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Design & Static Analysis of Steel, Glass/Epoxy Mono Leaf Spring of Same Stiffness for Shifting Natural Frequency to Reduce the Vibrations

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Abstract—The objective is to present experimentation, modeling and analysis of steel, Glass/Epoxy mono leaf spring for Static, analysis and compare its results. Static experimentation is carried out using UTM (Universal testing machine) and static analysis is carried out by using ANSYS 13.0 software for better understanding.. Modeling is done using Pro-E (Wild Fire) 4.0 From the study, it is seen that the GLASS FIBRE/E-POXY leaf spring weight is 2.7 times less as compared to steel leaf spring for same stiffness (same load carrying capacity). GLASS FIBRE/E-POXY natural frequency is 1.93 times more as compared to steel leaf spring for same stiffness.

Keywords - Composite Leaf Springs; Glass Fiber Reinforced Plastic (CFRP); Static load condition; Ride comfort; Static analysis; Suspension system; Natural frequency.

I. INTRODUCTION

Increasing competition and innovations in automobile sector tends to modify the existing products or replacing old products by new and advanced material products. A suspension system of vehicle is also an area where these innovations are carried out regularly. More efforts are taken in order to increase the comfort of user. Appropriate balance of comfort riding qualities and economy in manufacturing of leaf spring becomes an obvious necessity. To improve the suspension system many modification have taken place over the time. Inventions of parabolic leaf spring, use of composite materials for these springs are some of these latest modifications in suspension systems [1].This project is mainly focused on the implementation of composite materials by replacing steel in conventional leaf springs of a suspension system. A spring is defined as an elastic body, whose function is to distort when loaded and to recovers its original shape when the load is removed. Semi-elliptic mono leaf springs are almost universally used for suspension in light and heavy commercial vehicles. For cars also, these are widely used in rear suspension.

II. DESIGN OF CARBON FIBRE/E-POXY MONO-LEAF SPRING

Considering several types of vehicles that have leaf springs and different loading on them, various kinds of composite leaf spring have been developed. In multi-leaf composite leaf spring, the interleaf spring friction plays a spoil spot in damage tolerance. It has to be studied carefully.

The following cross-sections of mono-leaf composite leaf spring for manufacturing easiness are considered.

- *A.* Constant thickness, constant width design.
- *B.* Constant thickness, varying width design.
- *C.* Varying width, varying thickness design.[2].

In this paper, a mono-leaf composite leaf spring with varying width and varying thickness is designed and manufactured. Computer algorithm using C-language has been used for the design of same stiffness Leaf spring. The results showed that a spring width decreases hyperbolically and thickness increases linearly from the spring eyes towards the axle seat. The parameters at center and end points for composite leaf spring are shown in Table I. The design parameters for composite leaf spring are shown in table II. The material properties of Carbon fiber/Epoxy are listed in Table III.

Table I. Parameters at center and end points for composite leaf spring

Parameters	At center	At end
Breadth in mm	13.5	23
Thickness in mm	06	1.80

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A. Dimensions of Composite Leaf Spring

Table II. Design Parameter for composite leaf spring

Sr. No.	Parameters	Dimensions (mm)
1	Width at the center	13.5
2	Width at the end	23
3	Thickness at the center	06
4	Thickness at the end	1.80
5	Free camber	17.50
6	Total length without	280

Table III. Material properties of Carbon fiber/E-Poxy

Sr. No	Properties	Value
1	Tensile modulus along X-direction (Ex), MPa	45000
2	Tensile modulus along Y-direction (Ey), MPa	10000
3	Tensile modulus along Z-direction (Ez), MPa	10000
4	Shear modulus along XY-direction (Gxy), MPa	5000
5	Shear modulus along YZ-direction (Gyz), MPa	3846.2
6	Shear modulus along ZX-direction (Gzx), MPa	5000
7	Poisson ratio along XY-direction (NUxy)	0.3
8	Poisson ratio along YZ-direction (NUyz)	0.4
9	Poisson ratio along ZX-direction (NUzx)	0.3

B. Design of Steel Mono-Leaf Spring

1) *Materials of Steel leaf spring:* The material used for leaf spring is usually a plain carbon steel having 0.90 to 1.0% carbon. The leaves are 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.

