Simulation of Stress Distribution in Leaf Spring Under Variable Parametric and Loading Conditions

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***Abstract*— Leaf springs are used in suspension systems. The past literature survey shows that leaf springs are designed as generalized force elements where the position, velocity and orientation of the axle mounting gives the reaction forces in the chassis attachment positions. The present work attempts to find the maximum pay load of the vehicle by performing static analysis using ANSYS software. The obtained results are compared analytically and found good agreement. The optimality conditions such as maximum bending stress and the corresponding pay load are designed with proper consideration of the factor of safety. To assess the behavior of the different parametric combinations of the leaf spring, the modal analysis using ANSYS software for the natural frequencies is carried out and the corresponding mode shapes are obtained. The natural frequencies are compared with the excitation frequencies at different speeds of the vehicle with the various widths of the road irregularity. These excitation frequencies are validated with analytical results.**

***Keywords*— Leaf Spring, ANSYS, pay load, natural frequency, camber**

I. INTRODUCTION

A spring is an elastic body, whose function is to distort when loaded and to recovers its original shape when the load is removed. Semi-elliptic leaf springs are almost unanimously used for suspension in light and heavy industrial and commercial vehicles such as TATA- 407, LPT-1109, LPT-1613, utility vehicles like Tata Sumo, Tata safary, Scorpio, Quallise etc. The spring consists of a number of leaves called blades as shown in Fig 1.. The blades are varying in length. The blades are usually given an initial curvature or cambered so that they will tend to straighten under the load. The leaf spring is based upon the theory of a beam of uniform strength. The lengthiest blade has eyes on its ends. This blade is called main or master leaf, the remaining blades are called graduated leafs. All the blades are bound together by means of steel straps. The front eye of the leaf spring is constrained in all the directions, where as rear eye is not constrained in X-direction. This rear eye is connected to the shackle. During loading the spring deflects and moves in the direction perpendicular to the load applied. The springs are initially cambered. More cambered leaf springs are having high stiffness, so that provides hard suspension. Use of longer springs gives a soft suspension, because when length increases the softness increases. Generally rear springs are kept longer than the front springs. Sometimes the leaf springs are provided with metallic or fabric covers to exclude dirt. The covers also serve to contain the lubricant used in between the spring leaves. In case of metal covers, the design has to be of telescopic type to accommodate the length of cover after the change of spring length.

The suspension system consists of a spring and a damper. The energy of road shock causes the spring to oscillate. These oscillations are restricted to a reasonable level by the damper, which is more commonly called a shock absorber. When the rear wheel comes across a bump or pit on the road, it is subjected to vertical forces, tensile or compressive depending upon the nature of the road irregularity. These are absorbed by the elastic compression, shear, bending or twisting of the spring. The mode of spring resistance depends upon the type and material of the spring used.

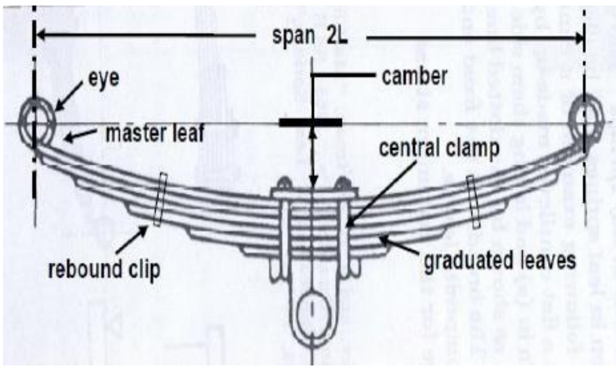

Fig 1. Leaf Spring and its parts

II. LITERATURE REVIEW

Zliahu Zahavi et all. [1] discussed the behavior of structures of leaf springs under practical conditions. Practically, a leaf spring is subjected to millions of load cycles leading to fatigue

failure. They performed free vibration analysis which determines the frequencies and mode shapes of leaf spring.
A.strzat and T.Paszek [2] performed a three dimensional contact analysis of the car leaf spring. They considered static three dimensional contact problem of the leaf car spring. The solution was obtained by finite element method performed in ADINA 7.5 professional system. Numerical results were verified with experimental investigations. The static characteristics of the car spring was obtained for different models and compared with experimental investigations.
Fu-Cheng Wang [3] performed a detailed study on leaf springs. Classical network theory is applied to analyze the behavior of a leaf spring in active and passive suspensions. Typically, these situations involved in specifying a soft response from road disturbances.
Shahriar Tavakkoli, Farhang Aslani, and David S. Rohweder [4] performed analytical prediction of leaf spring bushing loads using MSC/NASTRAN and MDI/ADAMS. Two models of leaf spring in MSC/NASTRAN and MDI/ADAMS were created to compare the bushing loads predicted by each model. Geometric non-linear capability of MSC/NASTRAN (SOL 106) was used to predict the bushing loads in MSC/NASTRAN model. The quasi-static simulation capability of MDI / ADAMS was used to predict the bushing loads in MDI/ADAMS model.
I.Rajendran and S.Vijayarangan [5] performed a finite element analysis on a typical leaf spring of a passenger car. Finite element analysis has been carried out to determine natural frequencies and mode shapes of the leaf spring. A simple road surface model was considered.
C.Madan Mohan Reddy, D.RavindraNaik, Dr M.Lakshmi Kantha Reddy [1] conducted study on analysis and testing of two wheeler suspension helical compression spring. The study on suspension system springs modelling, analysis and testing was carried out.
The present work discusses the behavior of the different parametric combinations of the leaf spring, the modal analysis is carried out using ANSYS software.

