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# Modal and Harmonic Analysis of Leaf Spring Using Composite Materials

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***Abstract:*** **In this paper, work is carried out on a multi leaf spring having five leaves used by a commercial vehicle. The main idea behind this work is to replace the existing steel material for the multi leaf spring with composite material with same width, thickness and load carrying capacity. By using composite materials the weight of the multi leaf spring is reduced drastically. In the present work four composite materials are considered. They are E-glass/epoxy, graphite/epoxy, carbon/epoxy, Kevlar/epoxy. The modal analysis is carried out theoretically for finding the natural frequencies for all the materials of the multi leaf spring for the first five modes. To validate the theoretical modal analysis, modal analysis is conducted in ANSYS software for the first five modes. Modeling is done using Creo3.0 and analysis is done using ANSYS 12.1 software. The ANSYS results are almost coincide with theoretical modal analysis values. In addition to the modal analysis harmonic analysis is carried for all the materials for finding the resonance frequency. From the harmonic analysis graphs the resonance frequency are identified for all the cases considered in this work.**

***Keywords:*** **Multi Leaf Spring, Creo, FEM, ANSYS, Modal Analysis and Harmonic Analysis.**

## I. INTRODUCTION

A leaf spring is a simple form of spring, commonly used for the suspension in wheeled vehicles. It is also one of the oldest forms of spring, dating back to medieval times. Sometimes referred to as a semi-elliptical spring or cart spring, it takes the form of a slender arc-shaped length of spring steel of rectangular cross-section. The center of the arc provides location for the axle, while tie holes are provided at either end for attaching to the vehicle body. For very heavy vehicles, a leaf spring can be made from several leaves stacked on top of each other in several layers, often with progressively shorter leaves. Leaf springs can serve locating and to some extent damping as well as spring functions. While the interleaf friction provides a damping action, it is not well controlled and results in satiation in the motion of the suspension.

**Fig 1: Leaf spring assembled at rear axle of automotive**

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A leaf spring can either be attached directly to the frame at both ends or attached directly at one end, usually the front, with the other end attached through a shackle, a short swinging arm as shown in the fig. 1.

**A. Composite Leaf Spring:**

Composite materials are engineering materials made from two or more constituent materials that remain separate and distinct on a macroscopic level while forming a single component. There are two categories of constituent materials: matrix and reinforcement. At least one portion of each type is required. The matrix material surrounds and supports the reinforcement materials by maintaining their relative positions. The reinforcements impart their special mechanical and physical properties to enhance the matrix properties. The primary functions of the matrix are to transfer stresses between the reinforcing fibers/particles and to protect them from mechanical and/or environmental damage whereas the presence of fibers/particles in a composite improves its mechanical properties such as strength, stiffness etc.

Following are the mainly three types of Composite.

i. Metal Matrix Composites (MMC)

ii. Ceramic Matrix Composites (CMC)

iii. Polymer Matrix Composites (PMC)

The raw materials used in this work are

a) E-Glass/epoxy

b) Graphite /epoxy

c) Carbon/epoxy

d) Kevlar/epoxy

**B. Problem Formulations:**

1. The leaf spring has been designed in Pro-E Creo 3.0 parametric software.
2. To perform structural analysis of Multi-Leaf Spring using ANSYS 12.1 software.
3. To perform Modal and Harmonic response analysis of Multi-Leaf Spring using ANSYS 12.1.

**C. Design Variables of Multi Leaf Spring:**

Following dimensions are taken for steel as well as composite leaf spring

**Table 1: Specification of leaf spring**

| S.No. | Parameter | Value |
|---|---|---|
| 1 | Total length of the spring (Eye to Eye) | 1020 mm |
| 2 | No. of full length leave (Master leaf) ($n_f$) | 1 |
| 3 | No. of gradual leaves ($n_g$) | 4 |
| 4 | Thickness of leaf | 10 mm |
| 5 | Width of leaf spring | 80 mm |
| 6 | Maximum load given on spring(w) | 3065.625 N |
| 7 | Young's modulus of leaf spring | $210x10^3$ N/mm$^2$ |

## II. MODAL ANALYSIS

Modal analysis is a worldwide used methodology that allows fast and reliable identification of system dynamics in complex structures. Modal analysis refers to measuring and predicting the mode shapes and frequencies of a structure. Modal analysis is performed using finite element modeling software ANSYS.

