Theoretical and Numerical Studies on Stress Analysis of Conventional Leaf Spring by Wrapping Composite Material on It

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Abstract— the oldest vehicle suspension gadgets currently in active use are potentially leaf springs. The key focus of the current scenario was the strengthening of car suppliers. In order to maximise strength, improved material, refining architecture and enhancing production processes can be accomplished primarily. The extra material for leaf spring is included in this dissertation. The new Leaf spring is used, which consists of composite material and increases strength. A vibration study of composite leaf spring with non-linear parameters is the main objective of the research. Composite Leaf Spring is carried out here in contrast to the Steel Leaf Spring, free and force vibration analysis. The nonlinear study of vibration is done. CATIA and ANSYS tools for this purpose were used respectively for three-dimensional modelling and analysis. Compared with experimental Findings, the virtual results.

Keywords: ANSYS, Composite, FFT, Layup, Leaf spring, Metal Matrix Composite, Mode Shapes, Von- Misses Stress

I. INTRODUCTION

We understand that on wheeled vehicles, springs were being used in the ancient world. They were, in fact, the first phase of spring used, while the older versions samples were rudimentary. older cars and trucks. They encountered developments, especially provide cushion the ride they increase no of leaf, and they existed prevalent in cars for many years ago. This improved with the introduction of front wheel drive cars in the 1970s.The coil springs took over at that point.

Commercial vehicles, you can often see leaf springs today; some SUVs still have them on the rear axle as well. A more recent discovery is the parabolic leaf spring. This greatly increases the efficiency of the journey, which can usually be seen on buses. The spring binds to the frame at either end. At the centre of the spring, the rear axle of the car resets and is fixed to it with "U" clamps, one on each foot. This makes the ride easy. As an option, where the springs connect directly to the frame at one end, leaf springs are fitted, but the other end is retained by a shackle to the frame allowing for further mobility. Leaf springs on antique vehicles

II. NEED OF COMPOSITE LEAF SPRING

In recent years, car makers have been seeking to reduce the weight of cars in order to satisfy the Demands of debates about renewable capital and the energy market. The suspension spring is one of the most significant automotive systems that decreases shake friction and shock absorption While driving. Fiber reinforced polymers, mainly due to the potential for weight reduction, have been strongly developed for many applications. Other benefits of using, instead of steel, fiber-reinforced polymers are:

1) The chance of decreasing noise, vibration and stiffness, regardless of Their elevated damping influences.
2) Lack of rust problems, which means reduced significantly operating costs; and
3) Decreasing tooling costs, with a positive effect on the cost of production.

Springs are critical suspension materials in cars that are required due to road disturbances to eliminate vertical shocks, impacts and bumps. In order to preserve Strong stability of regulation and enhancement of ride Convenience due to composite construction and production, problems occur from the suspension springs within a vehicle; for sample, the transition from comparatively Isotropic and anisotropic homogeneous steel alloys has not yet been achieved in homogeneous fiber-reinforced plastic The motion of the Nonlinear, considerably large weight, steel leaf spring, and changes in the solid axle Angle prior to weight change , particularly when the vehicle is cornered, which can contribute to over steering and lateral instability in such a situation. these are some metallic leaf spring fault, taking into account the growth of automobiles and relative aspects For reference, fuel consumption, weight, driving quality and handling are important, so it is important to develop new materials in the automotive industry.

III. CLASSIFICATION OF COMPOSITES

Although there are different ways of classifying materials, they can be categorised as natural and
Synthetic or man-made in the simplest and broadest sense.

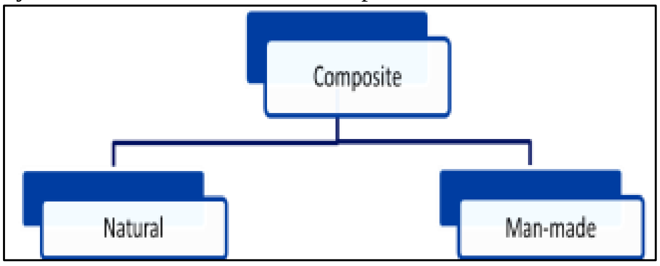

Fig. 1.1: Classification of Composite

The composites which occur in nature are called composites that occur naturally. Stone, human or animal bodies, or even rocks and minerals are common examples of such composites. The human body made up of bone tissue is also an example of natural composite, Composites composed of two parts, namely organic inorganic sea shells and elephant tusk, are the bones themselves.