III. ANALYSIS OF LEAF SPRING

The material selected for analysis is Manganese Silicon Steel and variables such as thickness, camber, span and no. of leaves are considered as variables. Bending stress is computed under different loading conditions.

A. Material Properties of leaf spring

Material = Manganese Silicon Steel
Young's Modulus E = 2.1E5 N/mm^2
Density = 7.86E-6 kg/mm^3
Poisson's ratio = 0.3
Yield stress = 1680 N/mm^2

B. Geometric Properties of leaf spring

1) Variation of thickness

The thickness of leaves changes from 7 mm to 10 mm with the interval of 1mm, the lengths, radius of curvatures, rotation angles are computed. The Sample readings for thickness 7 mm are shown in table 1.
Thickness of leaves = 7 mm to 10 mm
Other parameters are taken as:
Camber = 80 mm
Span = 1220 mm
Number of leaves = 10
Number of full length leaves n_F = 2
Number of graduated length leaves n_G = 8
Width = 70mm
Ineffective length = 60 mm
Eye diameter = 20 mm
Bolt diameter = 10 mm

Table1. Length of leaves when thickness is 7 mm

Leaf number	Full leaf Length (mm)	Half leaf Length (mm)	Radius of Curvature (mm)	Half Rotation angle (degrees)
1	1240	620	2372.625	14.972
2	1240	620	2379.625	14.928
3	1108	554	2386.625	13.299
4	978	489	2393.625	11.708
5	846	423	2400.625	10.096
6	716	358	2407.625	8.519
7	584	292	2414.625	6.929
8	454	227	2421.625	5.371
9	322	161	2428.625	3.798
10	190	95	2436.625	2.235

2) Variation of camber

The camber varies from 80mm to 110 mm with the interval of 10mm, the lengths, radius of curvatures, rotation angles are computed. The Sample readings for Camber 80 mm are shown in table 2.
Camber = 80 mm to 110 mm
Span = 1220 mm
Thickness of leaves = 7 mm
Number of leaves = 10
Number of full length leaves = 2
Number of graduated length leaves = 8
Width = 70mm
Ineffective length = 60 mm
Eye diameter = 20 mm
Bolt diameter = 10 mm

Table2. Length of leaves when camber 80 mm

Leaf number	Full leaf Length (mm)	Half leaf Length (mm)	Radius of Curvature (mm)	Half Rotation angle (degrees)
1	1240	620	2372.625	14.972
2	1240	620	2379.625	14.928
3	1108	554	2386.625	13.299
4	978	489	2493.625	11.705
5	846	423	2400.625	10.096
6	716	358	2407.625	8.519
7	584	292	2414.625	6.929
8	454	227	2421.625	5.371
9	322	161	2428.625	3.798
10	190	95	2436.625	2.235

3) Variation of span

The span varies from 1120 mm to 1420 mm with the interval of 100 mm, the lengths, radius of curvatures, rotation angles are computed. The Sample readings for span of leaf spring 1120 mm are shown in table 3.
Span of leaf spring = 1120 mm to 1420 mm
Span = 1220 mm
Thickness of leaves = 7 mm
Number of leaves = 10

Number of full length leaves = 2
Number of graduated length leaves = 8
Width = 70mm
Ineffective length = 60 mm
Eye diameter = 20 mm
Bolt diameter = 10 mm

Table 3. Length of leaves when Span 1120 mm

Leaf number	Full leaf Length (mm)	Half leaf Length (mm)	Radius of Curvature (mm)	Half Rotation angle (degrees)
1	1140	570	2007	16.272
2	1140	570	2014	16.216
3	1020	510	2021	14.459
4	900	450	2028	12.714
5	780	390	2035	10.981
6	660	330	2042	9.259
7	540	270	2049	7.55
8	420	210	2056	5.852
9	300	150	2063	4.166
10	180	90	2070	2.489

4) Variation of no. of leaves

The number of leaves varies from 9 to 12 with the interval 1, the lengths, radius of curvatures, rotation angles are computed. The Sample readings for no. of leaves 9 are shown in table 4.
number of leaves = 9 to 12
Span = 1220 mm
Thickness of leaves = 7 mm
Number of leaves = 10
Number of full length leaves = 2
Number of graduated length leaves = 8
Width = 70mm
Ineffective length = 60 mm
Eye diameter = 20 mm
Bolt diameter = 10 mm

Table 4. Length of leaves when Number of leaves 9

Leaf number	Full leaf Length (mm)	Half leaf Length (mm)	Radius of Curvature (mm)	Half Rotation angle (degrees)
1	1240	620	1917.5	18.526
2	1240	620	1924.5	18.459
3	1092	546	1931.5	16.196
4	946	473	1938.5	13.980
5	798	399	1945.5	11.751
6	650	325	1952.5	9.537
7	502	251	1959.5	7.339
8	356	178	1966.5	5.186
9	208	104	1973.5	3.019

C. Bending Stress of leaf spring

The bending stress of a leaf spring may be obtained from the formula:

Static Bending stress $f = \frac{6WL}{bt^2\,(2n_G+3n_F)}$

Where W = Static Load in Newton
L = Half span of leave spring in mm.
b = width of the leaf spring in mm.
t = thickness of the leaf spring in mm.
n_G = number of graduated leaves.
n_F = number of full length leaves.