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**A. Theoretical calculations of Modal Analysis:**

$\lambda_i = \beta_n \ell$ = 1.875, 4.694, 7.855, 10.996, and 14.137 are obtained for the first five natural frequencies $\omega_i = \sqrt{\frac{EI}{\rho A}} \lambda_i^2$

By using above formula mode shapes have been calculated theoretically

I.Steel Leaf Spring

$$E = 210 \times 10^9 \frac{N}{m^2}, I = 6.66 \times 10^{-9} m^4 , \rho = 7850 \text{ Kg/m}^3, A = 4 \times 10^{-2} m^2, L = 0.51 \text{ m}$$

a) 1st Mode Natural Frequency

$$\omega_i = \sqrt{\frac{EI}{\rho A}} \lambda_i^2 \quad , \quad \omega_1 = \frac{3.52}{l^2} \sqrt{\frac{EI}{\rho A}}$$

$$\omega_1 = \frac{3.52}{0.261} \sqrt{\frac{210 \times 10^9 \times 6.66 \times 10^{-9}}{7850 \times 4 \times 10^{-2}}} ==28.175 \text{ rad/s}$$

$$\omega_1 = 2\pi f_1 \Rightarrow f_1 = 28.175/2\pi = 4.483 \text{ Hz}$$

2nd Mode Natural Frequency

$$\omega_2 = \frac{22.0}{l^2} \sqrt{\frac{EI}{\rho A}} \Rightarrow \omega_2 = \frac{22}{0.261} \sqrt{\frac{210 \times 10^9 \times 6.66 \times 10^{-9}}{7850 \times 4 \times 10^{-2}}} = 176.08 \text{ rad/sec}$$

$$f_2 = \frac{\omega_2}{2\pi}$$

$$f_2 = 176.08/2\pi = 28.02 \text{ Hz}$$

b) 3rd Mode Natural Frequency $\omega_3 = \frac{61.7}{l^2} \sqrt{\frac{EI}{\rho A}}$

$$\omega_3 = \frac{61.7}{0.261} \sqrt{\frac{210 \times 10^9 \times 6.66 \times 10^{-9}}{7850 \times 4 \times 10^{-2}}}$$

$$= 493.83 \text{ rad/sec}$$

$$f_3 = 493.83/2\pi = 78.59 \text{ Hz}$$

c) 4th Mode Natural Frequency $\omega_4 = \frac{120.912}{l^2} \sqrt{\frac{EI}{\rho A}}$

$$\omega_4 = \frac{120.912}{0.261} \sqrt{\frac{210 \times 10^9 \times 6.66 \times 10^{-9}}{7850 \times 4 \times 10^{-2}}}$$

$$= 967.75 \text{rad/sec}$$

$$f_4 = \frac{\omega_4}{2\pi}$$

$$f_4 = 967.67/2\pi = 154.02 \text{ Hz}$$

d) 5th Mode Natural Frequency $\omega_4 = \frac{199.86}{l^2} \sqrt{\frac{EI}{\rho A}}$

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$$\omega_4 = \frac{199.86}{0.261}\sqrt{\frac{210 \times 10^9 \times 6.66 \times 10^{-9}}{7850 \times 4 \times 10^{-2}}}$$

$$= 1608.06\text{rad/sec}$$

$$f_4 = \frac{\omega_4}{2\pi}$$

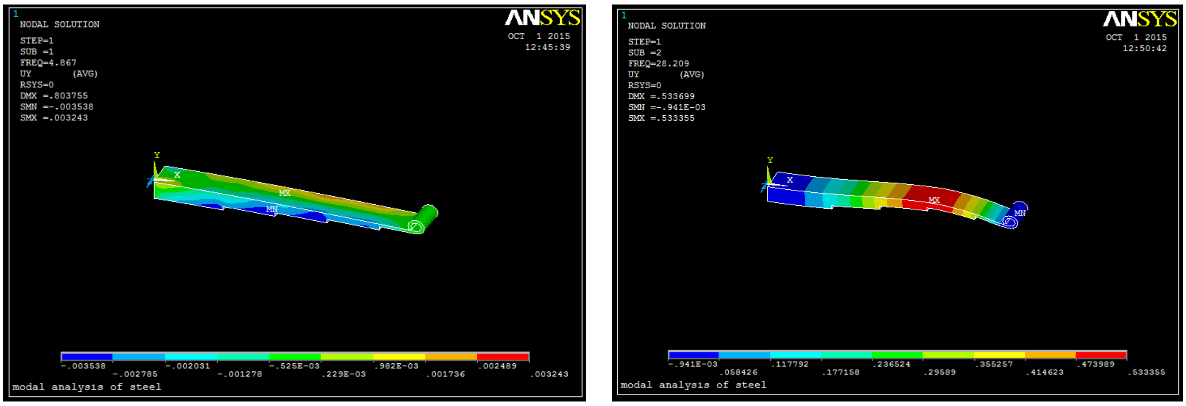
$f_4$=967.67/2π =255.93 Hz

Similarly, for remaining materials theoretical calculations are done and are tabulated in table

