VIBRATION ANALYSIS OF COMPOSITE MONO LEAF SPRING

Vijendra Sunil Ahire[1], J P Zope[2]

[1,2]D Y Patil Institute of Engineering Technology, Ambi, Pune, India

---***---

***Abstract**—The main use of Leaf springs is in suspension system to absorb shock loads in automobiles like light motor vehicles, heavy duty trucks and in rail systems. It carries lateral loads, brake torque, driving torque in addition to shock absorbing. The advantage of leaf spring over helical spring is that the ends of the spring may be guided along a definite path as it deflects to act as a structural member in addition to energy absorbing device. The suspension leaf spring is one of the potential items for weight reduction in automobiles unsprang weight. The main aim of our project is to study and analysis the leaf spring of Bolero Vehicle which is made up of Steel and epoxy material. The 3 D model of leaf spring was drawn with the help of CATIA software. The experimental testing was carried using FFT Analyzer. The analysis was carried out with the help of ANSYS software. The comparative analysis was carried out between the Analytical and experimental results. After making the comparative analysis result and conclusion was drawn.*

***Keywords**—* **Leaf Spring, Steel, Epoxy, ANSYS, FFT Analyzer**

I. INTRODUCTION

A leaf spring is a simple form of spring commonly used for the suspension in wheeled vehicles. Originally called a laminated or carriage spring, and sometimes referred to as a semi-elliptical spring or cart spring,[21] it is one of the oldest forms of springing, appearing on carriages in England after 1750 and from there migrating to France and Germany[3].

A leaf spring takes the form of a slender arc-shaped length of spring steel of rectangular cross-section. In the most common configuration, the Centre of the arc provides location for the axle, while loops formed at either end provide for attaching to the vehicle chassis. 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.[19] Leaf springs can serve locating and to some extent damping as well as springing functions. While the interleaf friction provides a damping action, it is not well controlled and results in stiction in the motion of the suspension. For this reason, some manufacturers have used mono-leaf springs.[2]

II. LITERATURE REVIEW

Ehab Samir Mohamed Mohamed Soliman [1] In this paper steel leaf spring is analyzed at maximum load using finite element analysis (FEA) ANSYS v16 software. Carbon fiber epoxy resin was used for manufacturing of composite leaf spring. Paper shows static, modal, Harmonic analysis was carried out using FEA. Weight reduction obtains 79% over conventional steel leaf spring.

Hemant Rajendra Nehete [2] In this paper they reduce the effect of vibration and to reduce the repulsive effect of damper using composite leaf spring. ANSYS software used for Finite Element Analysis for vibration analysis.

S. S. Chavan [3] In this paper E- glass Fibre/Epoxy Material is used for mono composite leaf spring. Statistical calculations and FEA analysis is done. Paper shows that 77% weight reduction in mono composite leaf spring as compare to steel leaf spring.

Amare Gebremeskel [4] In this project E-glass/Epoxy leaf spring is designed and simulated following the design rules of the composite materials considering static loading only. Constant cross sectional area is consider for design parameters.. The designed composite leaf spring has also achieved its acceptable fatigue life. This particular design is made specifically for light weight three-wheeler vehicles. Hand layup technique is used for manufacturing process.

S. N. Bansode[5] E-Glass Epoxy and Carbon Epoxy is used in this work. This present work the estimate and compare the deflection, bending stress induced in the leaf spring by these materials. The leaf spring, which is used for analysing, is a mono leaf spring of Light passenger vehicle. A model of such leaf spring has been designed from actual steel leaf spring and analysed using ANSYS in this paper. They have done Theoretical calculations and Testing for validation of results.

Sriram Kumar[6] This paper shows design and experimental analysis of composite leaf spring made of glass fibre reinforced polymer. Paper shows that comparison of load carrying capacity, stiffness and weight savings of composite leaf spring and steel leaf spring.

N. Ramesh[7] Paper shows that design and fabrication of complete mono composite leaf spring. In this paper A single leaf with variable thickness and variable width for constant cross-sectional area of different composite materials, with similar mechanical and geometrical properties to the multi leaf spring, were modelled and analysed. FEM is used for design constraints were stresses and displacement. They have achieved weight reduction by 78% in mono composite leaf spring.