1) Geometric Properties of leaf spring

The geometrical properties are mentioned below:
Camber = 80 mm
Span = 1220 mm
Thickness = 7 mm
Width = 70 mm
Number of full length leaves n_F = 2
Number of graduated leaves n_G = 8
Total Number of leaves n = 10

2) Material Properties of leaf spring

The material properties of the leaf spring material are presented:
Material = Manganese Silicon Steel
Young's Modulus E = 2.1E5 N/mm^2
Density = 7.86E-6 kg/mm^3
Poisson's ratio = 0.3
Yield stress = 1680 N/mm^2

The bending stress for different loading conditions from 1000 N to 15000 N is given in the table 5.

Table 5 variation of Bending Stress with load

Load (N)	Bending Stress (N/mm^2)
1000	48.502
2000	97.005
3000	145.075
4000	194.010
5000	242.512
6000	291.015
7000	339.517
8000	388.020
9000	436.52
10000	485.025
11000	533.527
12000	582.03
13000	630.532
14000	679.035
15000	727.537

D. Modeling of Road Irregularity

An automobile assumed as a single degree of freedom system traveling on a sine wave road having wavelength of L as shown in Fig.2. The contour of the road acts as a support excitation on the suspension system of an automobile .The period is related to ω by $t = 2\pi/\omega$ and L is the distance traveled as the sine wave goes through one period.
$L = v.t = 2\pi v/\omega$.
so, Excitation frequency $\omega = 2\pi v/L$
L = width of the road irregularity (WRI)
V = speed of the vehicle
The variation of road irregularities is highly random. However a range of values is assumed for the present analysis i.e. 1m to 5m for the width of the road irregularity (L).

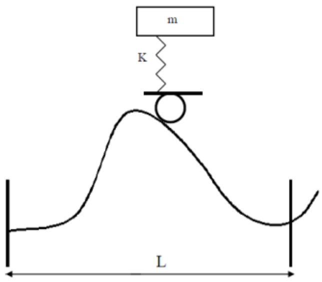

Fig 2. An automobile traveling on a sine wave road

1) Variation of Exciting Frequency with Vehicle Speed

The variation of exciting frequency with vehicle speed for assumed width of road irregularity. At low speeds the wheel of the vehicle passes over road irregularities and moves up and down to the same extent as the dimensions of the road irregularity. So, the frequency induced is less. If the speed increases and the change in the profile of the road irregularity is sudden, then the movement of the body and the rise of the axles which are attached to the leaf spring are opposed by the value of their own inertia. Hence, the frequency induced also increases. The exciting frequency is very high for the lower value of road irregularity width, because of sudden width. The following table 6 shows the variation of exciting frequency with vehicle speed.

Table 6. Variation of Exciting Frequency with Vehicle Speed

Speed (Kmph)	Frequency Hz (at WRI =1m)	Frequency Hz (at WRI = 2m)	Frequency Hz (at WRI =3m)	Frequency Hz (at WRI =4m)	Frequency Hz (at WRI =5m)
20	5.5500	2.77	1.8518	1.3888	1.11111
40	11.1111	5.54	3.7037	2.7777	2.22222
60	16.6666	8.31	5.5555	4.1664	3.33333
80	22.2222	11.08	7.4074	5.5552	4.44444
100	27.7777	13.85	9.2593	6.9440	5.55555
120	33.3333	16.66	11.1111	8.3333	6.66666
140	38.8888	19.44	12.9630	9.7222	7.77777

E. Geometric Modeling of Leaf Spring

The solid model of the leaf spring is modeled in CATIA software under part design module are shown in figures 3 and 4.

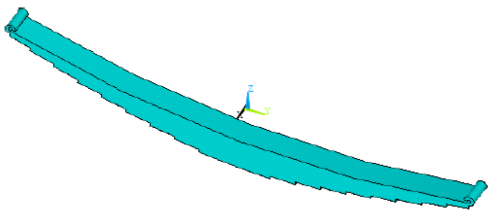

Fig 3. Full model of Leaf Spring

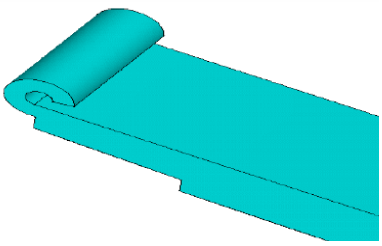

Fig 4. Front eye of the leaf spring

1) Analysis of leaf spring by ANSYS

The stress, strain analysis is carried out using ANSYS software under static loading conditions for a given specifications. The natural frequencies and mode shapes are computed performing the modal analysis to assess the behavior of the leaf spring with various parametric combinations. The element Solid 92: 3D- 10 Node Tetrahedral Structural solid with Rotations is considered for analysis. Solid92 has a quadratic displacement behavior and is well suited to model irregular meshes. The element is defined by ten nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element also has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities.