According to Indian standards, the recommended materials are:

a) For automobiles : 50 Cr 1, 50 Cr 1 V 23, and 55 Si 2 Mn 90 all used in hardened and tempered state.

b) For rail road springs: C 55 (water-hardened), C 75 (oil-hardened), 40 Si 2 Mn 90 (water-hardened) and 55 Si 2 Mn 90 (oil-hardened) [3].

Table IV. The material properties for steel leaf springs

Sr. No.	Parameter	Descriptions
1	Material	SiMn Steel
2	Young's Modulus E	2.1×10^5 N/mm^2
3	Density ρ	7.86×10^{-6} kg/mm^3
4	Poisson's ration	0.3
5	Yield stress	1680 N/mm^2

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Table V. Design Parameters for steel leaf spring

Sr. No.	Parameters	Dimensions (mm)
1	Width at the center	13.5
2	Width at the end	23
3	Thickness at the center	5.5
4	Thickness at the end	1.60
5	Free camber	17.50
6	Total length without eye	280

III. TESTING OF COMPOSITE AND STEEL MONO LEAF SPRING FOR LOAD, DEFLECTION

The steel and composite leaf springs are tested by using UTM. The experimental set up is shown in Figs. 4.1 the leaf springs are tested following standard procedures recommended by SAE. The spring to be tested is examined for any defects like cracks, surface abnormalities, etc. The spring is loaded from zero to the prescribed maximum deflection and back to zero. The load is applied at the centre of spring; the vertical deflection of the spring centre is recorded in the load interval of 0.5 Kg.

Fig. 1. Static test set up for both composite and steel leaf spring.

Table VI. The Load, Deflection for steel & composite

Sr. No.	Load	Deflection (mm)	
		Steel	Composite
1	4.9	0.83	0.43
2	9.81	1.28	0.82
3	14.71	1.71	1.4
4	19.62	2.07	2.09
5	24.52	2.89	2.44
6	29.43	3.43	3.09
7	34.33	3.93	3.88
8	39.24	5.15	4.47
9	44.14	5.71	5.15
10	49.05	6.02	6.01

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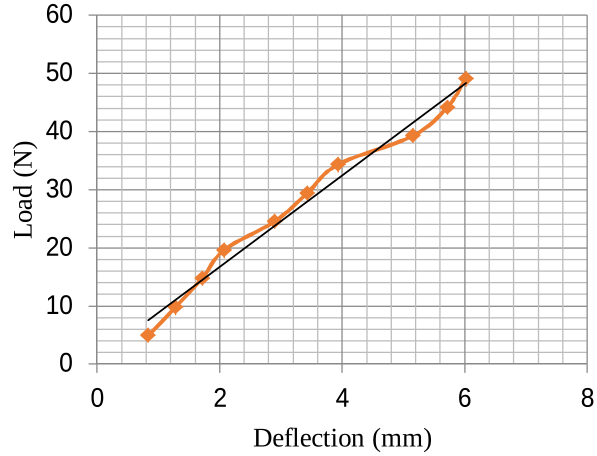