**B. Modal Analysis using ANSYS:**

Modal analysis is a technique used to obtain Eigen value and Eigen vectors under forced vibration. The natural frequencies and mode shapes of Steel, E-glass/epoxy, graphite/epoxy, carbon/epoxy and Kevlar/epoxy leaf springs are as shown in figure 2 to 6 respectively

**a) For Steel**



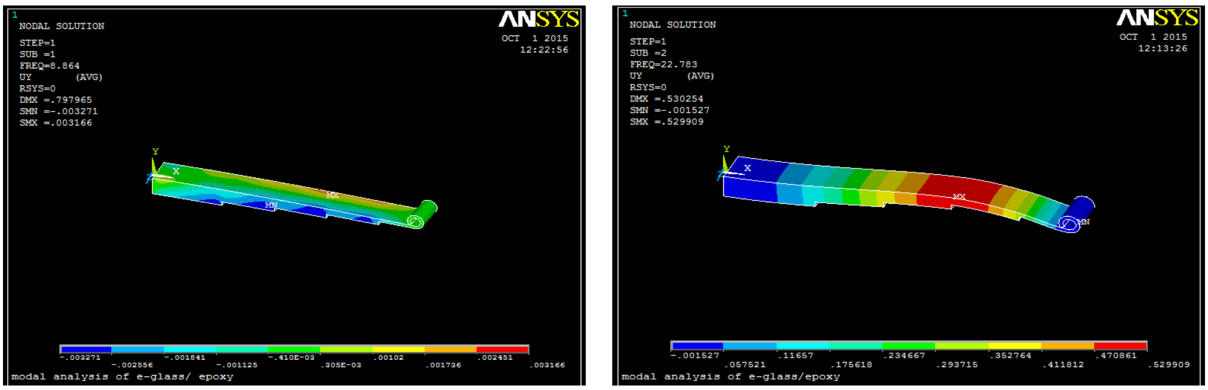

**a) 1st mode shape** **b) 2nd mode shape**

**Fig 2: Mode shapes for steel (EN45)**

The first two mode shapes obtained for steel leaf spring are shown in the fig. 2 a, b and the natural frequencies are 4.48 Hz and 28.20 Hz respectively. For the higher modes i.e. 3rd, 4th and 5th modes the values are tabulated in table 2

**b) For E-Glass/ Epoxy**

The first two mode shapes obtained for E-glass/epoxy leaf spring are shown in the fig. 3 a, b and the natural frequencies are 8.88 Hz and 23.34 Hz respectively. For the higher modes i.e. 3rd, 4th and 5th modes the values are tabulated in table 2




**a) 1st mode shape** **b) 2th mode shape**

**Fig 3: Mode shape for E-glass/ epoxy composite material**

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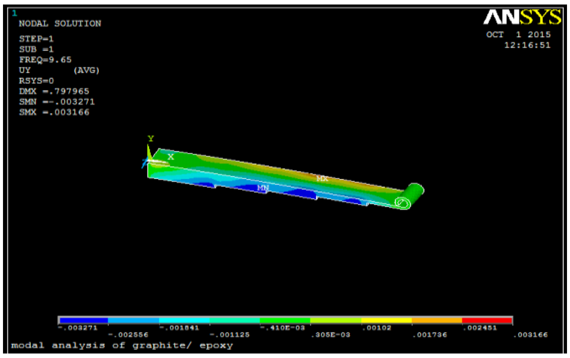
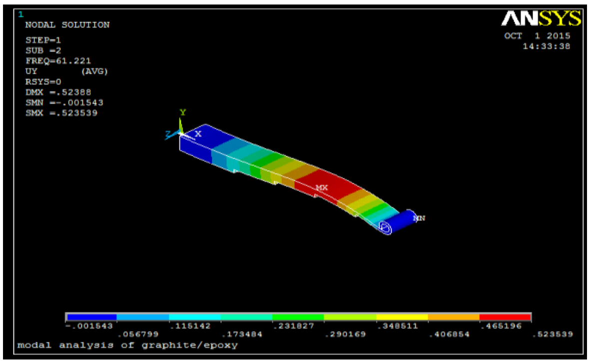
**b) For Graphite / Epoxy**