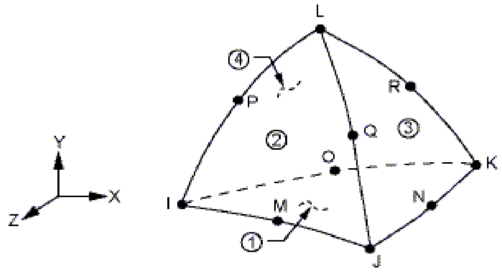

Fig 5. element Solid 92: 3D- 10 Node Tetrahedral Structural solid with Rotations

2) Static Analysis

Static analysis is to be performed to find the allowable stresses. The meshing and boundary conditions are given in ANSYS and are shown in Fig 6 and Fig7.

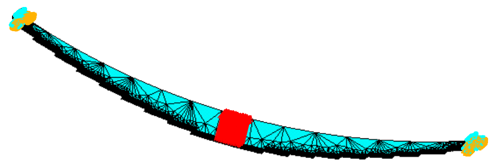

Fig. 6. Meshing, Boundary conditions and loading of leaf spring

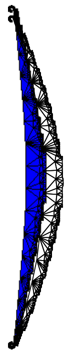

Fig.7. Deformed and undeformed shape of leaf spring

The Von-Mises stresses with different loading conditions are tabulated and presented in Table 7.

Table 7 variation of Von-Mises stress with load

Load (N)	Von-Mises Stress (N/mm^2)
1000	50.095
2000	101.856
3000	150.428
4000	200.712
5000	254.640
6000	305.150
7000	356.535
8000	407.469
9000	458.124
10000	509.928
11000	560.270
12000	611.204
13000	662.064
14000	713.071
15000	727.537

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IV. RESULTS AND DISCUSSIONS

A. Static Analysis

Static analysis is performed to find the Von-Mises stress by using ANSYS software and these results are compared with bending stresses calculated in mathematical analysis at various loads and are tabulated in Table 8.

Table 8 variation of Von-Mises stress with load – comparison between theoretical and ANSYS

Load (N)	Von-Mises stress N/mm^2	
	Theoretical	ANSYS
1000	48.502	50.095
2000	97.005	101.856
3000	145.075	150.428
4000	194.010	200.712
5000	242.512	254.640
6000	291.015	305.585
7000	339.517	356.565
8000	388.020	407.469
9000	436.520	458.124
10000	485.025	509.928
11000	533.527	560.270
12000	582.030	611.204
13000	630.532	662.264
14000	679.035	703.071
15000	727.537	764.005

From Theoretical and ANSYS the allowable design stress is found between the corresponding loads 8000 to 10000 N, the near corresponding safe loads are given in Table 9.

Table 9. Von-Mises stress under different loading conditions – Comparison between Theoretical and ANSYS

Load (N)	Von-Mises stress N/mm^2	
	Theoretical	ANSYS
9500	460.770	481.916
9700	470.470	494.565
9900	480.174	504.243

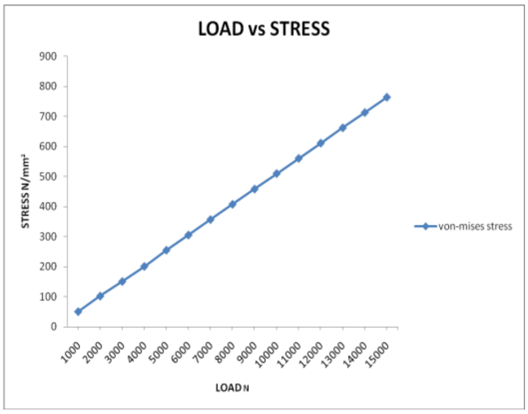

Fig 8 Variation of Von-mises stress with load

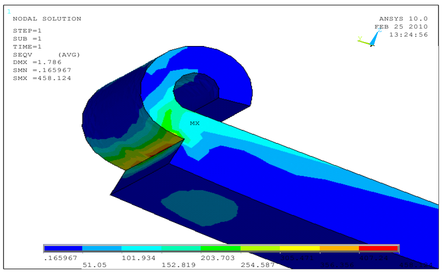

Fig. 9 Von-mises Stress contour plot of Front eye of leaf spring

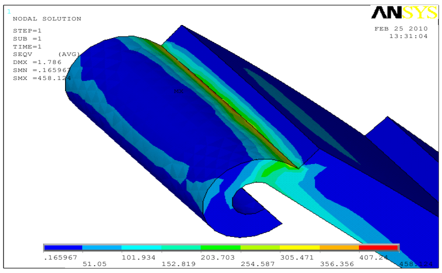

Fig. 10. Von-mises Stress contour plot of Rear eye of leaf spring

B. Modal Analysis

From the leaf spring specification width is fixed and other parameters namely thickness, camber, span and number of leaves are taken for parametric variation. First ten modes are considered for analysis. Variations of natural frequencies with spring parameters are studied.

1) Variation of natural frequency with span

The variation of natural frequency is computed with different span and tabulated in Table 10 and variations of arc radius are shown in Table 11.

