.513062
Leaf spring is safe from stress point of view.
```

V. FINITE ELEMENT ANALYSIS OF LEAF SPRING BY ANSYS FEM PACKAGE

A. *CAD modeling*

The CAD models of the eye design were prepared in CATIA V5 and the analysis and comparison of results are performed using ANSYS 14.5. The CAD model of Leaf spring is shown in Figure 5.1.

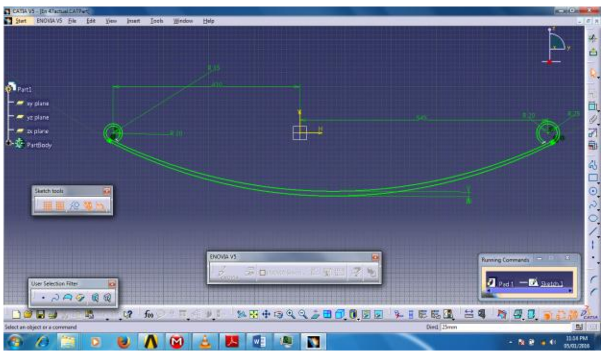

Figure :5.1 2D Sketch in CATIA V 5 R 17

B. Boundary Conditions

Both the springs were analyzed for static strength and deflection using finite element analysis. For steel leaf spring center bolt, u-clamp rebounded clip conditions are included in the boundary conditions. Non-liner 3D finite element analysis has been done to predict stress and deflection values in the spring.

The boundary conditions & loading details are described in following Table 5.1

Table 5.1 Boundary conditions & loading

Location	Description	Boundary Condition
A	Center Bolt	All nodes move together along X,Y&Z. All nodes move rotate along X,Y & Z.
B	U- clamp	UZ, ROT x & ROT y=0
C	Rebound Clip	UZ, ROT x & ROT y=0
D	Rebound Clip	UZ, ROT x & ROT y=0
E	Connection of main leaf with shackle.	All nodes move together along X,Y& Z.All nodes rotate along X,Y & Z.
F	Connections of shackle with support	UX ,UY,UZ,ROT x&ROT y = 0
G	Axle seat on leaf spring	Pressure on bottom elements between U clamps.

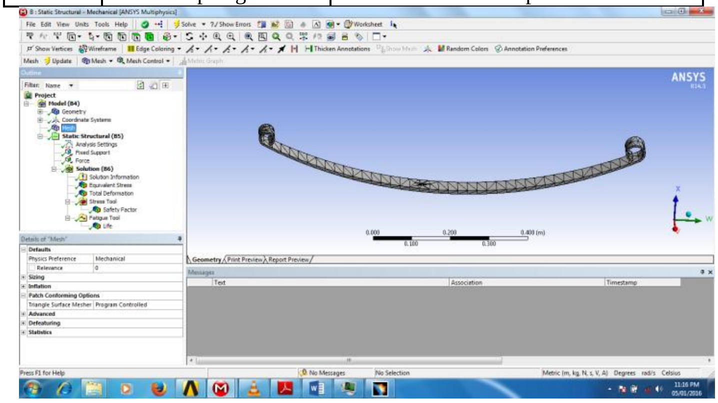

Figure:5.2 Meshed models of EN 45 leaf spring with force and boundary conditions.

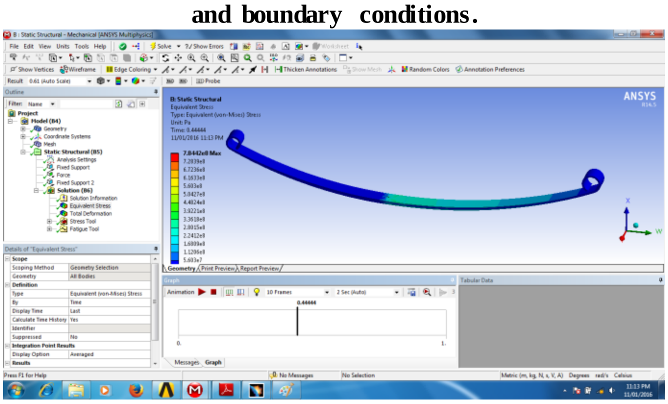

Figure 5.2 Stress Analysis of EN 45 Leaf Spring Without Crack.