Many of today's plastic materials are man-made. The man made composite grouping is seen in Figure 1.2.

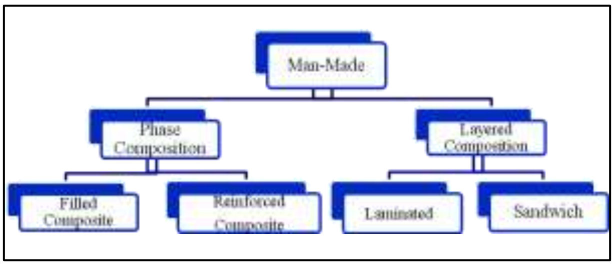

Fig. 1.2: Classification of Man-made

Composites are usually made up of two different materials. It is only feasible to mix the two product materials in two ways:

1) from the injection of one substance into another
2) By bonding layer by layer for them.

The previous method of composition is considered the layered composition of the latter type of phase composition. The composition of the phase is normally visualised at the microscopic level and at the microscopic level they layered the composition.

The substance that receives the insert is continuous in nature in the phase composition and is called the matrix. The insert is completely different things and can be referred to as a filler or reinforcement. If cost reduction is the primary feature of the insert process. The filled composite is considered the resulting material. Any common examples of filled composites are carbon black filled natural rubber, asphalt, Portland cement concrete and reinforced cement concrete. If the insert's primary purpose is to strengthen its mechanical properties, it is considered a reinforced composite On the basis of the matrix used (2), depending on the geometry of the reinforcement, the reinforced composite can be further described in two ways (1).

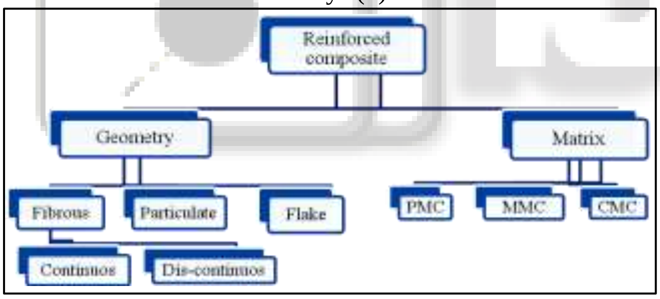

Fig. 1.3: Classification of Reinforced Composite

IV. ITHEORETICAL STUDY OF VIBRATION ANALYSIS OF STEEL LEAF SPRING AND COMPOSITE LEAF SPRING

A. Theoretical Analysis

Consideration of the equilibrium of the forces and moments yields the following Governing differential equation of motion

$$\frac{\partial 2}{\partial x2}\left\{EI(x)\frac{\partial 2y}{\partial x2}\right\}+m(x)\frac{\partial 2y}{\partial t2}=f(x,t)$$

With inclusion of viscous damping per unit length, the above eq (3.1) can be modified as

$$\frac{\partial 2}{\partial x2}\left\{EI(x)\frac{\partial 2y}{\partial x2}\right\}+m(x)\frac{\partial 2y}{\partial t2}+C(x)\frac{\partial y}{\partial t}=f(x,t)$$

For the continuous structure of linear actions, an elegant technique known as "Mode Superimposition" technique occurs. An explanation would explain the methodology in depth. It is important to first know the normal frequencies and corresponding mode forms in order to implement the mode superimposition technique.

B. Normal Frequencies and Shapes of Mode

The standard frequencies and shapes mode are calculated considering the homogeneous sol^{n} of the vibration beam eq^{n}. For the Bending beam vibration with a consistent sectional property, we consider the undamped mode. Let f (x, t) = 0 for free vibration, and assume that the reaction is given by

$$Y(x, t) = \Phi(x)\sin\omega t$$

In which Φ (x) is the function of the mode form, and al is the normal The Frequency Circular.