Table 10. Variation of natural frequency with Span

Frequency Hz at	Span in mm			
	1120	1220	1320	1420
Mode 1	2.464	2.362	2.038	1.741
Mode 2	3.700	3.624	3.053	2.603
Mode 3	7.168	6.874	5.916	5.042
Mode 4	14.409	14.240	12.192	10.416
Mode 5	15.553	15.412	14.862	12.995
Mode 6	18.224	17.652	15.246	13.413
Mode 7	26.208	25.596	23.181	20.292
Mode 8	31.377	31.126	26.798	22.968
Mode 9	31.690	31.149	27.889	24.651
Mode 10	46.567	45.532	39.470	33.549

Table 11. Variation of Arc radius with Span

Span in mm	Arc radius in mm
1120	2000.000
1220	2365.600
1320	2762.500
1420	3190.625

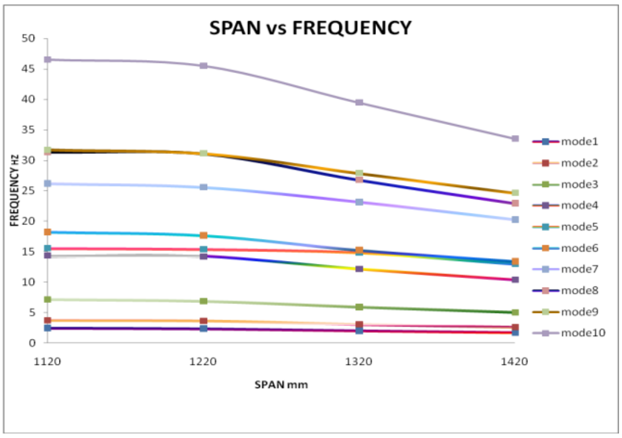

Fig. 11. Frequency vs span for different modes

It is observed from the Fig 11. that, when span increases the spring becomes soft and hence the natural frequency decreases. Every three modes are in one set of range. There is a considerable gap between mode3 to mode4, mode6 to mode 7 and mode 9 to mode10. It is observed from the Fig. 8.4 that the decrease of frequency value with the increase of span is very high for mode10 compared to remaining modes.

2) Variation of natural frequency with camber

The variation of natural frequency is computed with different span and tabulated in Table 12 and variations of arc radius are shown in Table 13.

Table 12. Variation of natural frequency with Camber

	Camber in mm			
Frequency Hz at	80	90	100	110
Mode 1	2.362	2.344	2.344	2.414
Mode 2	3.624	3.527	3.446	3.571
Mode 3	6.874	6.791	6.760	7.063
Mode 4	14.240	14.107	13.988	14.361
Mode 5	15.412	16.006	16.642	15.395
Mode 6	17.652	17.506	17.458	18.122
Mode 7	25.596	25.625	25.741	27.007
Mode 8	31.126	30.895	30.702	30.557
Mode 9	31.149	31.215	31.391	31.667
Mode 10	45.532	45.241	45.109	45.915

Table 13. Variation of Arc radius with Camber

Camber in mm	Arc radius in mm
80	2165.60
90	2112.20
100	1910.50
110	1746.36

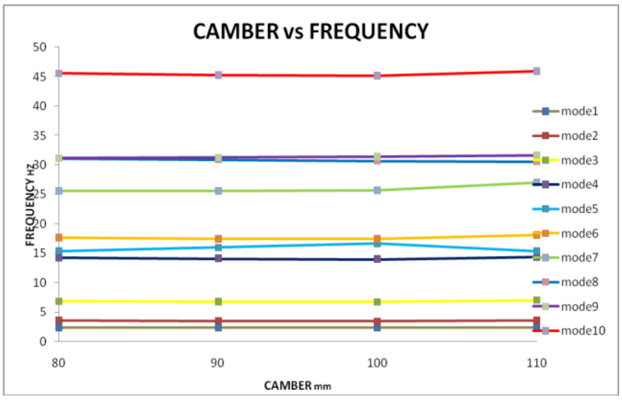

Fig. 12. Frequency vs Camber for different modes

It is noticed from the Fig 12 that it shows the variation of natural frequency with camber. When camber increases the spring becomes stiff and hence the natural frequency increases. Every three modes are almost in one set of range. There is a considerable gap between mode 3 to mode4, mode6 to mode 7 and mode 9 to mode 10. It is observed from the *Fig.12* that the increase of frequency value with the increase of camber is very high for mode 10 compared to remaining modes.

3) Variation of natural frequency with thickness

The variation of natural frequency is computed with different span and tabulated in Table 14.

Table 14. Variation of natural frequency with thickness

	Thickness in mm			
Frequency Hz at	7	8	9	10
Mode 1	2.362	2.744	2.945	3.270
Mode 2	3.624	3.697	3.650	3.702
Mode 3	6.874	7.950	8.502	9.403
Mode 4	14.240	14.293	14.092	14.116
Mode 5	15.412	15.710	15.656	15.736
Mode 6	17.652	20.244	21.716	23.691
Mode 7	25.596	26.669	26.678	27.275
Mode 8	31.126	31.233	30.955	31.004
Mode 9	31.149	34.630	37.249	40.714
Mode 10	45.532	51.608	51.091	51.025

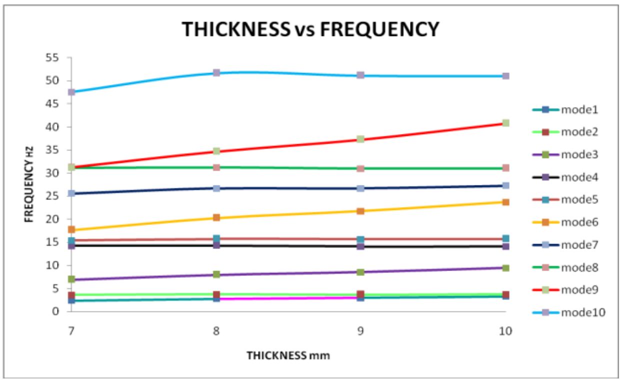

Fig. 13. Frequency vs Camber for different modes

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It is observed from the Fig 13. that it shows the variation of natural frequency with thickness of the spring. When thickness increases the natural frequency also increases. Its natural frequency increases like variation of natural frequency with camber, but with thickness the natural frequency increasing rate is lesser than that of variation of natural frequency with camber. Every three modes are almost in one set of range. There is a considerable gap between mode3 to mode4, mode6 to mode 7 and mode 9 to mode 10.It is observed from Fig. 13 that the increase of frequency value with the increase of thickness is very high for mode9 and mode10 compared to remaining modes.