III. OBJECTIVES

- To determine strength of steel leaf spring and epoxy leaf spring using FEM.
- To calculate Natural bending Frequency and mode shape of the mono leaf spring.
- To carry out finite element analysis and experimental Investigation of mono leaf spring
- To validation of experimental and FEA results.

IV. METHODOLOGY

- Step 1: - I started the work of this project with literature survey. I gathered many research papers which are relevant to this topic. After going through these papers, I learnt about composite mono Leaf Spring.
- Step 2: - After that the components which are required for my project will be decided.
- Step 3: - After deciding the components, the 3 D Model and drafting will be done with the help of CATIA software.
- Step 4: - The components will be manufactured.
- Step 5:-The calculations of Leaf spring will be carried out.
- Step 6:- The Analysis will be carried out with the help of ANSYS software.
- Step 7:-The comparative analysis will be done between experimental observations and analysis and the result and conclusion will be drawn.

V. DESIGN CALCULATIONS

Weight of Vehicle = 1615 Kg

Maximum Load Carrying Capacity = 535 Kg

Total Weight = 1615 + 535 = 2150 Kg

Taking F.S. = 2 & Acceleration due to gravity = g = 10 m/s2

Total Weight = W = 2150*2*10 = 43000N

Since the vehicle is 4-wheeler a single leaf spring corresponding to one of the wheels takes up ¼th of the total weight.

F = 43000/4 = 10750 N

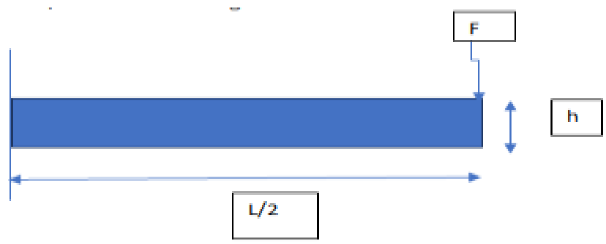
Measured data of the four-wheeler vehicle:

Leaf Span of the Load free Curved leaf spring (L') = 1016mm

Straight Length of Leaf Spring (L) = 1040mm

$\frac{C}{L'}$ = 0.089, C = 90.424mm

Where, C = Camber Length



L/2 = 520mm, F=10,750N, h =? b =? [2]

We Know that,

For Cantilever Beam [11]

Maximum Stress = $\frac{W*L}{Z}$

$$= \frac{F*L}{I/Y}$$

$$= \frac{F*L*Y}{I}$$

$$= \frac{F*L*h}{2*b*h3/12}$$

$$\sigma \max = \frac{6*F*L}{b*h2} \text{ ....(1)}$$

Maximum Deflection = $\frac{W*L3}{3*E*I}$

$$= \frac{F*L3}{3*E*b*h3/12}$$

$$^{\delta} \max = \frac{4*F*L3}{E*b*h3} \text{..................................(2)}$$

For Torsional Moment, as both ends are hinged the effective length will be considered as L = 2/3 Le

By solving Equation 1 & 2 we get,

$$h = 2/3 * \frac{\sigma \max*L2}{E*^{\delta} \max} *3/2$$

$$h = \frac{\sigma \max*L2}{E*^{\delta}\max}$$

σ max = 473MPa, $^{\delta}$ max = 105mm

h = 23mm

From equation 1 we get,

$$b = \frac{6*F*L/2}{\sigma \max*h2}$$

b = 134mm

Bending Stress Calculations (σb):

σb = $\frac{M*y}{I}$

Where, M = Bending Moment

Y = h/2

I = Moment of Inertia

M = $\frac{F*L}{2}$ = 5590 Nm

I = $\frac{b*h3}{12}$ = 1.36*10-7 m4

Y = h/2 = 23/2 = 11.5mm = 11.5*10-3 m

By putting all the values in equation of bending stress we get,

σb = 472.68*10^6 N/m2

VI. DESIGN

Computer-aided design (**CAD**) is the use of computer systems (or workstations) to aid in the creation, modification, analysis, or optimization of a design. CAD software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing. CAD output is often in the form of electronic files for print, machining, or other manufacturing operations. The term **CADD** (for Computer Aided Design and Drafting) is also used. [5]

Its use in designing electronic systems is known as electronic design automation (**EDA**). In mechanical design it is known as mechanical design automation (**MDA**) or **computer-aided drafting** (**CAD**), which includes the process of creating a technical drawing with the use of computer software. [10]