VI. EXPERIMENTATION

In Order to find the stress on Leaf Spring Strain Gauges are mounted on Leaf Spring. Universal Testing Machine is used for application of Load the arrangement of the set up along with Leaf spring is as shown in Figure 6.1.

Figure: 6.1 Experimental setup for Leaf Spring.

The steel leaf springs are tested by using leaf spring test rig. The experimental set up is shown in Figure 6.1. The leaf springs are tested by following standard procedures recommended. The spring to be tested is examined for any defects like cracks, surface abnormalities, etc. The spring is loaded from zero deflection to the prescribed maximum deflection and back to zero. The load is applied at the center of spring.

The figure 6.2 shows leaf spring with Strain gauges attached along its length.

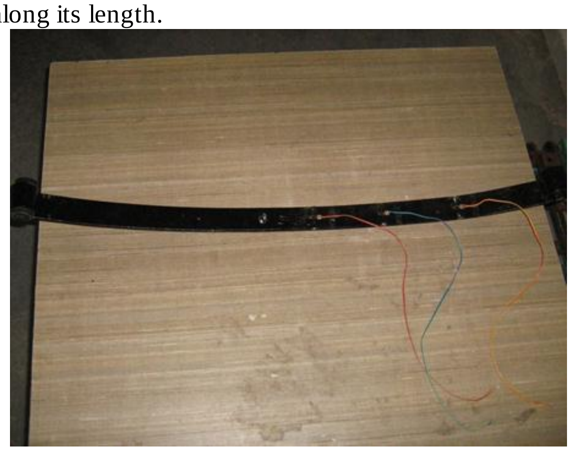

Figure: 6.2 Leaf spring with three strain gauges mounted.

Figure: 6.3 Setup for Modal Analysis

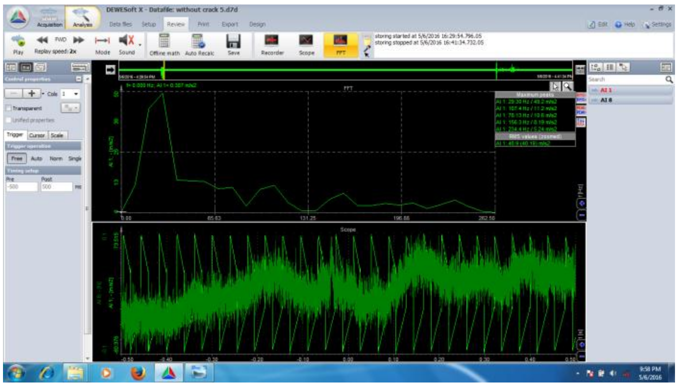

Figure: 6.4 Output from FFT analyser

Table 6.1 Modal Frequency Values:

Mode	Natural Frequency as per FFT(Hz)	Natural Frequency as per FEA(Hz)
1	29.30	22.64
2	78.13	73.817
3	107.4	109.86
4	234.4	270.14

VII. MODAL ANALYSIS OF LEAF SPRING WITH TRANSVERSE CRACK

Now to study impact of the transverse crack on the leaf spring performance, we analyses the same in ANSYS by considering a three crack depths values and at a distance L form Centre bolt hole. The Von misses stress and the modal analysis have been performed on the leaf spring for three depths

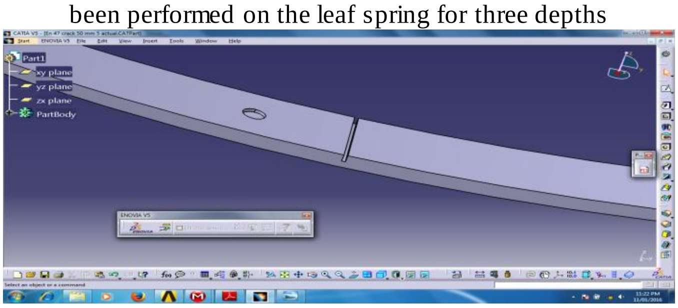

Figure: 7.1D Model of EN 45 Leaf Spring with Crack.