Fig. 2. The load, deflection curve for steel

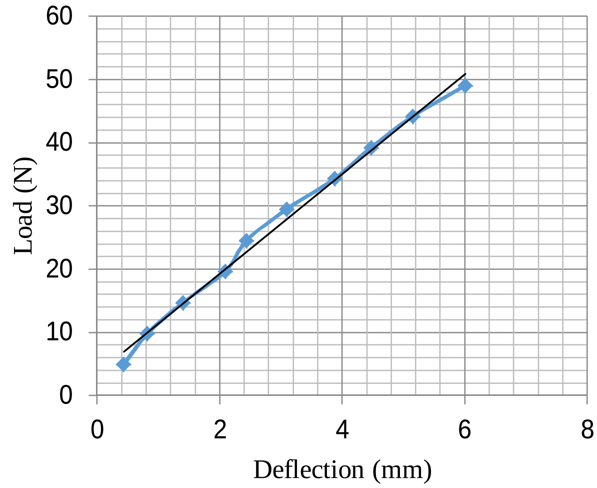

Fig. 3. The load, deflection curve for composite.

IV. THREE-DIMENSIONAL FINITE ELEMENT ANALYSIS OF SPRING

Modeling is done using Pro-E (Wild Fire) 4.0 and Analysis is carried out by using ANSYS 13.0 software for better understanding. SOLID187 element is used for analysis. SOLID187 element is a higher order 3-D, 10-node element. SOLID187 has a quadratic displacement behavior and is well suited to modeling irregular meshes (such as those produced from various CAD/CAM systems). The element is defined by 10 nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, hyperelasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyperelastic materials. The MPC184 rigid link/beam element can be used to model a rigid constraint between two deformable bodies or as a rigid component used to transmit forces and moments in engineering applications. This element is well suited for linear, large rotation, and/or large strain nonlinear applications [4].

Analysis is carried out for composite leaf spring with eyes and the results were compared with steel leaf spring with eye end. Figure 2. and 3. represent FEA results for steel and mono composite leaf spring (Glass Fiber/Epoxy). The load, deflection for Glass Fiber/Epoxy and for steel were measured and plotted as shown in Figure 4. and 5.

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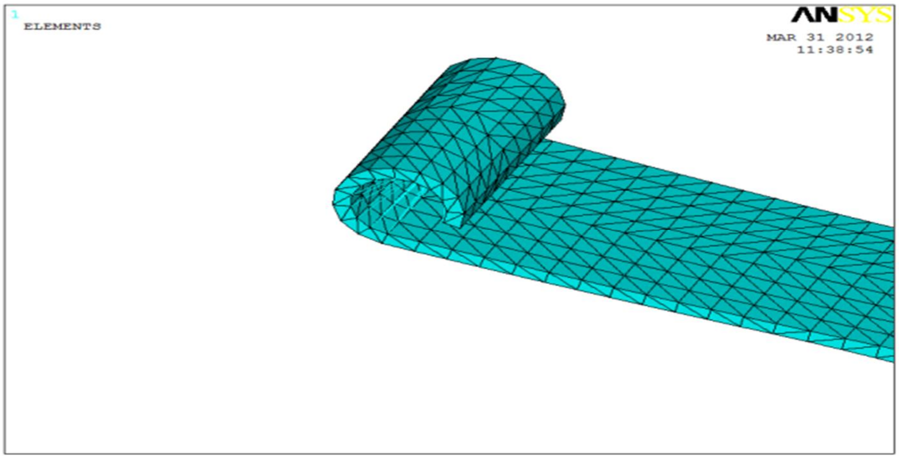