4) Variation of natural frequency with number of leaves

The variation of natural frequency is computed with different span and tabulated in Table 15.

Table 15 variation of natural frequency with number of leaves

	No. of leaves			
Frequency Hz at	9	10	11	12
Mode 1	2.240	2.362	2.527	2.559
Mode 2	3.571	3.624	3.440	3.285
Mode 3	6.506	6.874	7.262	7.301
Mode 4	14.202	14.240	14.006	13.720
Mode 5	16.473	15.412	16.410	15.887
Mode 6	17.044	17.652	18.873	19.360
Mode 7	25.060	25.596	26.346	26.188
Mode 8	30.567	31.126	30.789	30.446
Mode 9	30.906	31.149	33.002	33.751
Mode 10	42.669	45.532	48.544	50.096

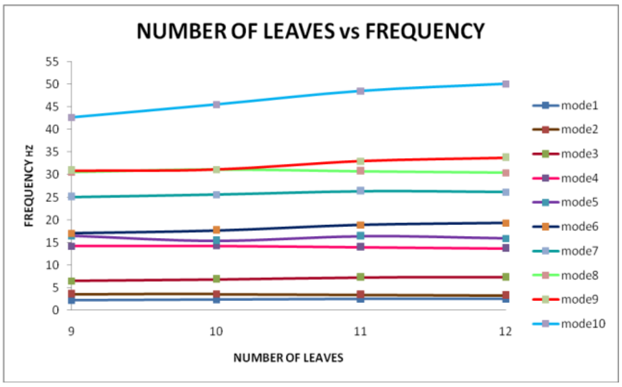

Fig. 14. Frequency vs No. of leaves for different modes

Figure 14 shows the variation of natural frequency with number of leaves of the spring. Even though the number of leaves increases there is no considerable increase in natural frequency, it is almost constant. It is observed from the Fig.14 every three modes are in gradual increment, there is considerable increase in natural frequency from mode3 to mode4, there is much increase in natural frequency from mode6 to mode7 and there is very much in increase in natural frequency from mode 9 to mode 10.

The mode shapes for modes 1, 3 & 10 and for different parameters like Camber, Span, Thickness of leaves and number of leaves are presented in the following Figures 15 to 23.

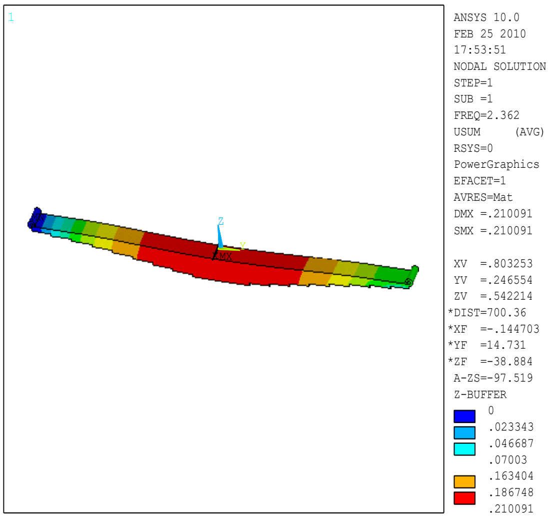

Fig.15 Mode 1 (Camber 80 mm, Span 1220 mm)

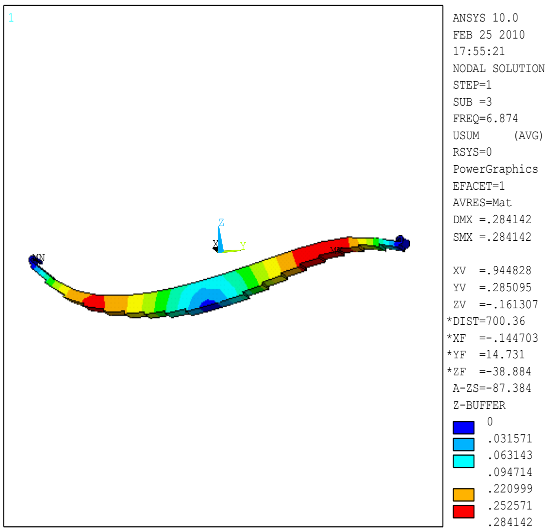

Fig. 16 Mode 3 (Camber 80 mm, Span 1220 mm)