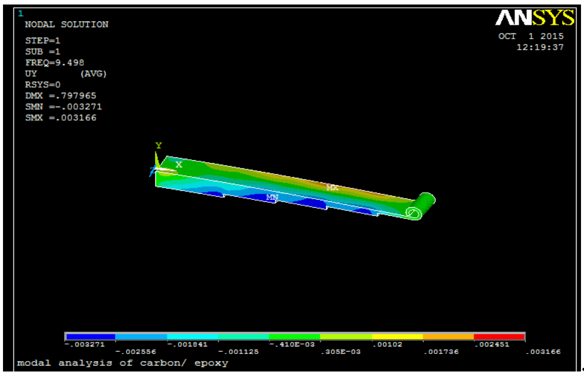



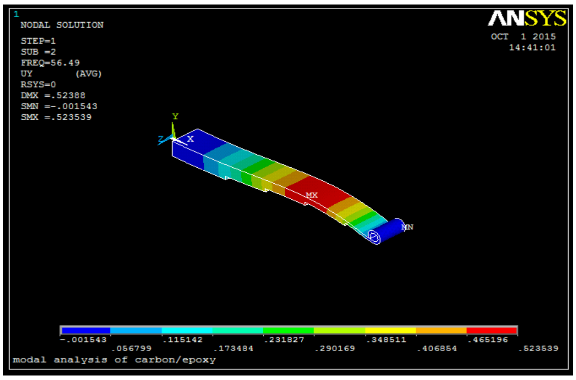

a) 1st mode shape b) 2nd mode shape

**Fig 4: Mode shape for graphite / epoxy composite material**

The first two mode shapes obtained for graphite /epoxy leaf spring are shown in the fig. 4 a, b and the natural frequencies are 9.65 Hz and 61.28 Hz respectively. For the higher modes i.e. 3rd, 4th and 5th modes the values are tabulated in table 2

**c) For Carbon/Epoxy**



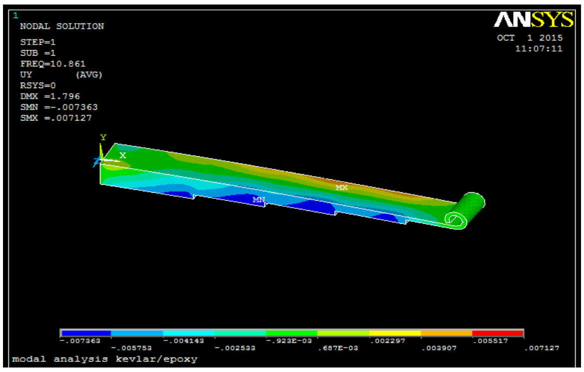



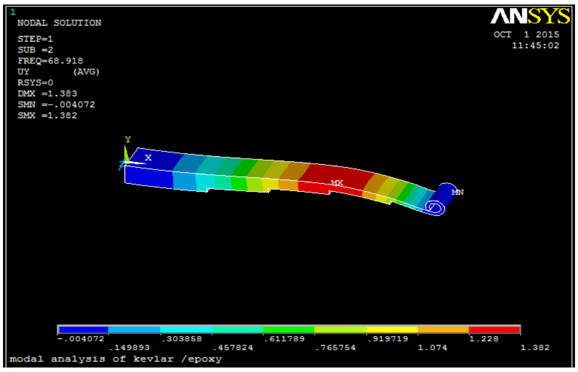

a) 1stmode shape b) 2nd mode shape

**Fig 5: Mode shapes for carbon/ epoxy composite material**

The first two mode shapes obtained for carbon/epoxy leaf spring are shown in the fig. 5 a, b and the natural frequencies are 9.49 Hz and 56.69 Hz respectively. For the higher modes i.e 3rd, 4th and 5th modes the values are tabulated in table 2