Fig. 4. Meshed Model

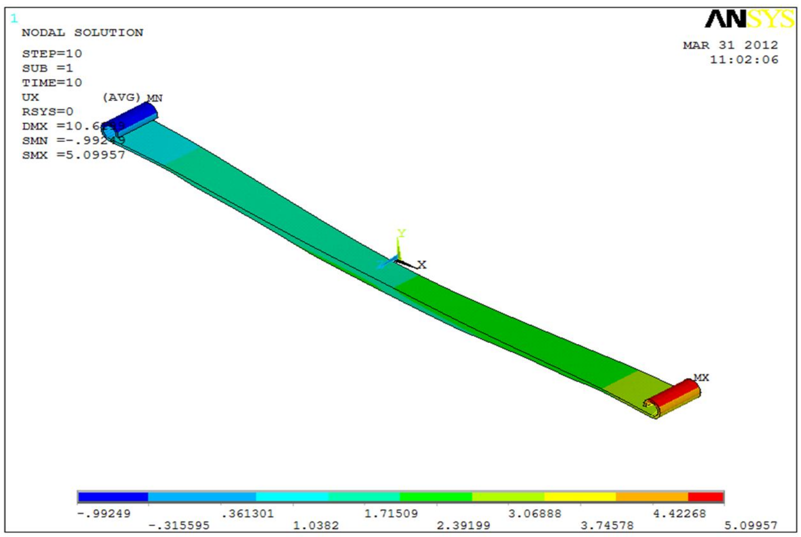

Fig. 5. Load Applied 49.05 N on composite spring

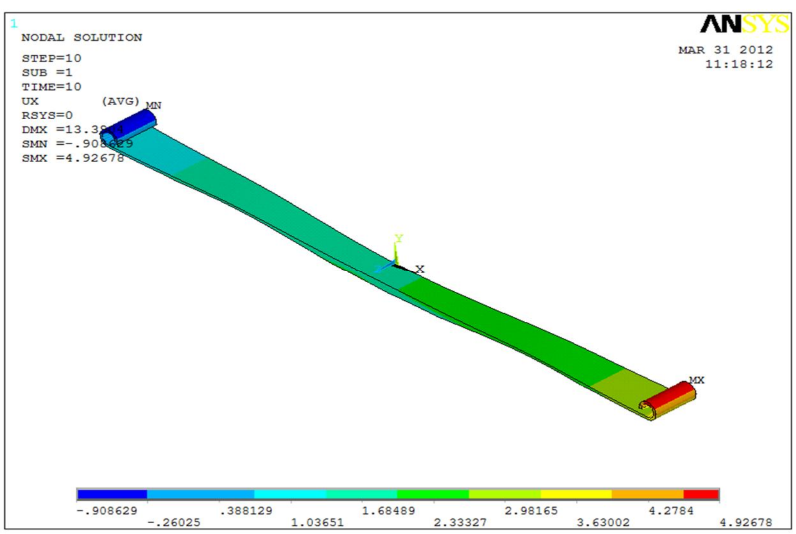

Fig. 6. Load Applied 49.05 N on steel spring

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Table VII. The load, deflection of steel & Composite spring.

Sr. No.	Load	Deflection (mm)	
		Steel	Composite
1	4.9	0.66	0.611
2	9.81	1.28	1.2
3	14.71	1.87	1.77
4	19.62	2.43	2.32
5	24.52	2.94	2.85
6	29.43	3.42	3.35
7	34.33	3.86	3.83
8	39.24	4.26	4.28
9	44.14	4.61	4.7
10	49.05	4.92	5.1