Take a beam into account; it is subject P load to a point load P, so the beam can Through a curve, deflect. It will revert to its original form when the power, P, is extracted from a displaced beam. The beam's inertia, however, The laser is going to make it vibrate around its original location. The beam the equation is equated with.

$$\frac{EI}{\rho A}\frac{\partial^4 y}{\partial x^4}+\frac{\partial^2 w}{\partial t^2}=0$$

Where the mass density is ρ and A is the beam's cross-sectional area.

$$c^2\frac{\partial^4 y}{\partial x^4}+\frac{\partial^2 y}{\partial t^2}=0$$

Where,

$$C=\sqrt{\frac{EI}{\rho A}}$$

The solution of is to separate the variables one depends on position and another on time. y=W(x)T(t)

By substituting and simplifying,

$$\frac{C^2}{w(x)}\frac{\partial^4 y}{\partial x^4}=-\frac{1}{T(t)}\frac{\partial^2 T(t)}{\partial t^2}$$

The eq. can be written as two separate differential equation

$$\frac{\partial^4 w}{\partial x^4}-\beta^2 W(x)=0$$

$$\frac{\partial^2 T}{\partial t^2}+\omega^2 T(t)=0$$

Where,

$$\beta^4=\frac{\omega^2}{c^2}=\frac{\rho A\omega^2}{EI}$$

To find out the solution of eq. consider the eq.

$$W(x)=C_1\cos h\beta x+C_2\sin h\beta x+C_3\cos h\beta x\,h+C_4\sin h\beta x$$

In order to solve eq. The following boundary conditions for cantilever beam are needed:

1) At x = 0 → W = 0
2) At x = 0 → W I= 0
3) At x = L→ W II= 0
4) At x = L→ W III= 0

By substituting boundary conditions in to WI, WII, WIII. We obtain the following values of C1, C2, C3, and C4:

$$[\cos h\beta l+\cos\beta l]C_3+[\sin h\beta l+\sin\beta l]C_4=0$$

$$[\sin h\beta l-\sin\beta l]C_3+[\cos h\beta l+\cos\beta l]C_4=0$$

Eq. can be written in matrix form as

$$\begin{bmatrix}\cos h\beta l+ & \cos\beta l+ & \sin h\beta l+\sin\beta l\\ \sin h\beta l- & \sin\beta l- & \cos h\beta l+\cos\beta l\end{bmatrix}\begin{bmatrix}C_3\\ C_4\end{bmatrix}=\begin{bmatrix}0\\ 0\end{bmatrix}$$

For solving matrix of eq. we get determinant

$$(\cos h\beta l+\cos\beta l)^2-(\sin h\beta l+\sin\beta l)(\sin h\beta l-\sin\beta l)=0$$

$$\cos h^2\beta l+2\cos h\beta l+\cos^2\beta l-\sin h^2\beta l+\sin^2\beta l=0$$

But it is well known that

$$\cos h^2\ \beta l - \sin h^2\ \beta l = 1$$

Hence we get,

$$\cos \beta l\ \cos h\beta l = 1$$

This transcendental equation has an infinite number of solutions βi = 1,2,3 ... n.

Corresponding giving an infinite number of natural frequencies,

$$\omega_1 = (\beta_1 l)^2 \sqrt{\frac{EI}{\rho A l^4}}$$

The first five roots of eq. are shown in Table 3.1.1

Root	$ß_n l$
1	4.73
2	7.85
3	10.99
4	14.13

Table 3.1: Value of Roots

Beam Condition	$(\beta_1 l)^2$ fundamental	$(\beta_2 l)^2$ second mode	$(\beta_3 l)^2$ third mode
Simply Supported	9.87	39.5	88.9
Cantilever	3.52	22.0	61.7
Free-Free	22.4	61.7	121.0
Clamped-Clamped	22.4	61.7	121.0
Clamped-Hinged	15.4	50.0	104.0
Hinged-Free	0	15.4	50.0

Table 3.2: Value of (Bnl)2 for different End Conditions

The dimensions and the material constant for a Steel Leaf spring and Composite Leaf Spring are studied in this dissertation are shown in Table 3.1.3 and Table 3.1.4 respectively.