CAD software for mechanical design uses either vector-based graphics to depict the objects of traditional drafting, or may also produce raster graphics showing the overall appearance of designed objects. However, it involves more than just shapes. As in the manual drafting of technical and engineering drawings, the output of CAD must convey information, such as materials, processes, dimensions, and tolerances, according to application-specific conventions.[12]

Fig. no.1 CATIA model

VII. ANSYS

The finite element method (FEM), is a numerical method for solving problems of engineering and mathematical physics. Typical problem areas of interest include structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential.[12]. The analytical solution of these problems generally require the solution to boundary value problems for partial differential equations. The finite element method formulation of the problem results in a system of algebraic equations. The method yields approximate values of the unknowns at discrete number of points over the domain.[16] To solve the problem, it subdivides a large problem into smaller, simpler parts that are called finite elements. The simple equations that model these finite elements are then assembled into a larger system of equations that models the entire problem. FEM then uses variation methods from the calculus of variations to approximate a solution by minimizing an associated error function [18]

Studying or analyzing a phenomenon with FEM is often referred to as finite element analysis (FEA).

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	7850	kg m^-3
4	Isotropic Secant Coefficient of Thermal Expansion		
5	Coefficient of Thermal Expansion	1.2E-05	C^-1
6	Isotropic Elasticity		
7	Derive from	Young's Modu...	
8	Young's Modulus	2E+11	Pa
9	Poisson's Ratio	0.3	
10	Bulk Modulus	1.6667E+11	Pa
11	Shear Modulus	7.6923E+10	Pa

Table no.1 Material properties of Structural steel

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	1.8E-09	tonne mm^-3
4	Isotropic Elasticity		
5	Derive from	Young's Modulu...	
6	Young's Modulus	54000	MPa
7	Poisson's Ratio	0.25	
8	Bulk Modulus	36000	MPa
9	Shear Modulus	21600	MPa

Table no.2 Material Properties of Epoxy

VIII. MESH

ANSYS Meshing is a general-purpose, intelligent, automated high-performance product. It produces the most appropriate mesh for accurate, efficient Metaphysics solutions. A mesh well suited for a specific analysis can be generated with a single mouse click for all parts in a model. Full controls over the options used to generate the mesh are available for the expert user who wants to fine-tune it. The power of parallel processing is automatically used to reduce the time you have to wait for mesh generation.

Statistics	
Nodes	26703
Elements	4545

Fig. no.4 Meshing of steel leaf spring

Statistics	
Nodes	111042
Elements	22747

Fig. no.3 Meshing of epoxy leaf spring

IX. Boundary Condition

A boundary condition for the model is the setting of a known value for a displacement or an associated load. For a particular node you can set either the load or the displacement but not both.

The main types of loading available in FEA include force, pressure and temperature. These can be applied to points, surfaces, edges, nodes and elements or remotely offset from a feature.

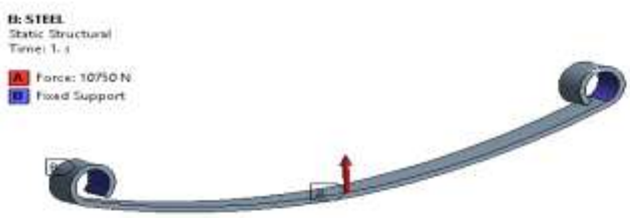


Fig. no.4 boundary condition of steel leaf spring

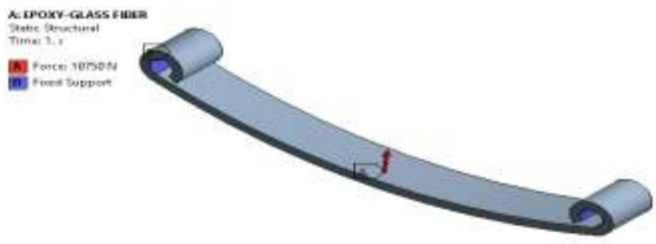


Fig. no.5 Boundary condition of epoxy leaf spring

Total Deformation

The total deformation & directional deformation are general terms in finite element methods irrespective of software being used. Directional deformation can be put as the displacement of the system in a particular axis or user defined direction.
Total deformation is the vectors sum all directional displacements of the systems.