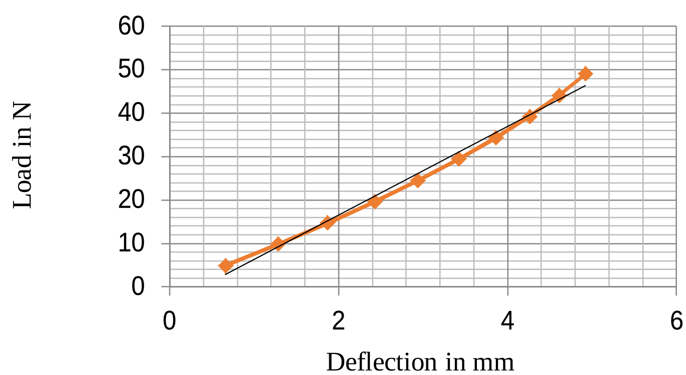

Fig. 7. The load, deflection curve for steel

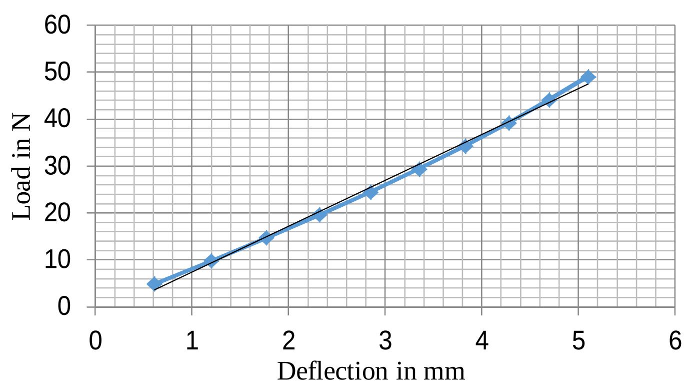

Fig. 8. The load, deflection curve forcomposite.

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Stiffness of both spring is calculated by taking the slope of the graph of load vs. Deflection which are listed in table 8.

Table VIII. Stiffness of both springs

Sr. No.	Parameters	Stiffness in N/m	
		Experimental	FEA
1	Stiffness of steel spring	7727	8200
2	Stiffness of composite	7741	8200

V. DYNAMIC ANALYSIS

When elastic bodies such as a spring, a beam and a shaft are displaced from the equilibrium position by the application of external forces, and then released, they execute a vibratory motion. This is due to the reason that, when a body is displaced, the internal forces in the form of elastic or strain energy are present in the body. At release, these forces bring the body to its original position. When the body reaches the equilibrium position, the whole of the elastic or strain energy is converted into kinetic energy due to which the body continues to move in the opposite direction. The whole of the kinetic energy is again converted into strain energy due to which the body again returns to the equilibrium position. In this way, the vibratory motion is repeated indefinitely.

There are two general cases of vibrations called free and forced vibrations. Free vibrations, takes place when a system oscillates under the action of forces inherent in the system itself, and when external impressed forces are absent. The system under free vibration will vibrate at one or more of its natural frequencies, which are properties of the dynamical system established by its mass and stiffness distribution.

Vibration taking place under the excitations of external forces is called forced vibration. When the excitation is oscillatory, the system is forced to vibrate at the excitation frequency. If the frequency of the excitation coincides with one of the natural frequencies of the system, the condition of resonance is encountered, and large oscillations may result. The failure of major structures, such as bridges, buildings or airplane wings, is an awesome possibility under resonance. Thus, the calculations of natural frequencies are very important [5].

A. *Calculation for Natural Frequency*

1) *Natural frequency of composite leaf spring*

Natural frequency, $$f_n = \frac{1}{t_p} = \frac{1}{2\pi}\sqrt{\frac{k}{m_{eff}}}$$

$$= \frac{1}{2\pi}\sqrt{\frac{7741}{0.040 \times 0.486}}$$

$$= 100.43 \text{ Hz}$$

2) *Natural frequency of steel leaf spring*

Natural frequency, $$f_n = \frac{1}{t_p} = \frac{1}{2\pi}\sqrt{\frac{k}{m_{eff}}}$$

$$= \frac{1}{2\pi}\sqrt{\frac{7727}{0.108 \times 0.486}}$$

$$= 61.07 \text{ Hz}$$

Where, k= spring stiffness in N/m

m_{eff} = effective mass in kg.

It is given by the formula

$$m_{eff} = R_{end} \times m_{beam}$$

According to, Rayleigh Effective Mass Concept for a simple beam in its first bending mode, R_{end} is approximately 0.384 with fixed ends, 0.486 simply supported and 0.775 cantilevered.