Parameter	Symbol	Value
Total Effective Length	L	1.17 m
Width	B	0.2 m
Moment of Inertia	I	$624\times10^{-3} m^4$
Young's Modulus	E	$2.1 \times 10^{11} N/m^2$
Mass Density	ρ	$7830\ kg/m^3$

Table 3.3: Experimental Parameters for Steel Leaf Spring

Parameter	Symbol	Value
Total Effective Length	L	1.17 m
Width	B	0.022 m
Moment of Inertia	I	$918\times10^{-6} m^4$
Young's Modulus (Ex)	E	$7.3 \times 10^{10} N/m^2$
Mass Density	ρ	$1400\ kg/m^3$

Table 3.4: Experimental Parameters for Composite Leaf Spring

The natural frequency of both the steel leaf spring and composite leaf spring is calculated analytically by Euler's Beam Theory for Continuous System.

The Euler's Equation for natural frequency is given as

$$F = (1/2\pi)(Bnl)^2(EI/\rho A l^4)^{1/2}$$

Where,

$(Bnl)^2$= constant depending on end conditions

I = Moment of inertia of system

ρ = Density of Material

A = Area of cross section

L = Length of spring

The end conditions for system are same as that of suspension connected to vehicle body. Both ends are fixed. The values of different parameters for Conventional Leaf Spring are

$$(Bnl)^2 = 22.4., 61.7, 121.$$

$E = 210 \times 10^3\ N/mm^2$

$I = 624 \times 10^6\ mm^4$

$\rho = 7.41 \times 10^{-7}$

$A = 156 \times 10^3\ mm^2$

L = 1170 mm

By substituting these values in above equation we get natural frequencies for Steel Leaf Spring are Fundamental Natural frequency equals 26.12 Hz

The Second Natural frequency equals 83.23 Hz

The Third Natural frequency equals 142.18 Hz

The values of different parameters for Composite Leaf Spring are

$$(Bnl)^2 = 22.4, 61.7, 212.$$

$E = 73 \times 10^9\ N/mm^2$

$I = 918 \times 10^3\ mm^4$

$\rho = 3.193 \times 10^{-4}$

$A = 156 \times 10^3\ mm^2$

L = 1170 mm

By substituting these values in above equation we get natural frequencies for Composite Leaf Spring are Fundamental Natural frequency equals 34.89 Hz

The Second Natural frequency equals 99.23 Hz

The Third Natural frequency equals 234.65 Hz

Mode	Steel Leaf Spring	Composite Leaf Spring
1st Mode	26.74	34.89
2nd Mode	73.66	99.23
3rd Mode	142.18	234.65

Table 3.5: Natural Frequencies of Steel and Composite Leaf Spring

It may be assumed from the above findings that the theoretical results are in reasonable alignment with the negligible error that can be related to the truncation. Certain conclusions are made during the theoretical study that would not take into account nonlinearities found in the system. The findings derived from theoretical analysis are not true because of this. In experimental analysis nonlinearities will be considered such that real world effects are the findings obtained during experimental analysis. Experimental analysis can also be conducted for accurate calculation of the steel and leaf spring composite

V. Analysis of Finite Elements of Conventional Steel and Composite Leaf Spring

A. Finite Element Method

Usually, the physical issue requires an individual structure or structural part exposed to such loads. The idealisation of the physical problem to a mathematical model involves some assumptions that together contribute to the mathematical model governing differential equations. Since the methodology of the finite element solution is a numerical method, it is important to access the precision of the solution. If the precision requirements are not satisfied, it is appropriate to replicate the numerical solution with refined solution parameters before adequate precision is achieved.

B. Important Features of Finite Element Method

Division of the entire into elements, allowing geometrically complex domains to be interpreted as a set of simple domains, allowing the approximation functions to be systematically derived. Algebraic polynomials that are derived using interpolation theory are the derivation of approximation functions over and part of the approximation functions. Assembly of elements based on solution consistency and internal flux equilibrium.