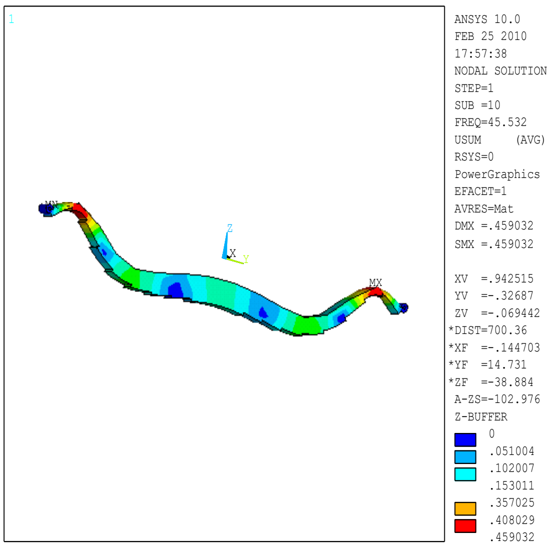

Fig. 17. Mode 10 (Camber 80 mm, Span 1220 mm)

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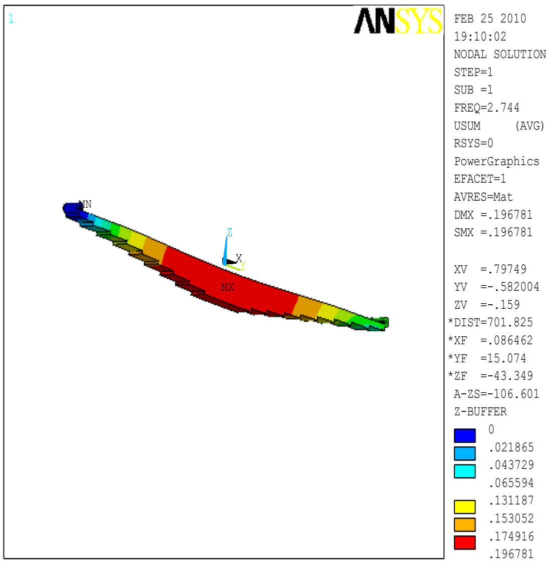

Fig. 18. Mode 1 (Thickness 8 mm)

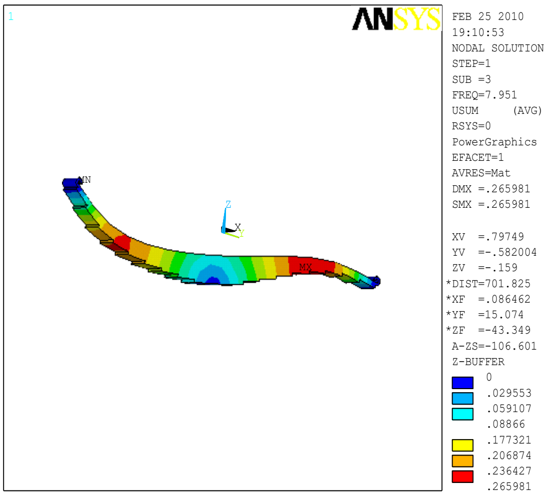

Fig. 19. Mode 3 (Thickness 8 mm)

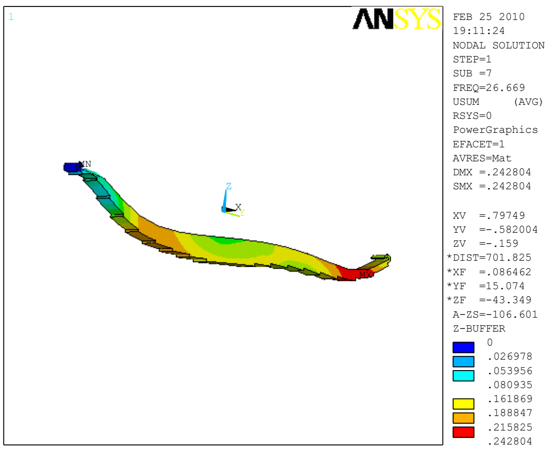

Fig. 20. Mode 7 (Thickness 8 mm)

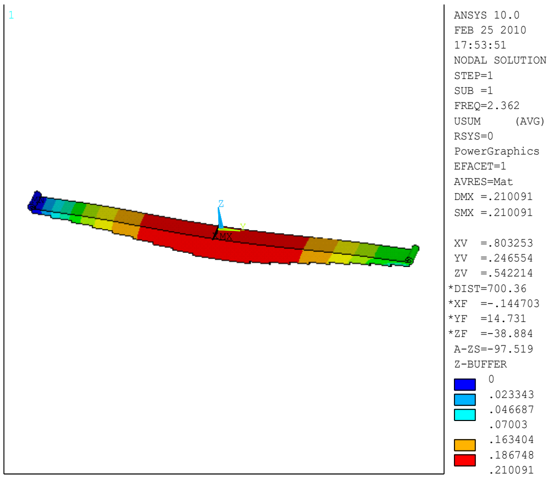

Fig. 21. Mode 1 (umber of leaves 10)

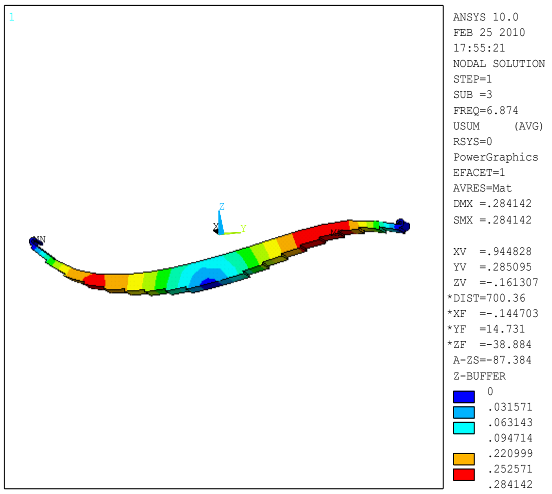

Fig. 22. Mode 3 (Number of leaves 10)