B. *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.

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6.4 the contour of the road acts as a support excitation on the suspension system of an automobile. The period is related to ω by $\frac{2\pi}{\omega}$ and L is the distance traveled as the sine wave goes through one period.

$$L = v.t = \frac{2\pi v}{\omega}$$

So, Excitation frequency $\omega = \frac{2\pi v}{L}$

L = width of the road irregularity (WRI)

V = speed of the vehicle

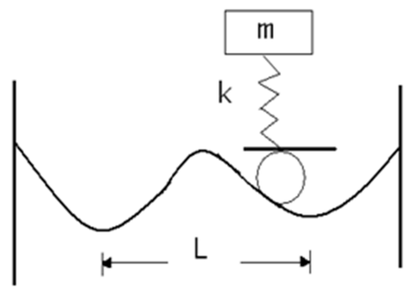

Fig. 9 An automobile traveling on a sine wave road

The variation of road irregularities is highly random however a range of values is assumed for the present analysis i.e., 0.5 m to 5 m for the width of the road irregularity (L).

C. 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 is 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 steel leaf spring, hence resonance will takes place.

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

Table IX Variation of Exciting Frequency with Vehicle Speed

Speed (Kmph)	Frequency Hz (at WRI = .5m)	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	11.1111	5.5500	2.7777	1.8518	1.3888	1.1111
40	22.2222	11.1111	5.5555	3.7037	2.7777	2.2222
60	33.3333	16.6666	8.3333	5.5555	4.1664	3.3333
80	44.4444	22.2222	11.1111	7.4074	5.5555	4.4444
100	55.5555	27.7777	13.8888	9.2593	6.9440	5.5555

C. Model Calculation for Excitation Frequency

$$\text{Speed } v = 100 \text{ kmph} = \frac{100\times1000}{3600} = 27.77 \text{ m/s}$$

WRI, L= 1 m

$$\text{So, Excitation frequency } \omega = \frac{2\pi v}{L} \text{ rad/s}$$

$$\text{Excitation frequency } \omega = \frac{2\pi v}{2\pi \times L} \text{ Hz}$$
$$= \frac{2\pi \times 27.77}{2\pi} \text{ Hz}$$
$$= 27.77 \text{ Hz}$$

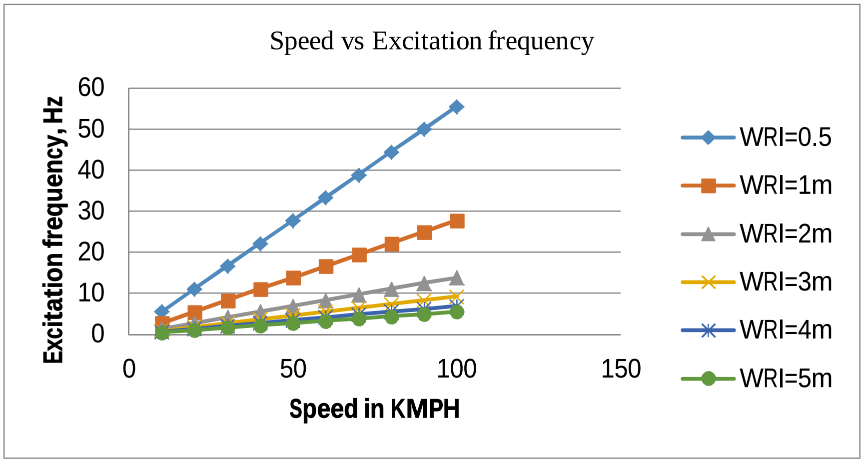

Fig. 10 Speed vs. Excitation frequency

VI. RESULTS AND DISCUSSIONS

The objective of this project was to evaluate the applicability of a composite leaf spring in automobiles by considering riding comfort. The comparison between steel leaf spring and composite leaf spring is made for the same stiffness and loading conditions. The comparison is based on four major aspects such as weight, riding comfort, cost and strength.

A. Comparison of Weight

The total weight of composite leaf spring is 29 gm excluding the metal eye weight of 12 gm. The weight of a convectional steel spring assembly is around 108 gm. So, around 270% of weight reduction is achieved. Thus the objective of reducing the unsprung mass is achieved to a larger extent.