C. Steps of Finite Element Method References

The measures are set out below, Steps for the study of finite elements: The FEA is mostly split into three phases:

- Pre-processing:
- Creating the model. Defining the element type
- Defining Material Properties
- Meshing
- Applying loads
- Applying boundary conditions
- Solution:
- Assembly of equations and obtaining solution.
- Post processing:
- Review of results such as deformation plot, stress plot, etc

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VI. NUMERICAL ANALYSIS OF CONVENTIONAL STEEL LEAF SPRING

Fig. 4.1: (a)

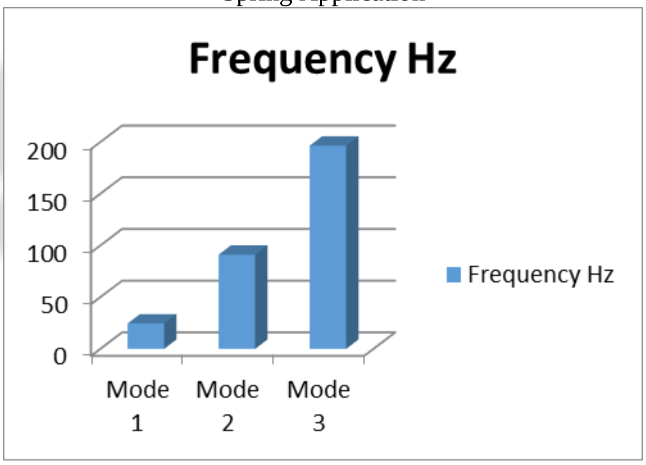
Fig. 4.1: (b)

Figure 4.1 (a) and 4.1 (b): the conventional Steel Leaf Spring CAD Model and FE Model

As seen in Table 4.1, the numerical results were obtained using ANSYS.

Mode	Numerical Frequency in Hz (for Steel Leaf Spring)
1	24.54
2	91.095
3	196.58

Table 4.1: Frequency of Shape Mode ANSYS for Steel Leaf Spring Application



The free vibration mode forms for the Steel Leaf Spring are seen in Figure Statistics 4.2, Figure Statistics 4.3 and Figure Statistics 4.4.