**d) For Kevlar/ epoxy**




a) 1st mode shape b) 2nd mode shape

**Fig 6: Mode shapes for Kevlar / epoxy composite material**

The first two mode shapes obtained for Kevlar /epoxy leaf spring are shown in the fig. 6 a, b and the natural frequencies are 11.02 Hz and 68.91 Hz respectively. For the higher modes i.e 3rd, 4th and 5th modes the values are tabulated in table 2

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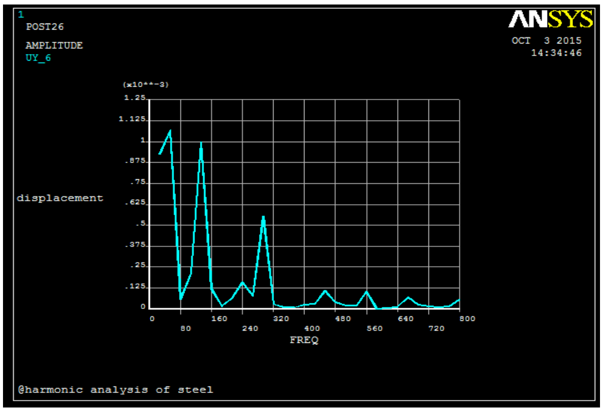
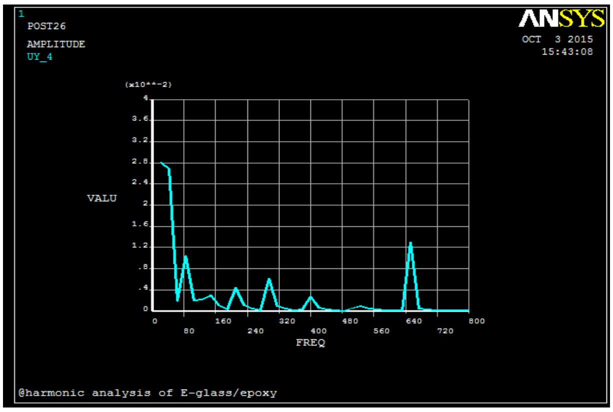
## III. HARMONIC ANALYSIS

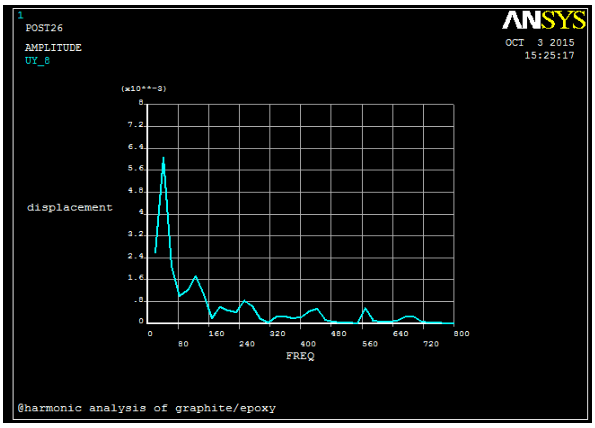
Harmonic response analysis is a technique used to determine the steady-state response of a linear structure to loads that vary sinusoidal (harmonically) with time. The idea is to calculate the structure's response at several frequencies and obtain a graph of some response quantity (usually displacements) versus frequency. "Peak" responses are then identified on the graph and stresses reviewed at those peak frequencies.