B. Comparison Based on Riding Qualities

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 55 Hz. Therefore the leaf spring should be designed to have a natural frequency, which is away from 55 Hz to avoid the resonance (poor ride comfort zone). It is found that the first natural frequency of composite leaf spring is nearly 2 times the maximum road frequency and therefore resonance will not occur. Therefore it is obvious that composite leaf spring provides improved ride comfort. The weight reduction of unsprung mass of an automobile will improve the riding quality. The suspension leaf contributes 10% - 20% of the unsprung mass. The weight of the composite leaf spring is 2.7 times less than steel leaf spring. Hence the riding comfort of an automobile is increased due to the replacement of the steel leaf spring by composite leaf spring. Also damping ratio of composite leaf spring is far more than conventional leaf spring, which will provide increased riding comfort.

C. Comparison Of Natural Frequency

GLASS FIBRE/E-POXY natural frequency is 1.92 times more as compared to steel leaf spring for same stiffness.

D. Cost comparison

The cost estimation of composite leaf spring provides a clear economic viability of the product in comparison to that of a convectional leaf spring.

VII. CONCLUSIONS

The conclusions drawn from the analysis carried out are as follows:

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A. The 3-D modeling of both steel and GLASS FIBRE/E-POXY leaf spring is done and analysed using ANSYS;
B. GLASS FIBRE/E-POXY leaf spring can be used on smooth roads & also on rough road with very high performance.
C. The study demonstrated that composites can be used for leaf springs for light weight vehicles for improved ride cofort.
D. A comparative study has been made between composite and steel leaf spring with respect to weight, Natural frequency.
E. From the results, it is observed that the composite leaf spring is lighter and more economical than the conventional steel spring with similar stiffness.