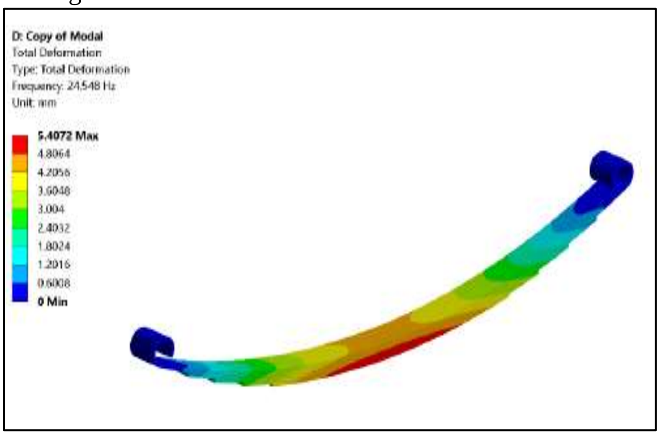


Fig. 4.2: 1st Mode Shape of Free Vibration of Steel Leaf Spring

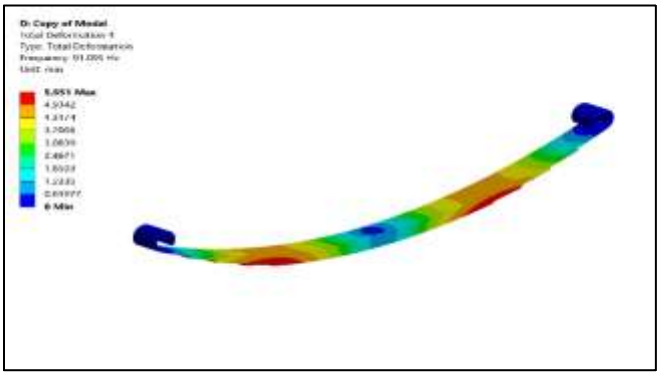


Fig. 4.3: 2nd Mode Shape of Free Vibration of Steel Leaf Spring

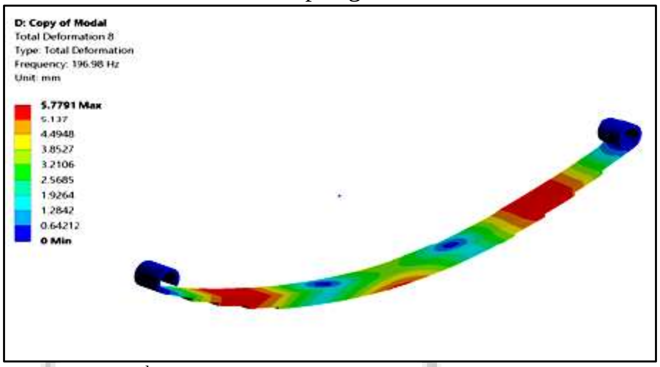


Fig. 4.4: 3rd Mode Shape of Free Vibration of Steel Leaf Spring

VII. NUMERICAL ANALYSIS FOR COMPOSITE LEAF SPRING

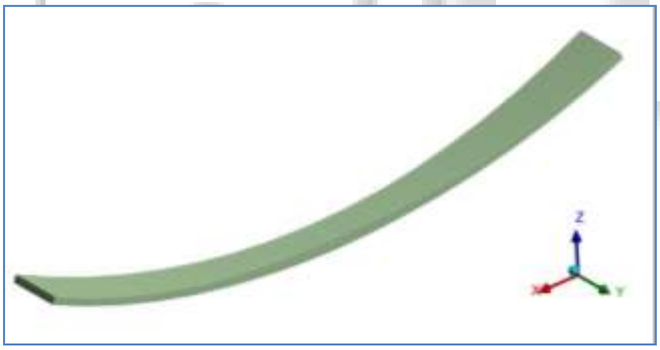


Fig. 4.5 (a)

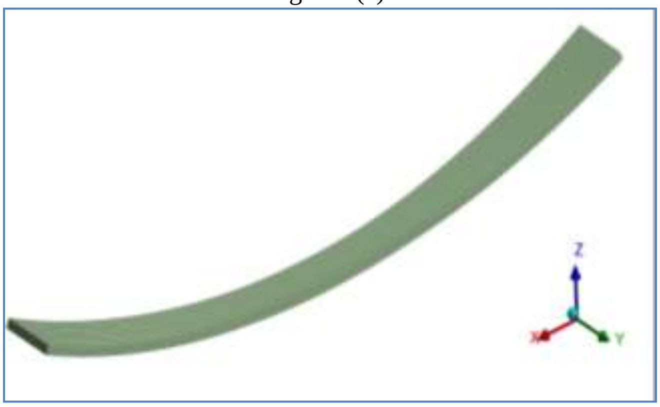
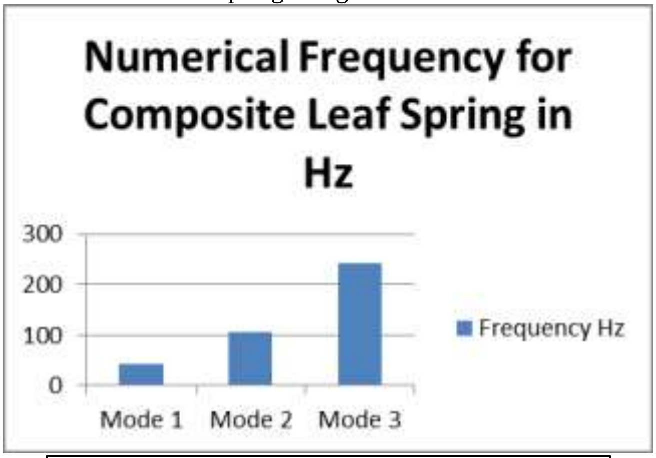


Fig. 4.5 (b)
Fig. 4.5: (a) and Figure 4.5 (b) CAD Model and FE Model of Composite Leaf Spring

As seen in Table 4.2, the numerical results were obtained using ANSYS.