Fig. no.6 Total deformation of steel leaf spring

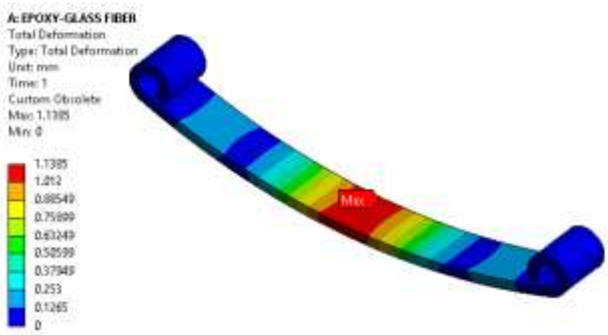


Fig. no.7 Total deformation of epoxy leaf spring

Equivalent Stress

Equivalent stress is related to the principal stresses by the

equation:

$$\sigma_e = \left[\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}{2} \right]^{1/2}$$

Equivalent stress (also called von Mises stress) is often used in design work because it allows any arbitrary three-dimensional stress state to be represented as a single positive stress value. Equivalent stress is part of the maximum equivalent stress failure theory used to predict yielding in a ductile material. [19]

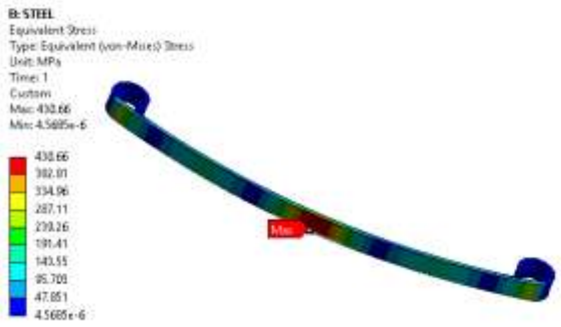


Fig. no.8 Equivalent stress of steel leaf spring

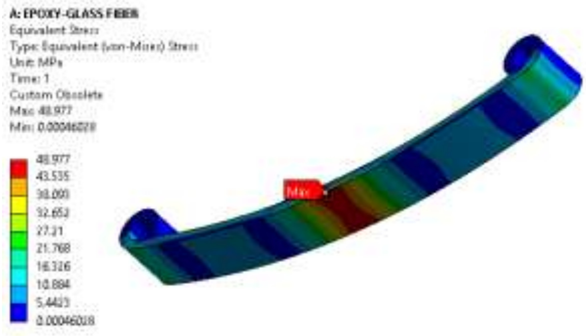


Fig. no.9 Equivalent stress of Epoxy leaf spring

Model analysis:

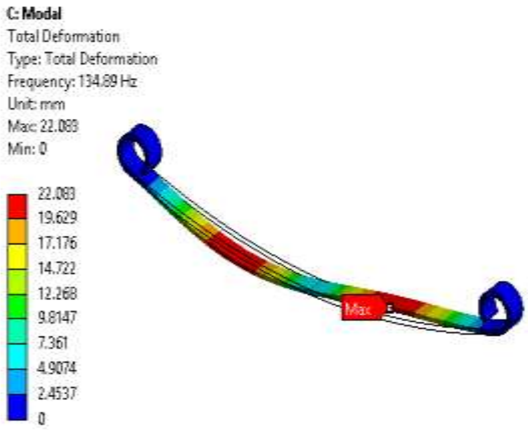


Fig. no.10 Natural frequency of steel leaf spring at mode 1

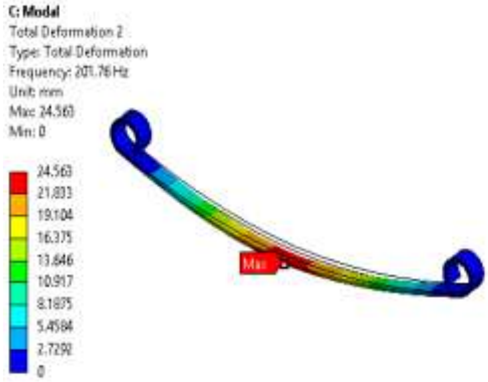


Fig. no.11 Natural frequency of steel leaf spring at mode 2

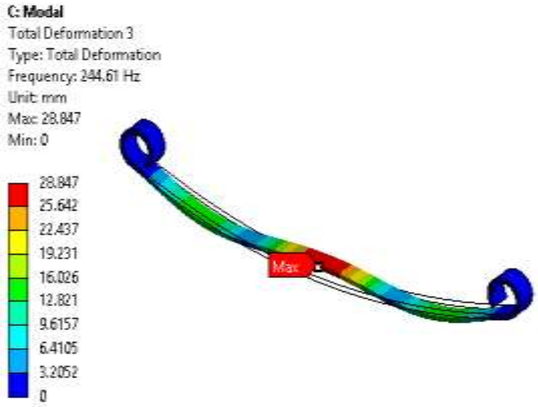


Fig. no.12 Natural frequency of steel leaf spring at mode 3

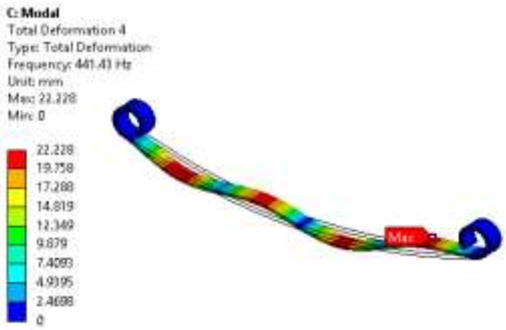


Fig. no.13 Natural frequency of steel leaf spring at mode 4

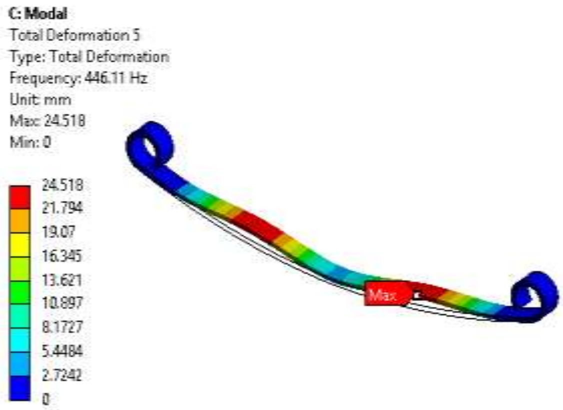


Fig. no.14 Natural frequency of steel leaf spring at mode 5

MODAL ANALYSIS OF EPOXY LEAF SPRING

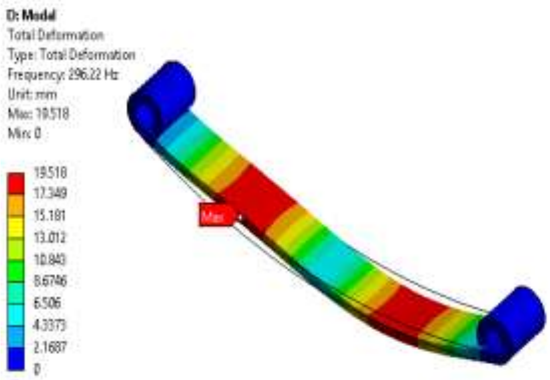


Fig. no.15 Natural frequency of epoxy leaf spring at mode 1

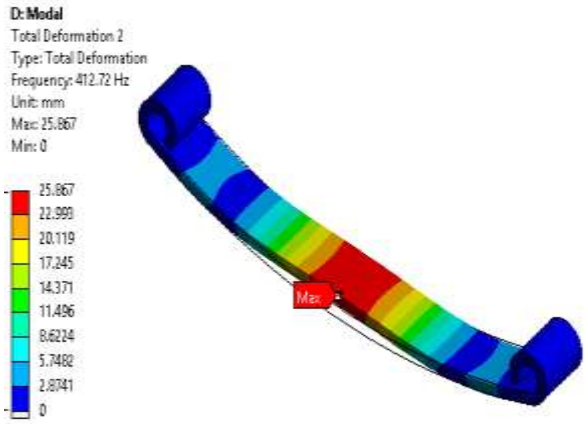


Fig. no.16 Natural frequency of epoxy leaf spring at mode 2

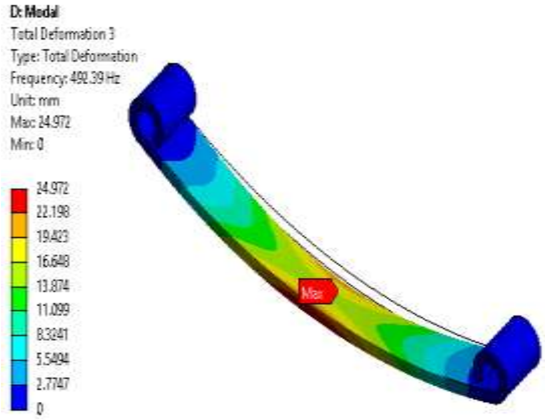


Fig. no.17 Natural frequency of epoxy leaf spring at mode 3

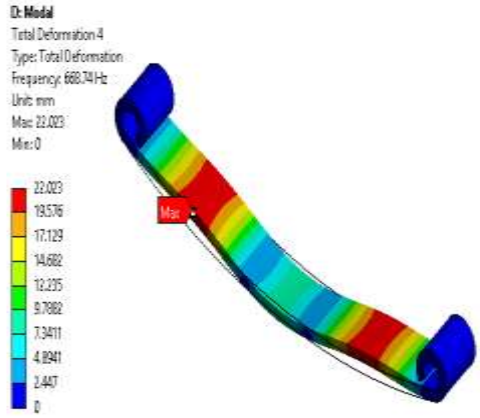


Fig. no. 18 Natural frequency of epoxy leaf spring at mode 4

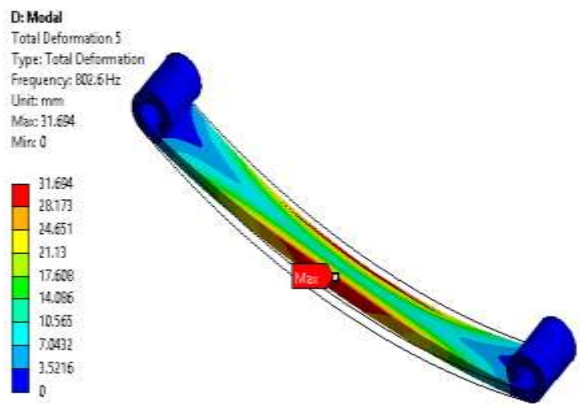


Fig. no.19 Natural frequency of epoxy leaf spring at mode 5

EXPERIMENTAL RESULTS

X. FFT analysis

FFT is one main property in any sequence being used in general. To find this property of FFT for any given sequence, many transforms are being used. The major issues to be noticed in finding this property are the time and memory management. Two different algorithms are written for calculating FFT