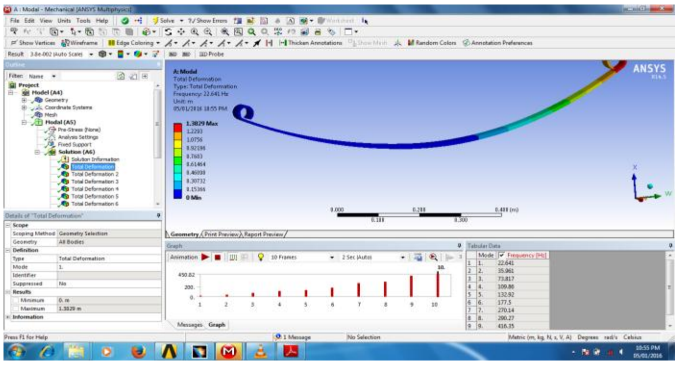

Figure: 7.2 Modal Analysis of EN 45 Leaf Spring with Crack.

Natural Frequency for four modal shapes for four crack depths as per ANSYS are tabulated Table 7.1 as below:

Table 7.1 Modal Analysis values for different crack depths in

Mode No.	Frequency for 1.5 mm Depth (in Hz)	Frequency for 2.5 mm Depth (in Hz)	Frequency for 3.5 mm Depth (in Hz)	Frequency for 5 mm Depth (in Hz)
1	22.55	22.42	22.2	21.726
2	80.377	80.162	79.823	79.119
3	109.32	109.07	108.57	107.59
4	273.29	272.93	272.47	271.72

VIII. RESULTS AND DISCUSSION

En 45 Material Steel Leaf Spring without Crack Analytical FEA and Experimental Stress values with gradually increasing Load as given in table below,

Table 8.1

Deflection in mm	Load In N	Analytical Stress (N/mm^2)	FEA Stress (N/mm^2)	Experimental Stress (N/mm^2)
01	37	9.97	13.16	8.28
05	186	49.87	46.42	35.19
10	372	99.74	88.00	69.13
15	558	149.61	129.59	102.67
20	745	199.48	171.17	135.99
25	931	249.35	212.73	170.36
30	1117	299.22	254.33	201.2
35	1303	349.09	295.91	238.67
40	1489	398.96	337.5	287.31
45	1675	448.84	379.08	331.22
50	1862	498.71	420.66	368.04
55	2048	548.58	462.62	413.17

E45 Material Steel Leaf Spring with Crack FEA Stress values with gradually increasing Load as given in table below,

Table 8.2 FEA Stress for varying crack depth

Load (N)	FEA Stress With Varying Crack depth (N/mm^2)			
	1.5 mm	2.5mm	3.5mm	5mm
37	21.17	21.63	21.78	22.19
186	109.55	112.48	115.39	120.18
372	218.06	219.8	223.38	233.9
558	326.99	327.06	331.53	333.69
745	436.8	437.36	442.47	453.47
931	546.17	557.38	551.96	561.66
1117	653.99	658.53	661.88	665.23
1303	764.14	768.44	765.93	839.23
1489	872.99	876.08	876.59	945.35
1675	983.72	984.76	995.76	1075.5
1862	1092.7	1091.4	1101.7	1193
2048	1202	1197.9	1211.2	1322.2

En 45 Material Steel Leaf Spring with Crack Experimental Stress values with gradually increasing Load as given in table below,

Table 8.3 Experimental Stress for Varying crack Depth.

Load (N)	Experimental Stress With Varying Crack depth (N/mm^2)			
	1.5 mm	2.5mm	3.5mm	5mm
37	16.29	16.75	16.90	17.31
186	98.32	101.25	104.16	108.95
372	199.19	200.93	204.51	215.03
558	300.07	300.14	304.61	306.77
745	401.62	402.18	407.29	418.29
931	503.80	515.01	509.59	519.29
1117	600.86	605.40	608.75	612.10
1303	706.90	711.20	708.69	781.99
1489	822.80	825.89	826.40	895.16
1675	935.86	936.90	947.90	1027.64
1862	1040.08	1038.78	1049.08	1140.38
2048	1152.55	1148.45	1161.75	1272.75

CONCLUSION

This work involves the Study of behavior of EN 45 Material steel Leaf Spring with Varying Load and Natural Frequency prediction with and without crack. As well as effect of Crack on Stress and Natural Frequency with varying crack depth is evaluated by using Strain Gauges and FFT analyzer. It is observe that as the crack depth increases Stress value increase and Natural Frequency decrease. Built a Computer Algorithm in C Language for Calculating Stress and Deflection of Leaf spring.

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