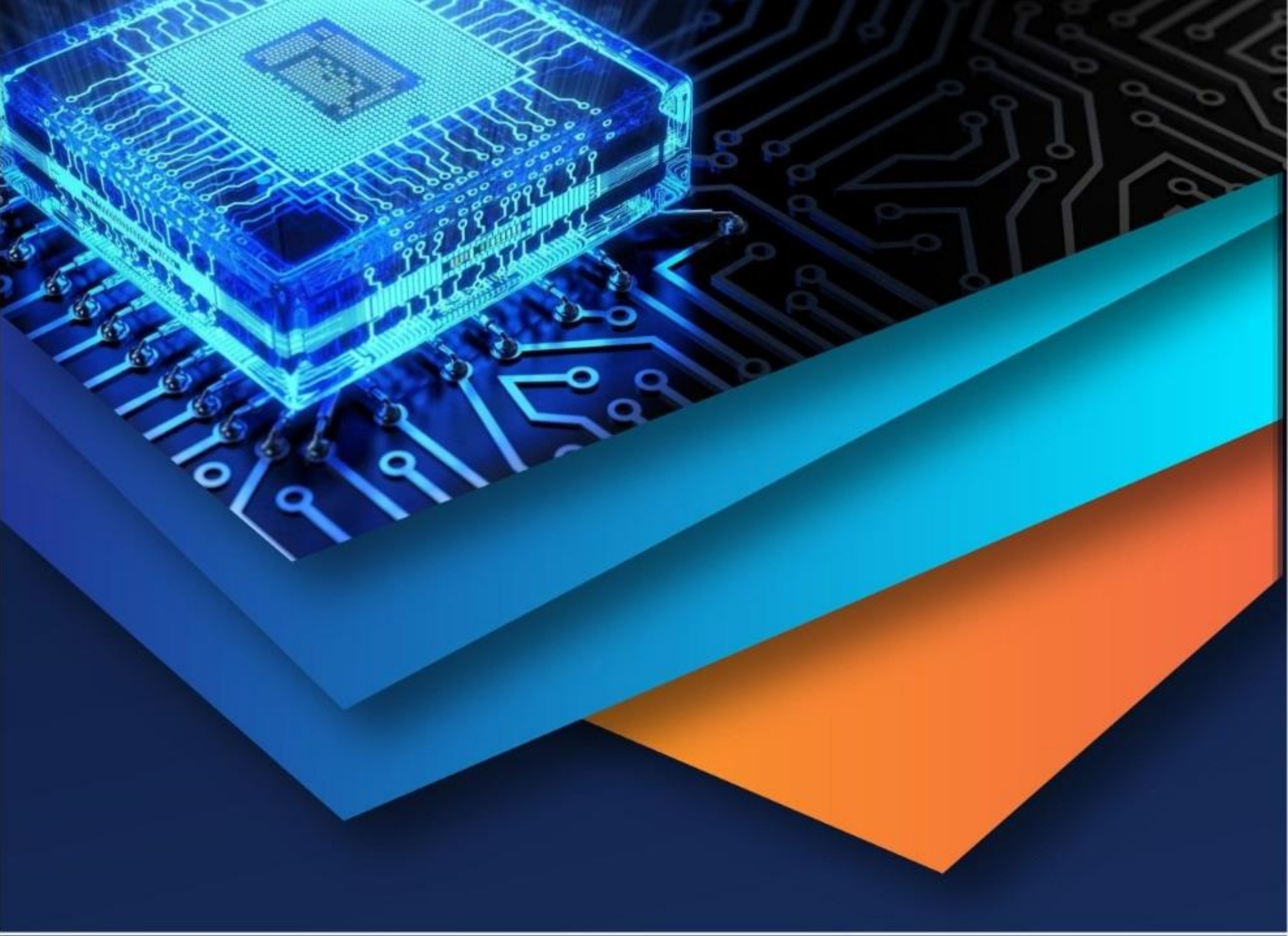
VIII. FUTURE SCOPE

After carrying out the work, it is found that following things can be added as an extension to this work.

A. Experimental work is carried out on small scale model, one can go for full scale model using shaker for dynamic analysis.
B. Experimental work is carried out in laboratory condition; one can go for actual road condition test.
C. Static analysis is done only for calculating stiffness, by using strain gauges one can find out stresses developed in both leaf spring.

REFERENCES

[1] M.M. Patunkar,D.R. Dolas, "Modelling and Analysis of Composite Leaf Spring under the Static Load Condition by Using FEA",International Journal of Mechanical & Industrial Engg.,Volume 1 Issue 1-2011.
[2] ANSYS V 13.0 Help for FEA Analysis.
[3] R.S. Khurmi, J.K. Gupta, "Theory of Machines",S. Chand Pub. Forteenth Edition ,2010.
[4] Gulur Siddaramanna SHIVA SHANKAR, sambagam VIJAYARANGAN, "Mono composite leaf spring for light weight vehicle-Design End joint analysis and testing", ISSN 1392-1320 MATERIALS SCIENCE (MEDZIAGOTYRA). Vol. 12, No.3. 2006.
[5] Mouleeswaran SENTHIL KUMAR, Sabapathy VIJAYRANGAN, "Analytical and Experimental studies on Fatigue Life prediction
[6] of Steel and Composite Multi-leaf for Light Passenger Vehicles Using life data analysis", ISSN 1392-1320 MATERIALS
[7] SCIENCE (MEDZIAGOTYRA). Vol. 13, No. 2. 2007.
[8] Al-Qureshi, H.A., "Automobile leaf springs from Composite materials", Journal of Materials Processing Technology, 118(1- 3):pp.58-
[9] 61. [doi:10.1016/S0924-0136(01) 00863-9]
[10] Mahdi, E., Alkoles, O.M.S., Hamouda, A.M.S., Sahari, B.B., Yonus, R., Goudah, G., "Light composite elliptic springs for vehicle
[11] suspension", Composite Structures, 75(1-4): pp.24-28. [doi:10.1016/j.compstruct.2006.04.082]



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