and Autocorrelation of any given sequence. Comparison is done between the two algorithms with respect to the memory and time managements and the better one is pointed. Comparison is between the two algorithms written, considering the time and memory as the only main constraints. Time taken by the two transforms in finding the fundamental frequency is taken. At the same time the memory consumed while using the two algorithms is also checked. Based on these aspects it is decided which algorithm is to be used for better results.

XI. DEWE-43 Universal Data Acquisition Instrument

When connected to the high speed USB 2.0 interface of any computer the DEWE-43 becomes a powerful measurement instrument for analog, digital, counter and CAN-bus data capture. Eight simultaneous analog inputs sample data at up to 204.8 kS/s and in combination with DEWETRON Modular Smart Interface modules (MSI) a wide range of sensors are supported Voltage Acceleration Pressure Force Temperature Sound Position RPM Torque Frequency Velocity And more The included DEWE Soft application software adds powerful measurement and analysis capability, turning the DEWE-43 into a dedicated recorder, scope or FFT analyzer.

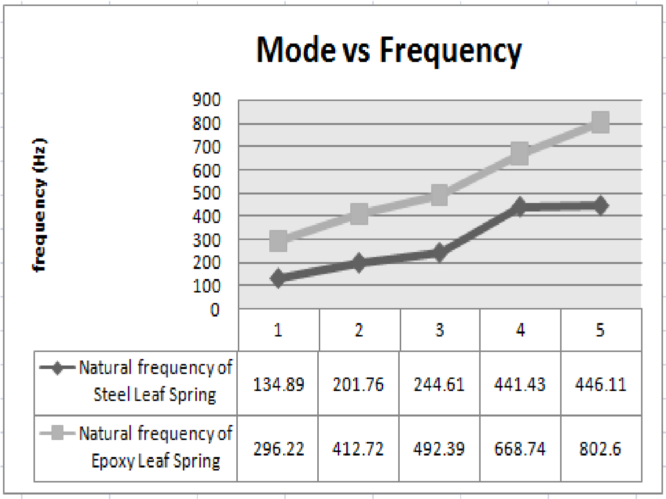
First accelerometer is attached to the Epoxy Leaf Spring specimen. After that we are applying Impact hammer to Epoxy Leaf Spring for validation of natural frequencies.