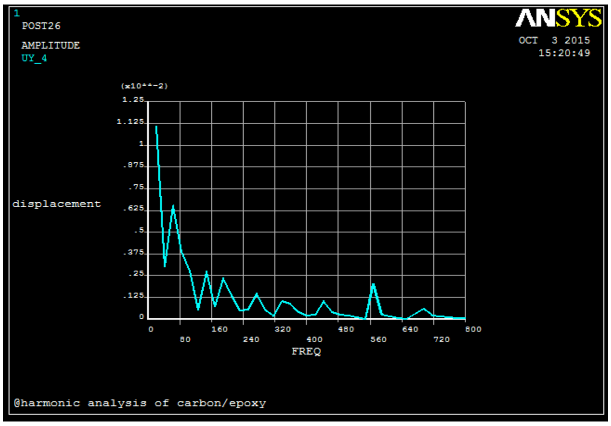

a) Steel EN45



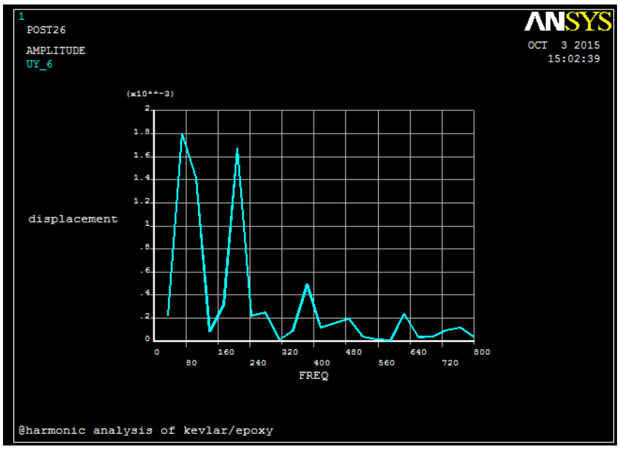

b) E-glass/epoxy




c) graphite/epoxy




d) Carbon/epoxy




e) Kevlar/epoxy

**Figure 7: Harmonic Analysis by using ANSYS**

The responses for steel and composite leaf springs at their corresponding resonance frequencies are show the fig. 7 a, b, c, d, e.

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## IV. RESULTS AND DISCUSSION

Result obtained from modal analysis and harmonic analysis for all material are presented this section

### A. Modal Analysis:

First theatrical modal analysis is done problem material and values are compared with the analysis result. Theoretical and ANSYS result calculated in the table 2 observed that all theoretical modal analysis result coincide with ANSYS values. The modal analysis Frequency also represented graphically for all material.

**Table 2: Comparison of Modal Analysis Results**

| Mode shape | Frequency[Hz] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Steel | | E-glass/ epoxy | | Graphite/epoxy | | Carbon/epoxy | | Kevlar/epoxy | |
| | Theoretical | ANSYS | Theoretical | ANSYS | Theoretical | ANSYS | Theoretical | ANSYS | Theoretical | ANSYS |
| 1 | 4.48 | 4.86 | 8.88 | 8.86 | 9.96 | 9.65 | 9.92 | 9.49 | 11.02 | 10.01 |
| 2 | 28.02 | 28.20 | 23.34 | 22.78 | 62.28 | 61.22 | 57.25 | 56.69 | 68.8 | 68.91 |
| 3 | 78.59 | 78..33 | 155.7 | 155.75 | 174.6 | 174.41 | 174.1 | 172.42 | 193.1 | 193.32 |
| 4 | 154.5 | 150.64 | 305.2 | 304.35 | 342.3 | 339.59 | 341.2 | 337.54 | 378.8 | 368.76 |
| 5 | 255.93 | 254.23 | 509.5 | 509.45 | 571.5 | 569.21 | 569.7 | 568.45 | 632.0 | 632.65 |

For Kevlar/epoxy material modal are frequency are higher compared other material

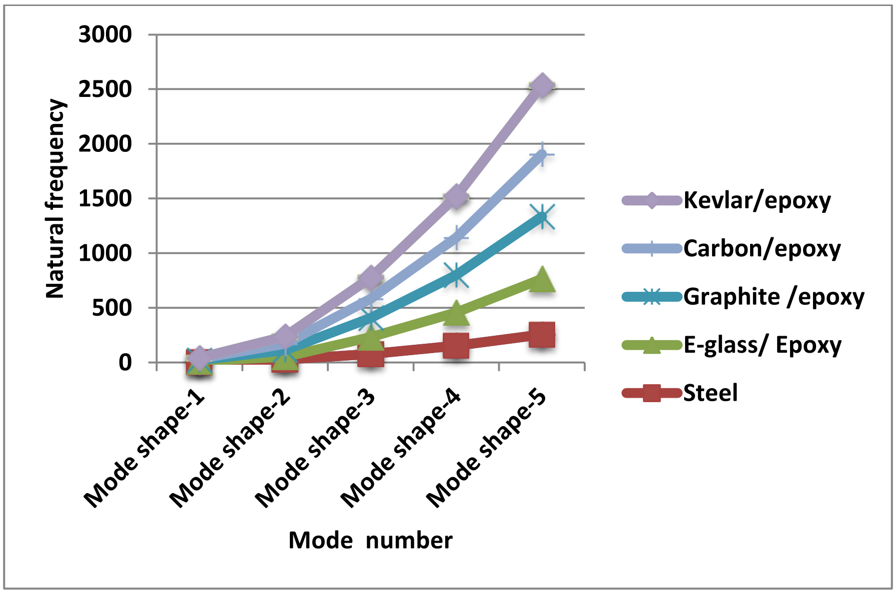


**Fig 8: Comparisons of results for material natural frequencies**

In the modal analysis natural frequencies are obtained and from the fig. 8 (graph) it shows that natural frequencies are higher for Kevlar/ epoxy than steel and other composite materials.