Mode	Numerical Frequency in Hz (for Composite Leaf Spring)
1	42.15
2	105.34
3	241.74

Table 4.2: Mode Form Frequency for Composite Leaf Spring using ANSYS



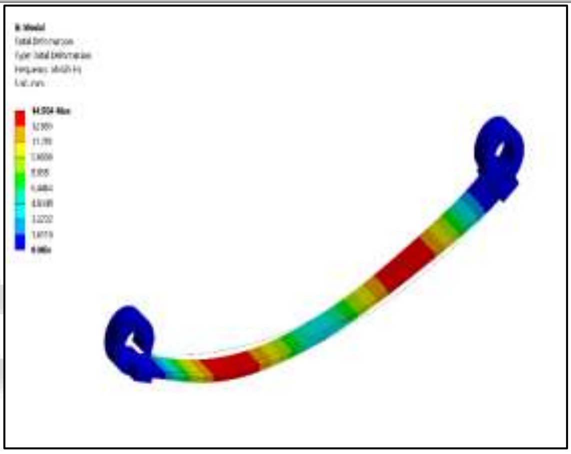


Fig. 4.6: 1st Mode Shape of Free Vibration of Composite Leaf Spring

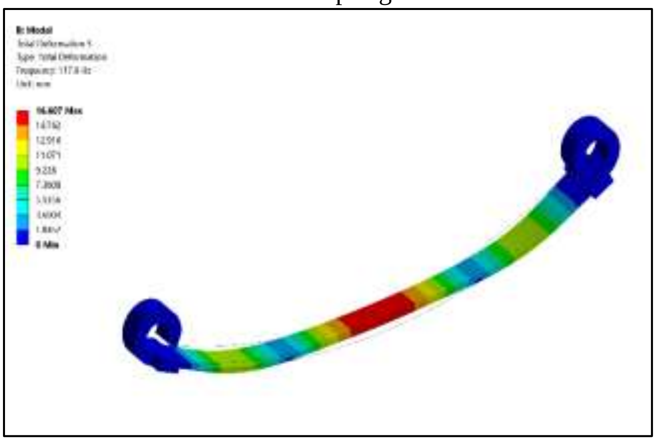


Fig. 4.7: 2nd Mode Shape of Free Vibration of Composite Leaf Spring.

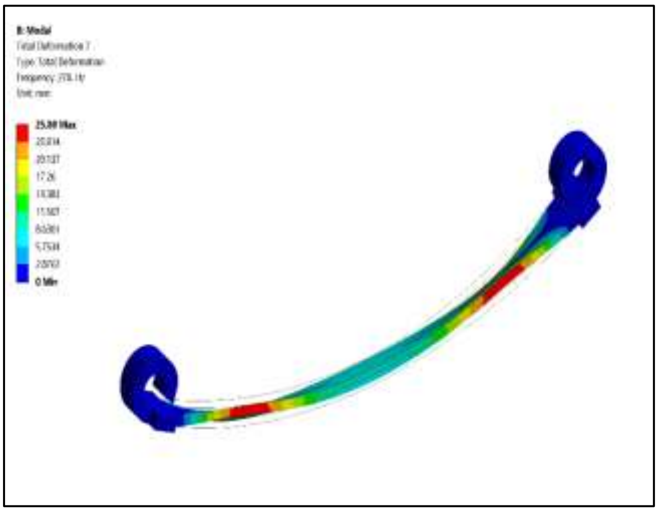


Fig. 4.8: 3rd Mode Shape of Free Vibration of Composite Leaf Spring

The Computational Analysis using ANSYS enables the free vibration of Steel as well as Composite Leaf Spring to be investigated with high precision to find Mode Structure and their Frequencies. It can also be assumed that, owing to truncation, the statistical results are in reasonable alignment with the numerical results, with a negligible error. Certain predictions are made during the theoretical and numerical analysis, but the nonlinearities found in the scheme are not considered. The conclusions derived From numerical and theoretical analysis are not true because of this. Nonlinearities would be taken into account in experimental analysis; so that the findings produced they are true during experimental research. Therefore, laboratory work should be carried out for precise analysis of standard steel and leaf springs composite.

VIII. Results and Discussions

A. Comparison of frequencies obtained by theoretical analysis for Steel Leaf Spring and Composite Leaf Spring

Table Shows Comparison of Frequencies obtained by theoretical analysis for Steel Leaf Spring and Composite Leaf Spring

Sr. No.	Frequency (Hz)	
	Steel Leaf Spring	Composite Leaf Spring
1	26.74	34.89
2	73.66	99.23
3	142.18	234.65

B. Comparison of frequencies obtained by numerical Analysis for Steel Leaf Spring and Composite Leaf Spring

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