Fig. no.20 Experimental setup of FFT

Fig. no.21 Experimental setup of FFT

XII. FEA Result

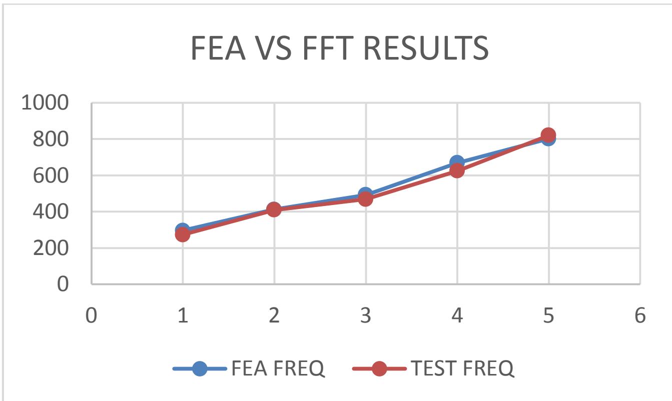
	Total deformation (mm)	Equivalent stress (MPa)
Steel Leaf Spring	4.070	430.66
Epoxy Leaf Spring	1.138	48.977



Graph 1

XIII. FEA and FFT Comparative Result

MODE NO	Natural frequency of Epoxy Leaf Spring (FEA)	Natural frequency of Epoxy Leaf Spring (Test)
1	296.22	273.43
2	412.72	410.15
3	492.39	468.75
4	668.74	625
5	802.6	820.31



Graph 2

XIV. CONCLUSIONS:

1. From the analysis results, we can conclude that the strength of the epoxy leaf spring is more than that of the steel leaf spring.
2. The modal analysis of steel and epoxy leaf spring is carried out.
3. From FEA result it conclude that total deformation of Epoxy Leaf Spring is less than Steel Leaf Spring that is 1.138 mm.
4. Natural Frequencies of epoxy leaf spring from FEA and FFT analyzer are in good relationship.
5. Stiffness of epoxy leaf spring is maximum than Steel Leaf Spring.

XV. References:

[1] Ehab Samir Mohamed Mohamed Soliman (25 January 2019) "Static and Vibration Analysis of CFRP Composite Mono Leaf Spring'' ASM International. Available: https://doi.org/10.1007/s11668-019-00597-y

[2] Hemant Rajendra Nehete (January 2018) "Vibration Analysis of Composite Leaf Spring by Finite Element Method'' Vol 4 Issue 8 ISSN (online): 2349-6010

[3] Vandana Purohit, Dr. Ashish Manoria, Prof. Sanjay Jain, Dr.Pankaj Agarwal (August 2018) "Vibration frequency optimization of automobile leaf spring using 0?90?lay-up gfrp leaf spring'' ISSN No.: 2454- 2024 (online) Available: www.ijtrs.com

[4] Dayanand. S. Hasbe M.C.Swami (2017) " Vibration Analysis of Composite Leaf Spring by FEA ''International Journal for Scientific Research & Development| Vol. 4, Issue 12 ISSN (online): 2321-0613

[5] Sandeep Bhattacharjee, Suyog Kanitkar, Naveen Kalasapur, Vivek Patel (Nov -2017) "COMPOSITE LEAF SPRING'' (IRJET) Volume: 04 Issue: 11 p-ISSN: 2395-0072 Available: www.irjet.net

[6] Karan K. Sharma, Arshad Rashid, Saiprasad Mandale (2016) "Critical Analysis of Vibration Behaviour of Multi-Leaf Spring under Loading Condition by ANSYS Software'' Volume 13, Issue 6 PP 34-38 Available: www.iosrjournals.org

[7] Mayourshikha Pancholi (Bhatnagar), Dheeraj Mandliya (June 2016) "VIBRATION ANALYSIS OF LEAF SPRING USING FINITE ELEMENT METHOD'' IJESRT ISSN: 2277-9655