### B. Harmonic Analysis:

From the harmonic analysis graphs the resonance frequency are identified for all the cases considered in this work. The responses for steel and composite leaf springs at their corresponding resonance frequencies are show the figure 7 a, b, c, d, e .The maximum amplitude obtained at a frequency is matched with the natural frequency obtained from modal analysis.

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### C. Weight Reduction of the Material:

**Table 3: % saving of weight by using composite materials**

| S. No. | Material | Weights | % Weight saving |
|---|---|---|---|
| 1 | Steel | 6.405 Kg | ……… |
| 2 | E-glass/ epoxy | 1.63 kg | 74.51 |
| 3 | Graphite /epoxy | 1.29 kg | 79.75 |
| 4 | Carbon/epoxy | 1.14 kg | 82.18 |
| 5 | Kevlar/epoxy | 1.101 kg | 82.82 |

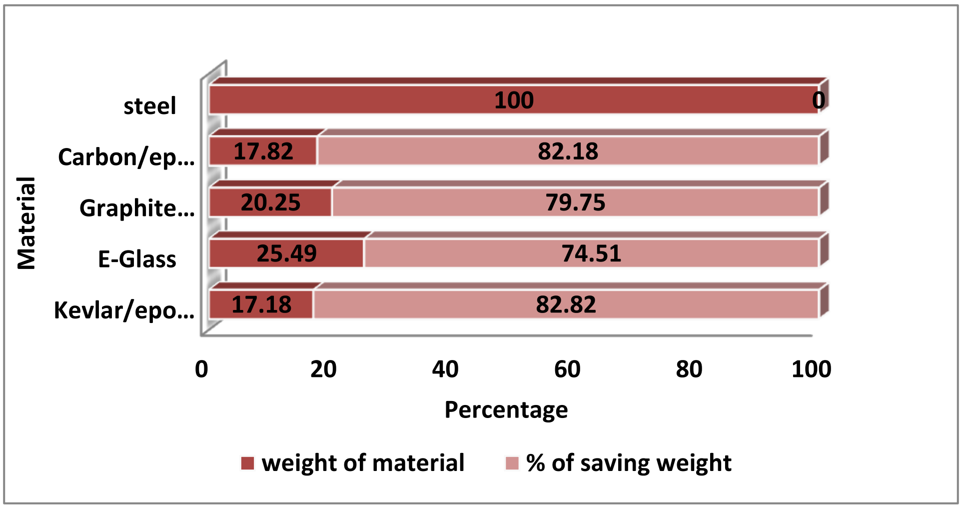


**Fig 9: Weight reduction ratio**

From the above fig. 9 (graph) steel is compared with other composite materials in the aspect of weight saving, thereby from above Kevlar/epoxy has the more tendency of saving weight.

## V. CONCLUSION

In this paper work modal and harmonic analysis for multi leaf spring for different materials is carried out using ANSYS 12.1 and compared with theoretical values.

From the obtained results it can be concluded that,

- In the modal analysis it seen that (table 2) it shows that natural frequencies are higher for Kevlar/ epoxy than steel and other composite materials

From the graphs of harmonic analysis it is observed that E-glass/epoxy and carbon/epoxy have high amplitude of response than other materials and Kevlar/epoxy, graphite/epoxy and steel have low amplitude of response.

The natural frequencies (only for fundamental mode) of the specimens are identified as the frequencies corresponding to peaks present in the FFT spectrum.

1. For The harmonic analysis is carried out resonance frequencies for all the materials of the multi leaf spring.
2. For Steel maximum amplitude value obtained is 1.11 mm at frequency 78.55 Hz.
3. For E-glass/epoxy maximum amplitude value obtained is 2.5 mm at frequency 23 Hz.
4. For graphite/epoxy maximum amplitude value obtained is 5.8 mm at frequency 62 Hz.
5. For carbon/epoxy maximum amplitude value obtained is 1.11 mm at frequency 9 Hz.
6. For Kevlar/epoxy maximum amplitude value obtained is 1.7 mm at frequency 68 Hz.

It is observed that Kevlar/ epoxy have high resonance point that compared all composite material.

- Kevlar/epoxy has more tendency of weight saving compared with other composite materials.

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