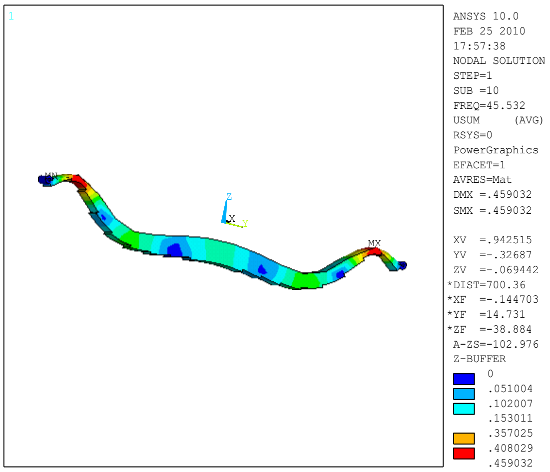

Fig. 23. Mode 10 (Number of leaves 10)

The following table shows the variation of exciting frequency with vehicle speed.

Table 16 variation of natural frequency with vehicle speed

Speed in Kmph	Frequency at WRI = 1 m	Frequency at WRI = 2 m	Frequency at WRI = 3 m	Frequency at WRI = 4 m	Frequency at WRI = 5 m
20	5.5500	2.77	1.8518	1.3888	1.11111
40	11.1111	5.54	3.7037	2.7777	2.22222
60	16.6666	8.31	5.5555	4.1664	3.33333
80	22.2222	11.08	7.4074	5.5552	4.44444
100	27.7777	13.85	9.2593	6.9440	5.55555
120	33.3333	16.66	11.1111	8.3333	6.66666
140	38.8890	19.44	12.9630	9.7222	7.77777

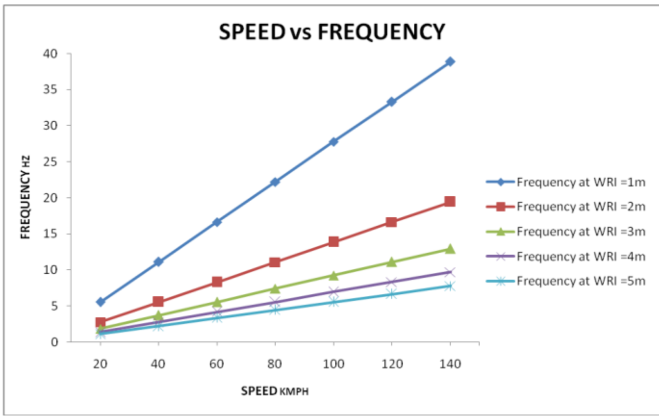

Fig 24. Variation of Excitation frequency with vehicle speed (wri = width of road irregularity in meters)

The variation of exciting frequency is computed with vehicle speed as parameter under dynamic conditions, for assumed width of road Irregularity. At low speeds the wheel of the vehicle passes over road irregularities and moves up and down to the same extent as the dimensions of the road irregularity.

So, the frequency induced is less. If the speed increases and the change in the profile of the road irregularity are sudden, then the movement of the body and the rise of the axles which are attached to the leaf spring are opposed by the value of their own inertia. Hence, the frequency induced also increases. The exciting frequency is very high for the lower value of road irregularity width, because of sudden width.

It is noted that the some of the excitation frequencies are very close to natural frequencies of the leaf spring, but they are not exactly matched, hence no resonance will take place.

V. CONCLUSIONS AND FUTURE SCOPE OF WORK

The leaf spring is considered for analysis under static and dynamic loading conditions. The spring is modeled using CATIA software and analysis is carried out in ANSYS for different loading conditions. The following conclusions are made.

- The Leaf spring has been modeled using solid tetrahedron 10 node element.
- By performing static analysis it is concluded that the maximum safe load is 9900 N for the given specification of the leaf spring from the analysis.
- In model analysis, the leaf spring width is kept as constant and variation of natural frequency with leaf thickness, span, camber and numbers of leafs are studied.
- It is observed from the present work that the natural frequency increases with the increase of thickness of leaves as well as camber, and decreases with decrease of thickness of leaves as well as camber.
- The natural frequency decreases with increase of span, and increases with decrease of span.
- The natural frequency almost constant with number of leaves.
- The natural frequencies of various parametric combinations are compared with the excitation frequency for different road irregularities.
- This study concludes that it is advisable to operate the vehicle such that its excitation frequency does not match the above determined natural frequencies i.e. the excitation frequency should fall between any two natural frequencies of the leaf spring.
- An extended study of this nature can be used along with appropriate sensors and microprocessors to enable achievement of optimum speed at which one can drive the vehicle with maximum comfort.
- In this work no contact elements are considered only nodal coupling has taken, instead of nodal coupling contact elements can be considered.
- Also, instead of steel leaf springs the composite material can be considered to optimize the cost and weight of the vehicle through experimental setup.

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