[8] Khairnar N.D, Mhaske V.M, Aher V.S, Nagare P.N, Bajaj D.S. (March 2016) "Active Vibration Suppression of Leaf Spring by using Piezoelectric Actuator'' Vol. 3, Special Issue 1, ISSN (Online) 2393-8021

[9] Mr. Pramod K Shinde, Mr. Piyush R Talekar, Mr. Yogesh Y Kamble, Mr. Sandip Desai (2016) " Vibration analysis of composite leaf spring used for passenger car'' Vol 2 Issue 3 Available : www.ijirse.com

[10] GANJI MADHUKAR GOROGINAM SANTHI (2016)

"Design And Analysis Of Leaf Spring For

Heavy Commercial Vehicle''(IJITR) Volume No.4, Issue No.5, 4224-4228

[11] K. K. Jadhao, R. S. Dalu, (2017) "Impact analysis of steel and composite leaf spring for light commercial vehicle'', IJEDR Vol. 5 Issue3 (IJEDR) ISSUE 2321-9939

[12] S.Vinoth Kumar, T.S.Kiruba Shankar, C. Arun, M.Yuvaperiyasamy, (April 2016) "Design and analysis of three leaf composite spring for light weight vehicle by finite element analysis method'' Volume 7 Issue 4 (IJSER) ISSN 2229-5518

[13] T.G. Loganathan K.Chandra Sekaran, R. Krishna Murthy, P.K.Devan,(2016)"Influence of selective reinforcement in dynamic performance of glass epoxy composite", (ICMPC) Science direct Available: www.sciencedirect.com

[14] B. Raghu Kumar, R. Vijaya Prakash and N. Ramesh (February 2013) "Static analysis of mono leaf spring with different composite materials'' DOI: 10.5897/ JMER11.075 ISSN 2141-2383 Available: http://www.academicjournals.org

[15] Achamyeleh a Kassie, R Reji Kumar and Amrut Rao (January 2014) "DESIGN OF SINGLE COMPOSITE LEAF SPRING FOR LIGHT WEIGHT VEHICLE'' Vol. 3, No 1 ISSN: 2278-0149. Available: www.ijmerr.com

[16] V B Bhhandari "Design of machine elements'' by McGraw hill education (India) private limited, 1994. Page no 437

[17] Anup goel, S S Sabharwal "Design of machine element 1''by technical publications Pune (India). Page no 67-77.

[18] Akshay Kumar, V. J. Shinde, S. S. Chavan (12,December 2014) "Design, Analysis, Manufacturing and Testing of Mono Composite Leaf Spring Using UD E-Glass Fiber/Epoxy'' volume no 02, ISSN (ONLINE):2348-7550 Available: www.ijates.com

[19]Shishay Amare Gebremeskel (2012) "Design, Simulation, and Prototyping of Single Composite Leaf Spring for Light Weight Vehicle''(IJRITCC) VOL 12 ISSUE 7 VERSION 1.O (ONLINE) ISSN 2249-4596

[20] Atul J. Pawar Prof. S .N .Bansode (March 2015) "Weight Optimization of Mono Leaf Spring Used for Light Passenger Vehicle'' Volume 3 Issue 3 ISSN 2321- 8169 1079-1083 Available: www.ijritcc.com

[21] Rajagopal D, Varun S, Manikanth M, Bysani Somasai Sriram Kumar (Octomber 2014) "Automobile Leaf Spring from Composite Materials''(IJEAT), Vol. 4 Issue-1, ISSN:2249-8958.

[22] B Raghu Kumar, R. Vijaya Prakash and N. Ramesh (February 2013) "Static analysis of mono leaf spring with different composite materials'' Vol.(2), pp.32-37 Available: https://doi.org/10.5897/NMER11.075

[23] Parkhe Ravindra, Mhaske Raman, Belkar Sanjay (February 2014) "Modeling and Analysis of Carbon Fiber Epoxy Based Leaf Spring under the Static Load Condition by Using FEA'' (IJESE) Vol. 2, issue- 4 ISSN: 2319-6378

[24] Malaga Anil Kumar, T. N. Charyulu, Ch .Ramesh (December 2012) "Design Optimization of Leaf Spring'' (IJERA) Vol.2 Issue 6, pp.759-765 Available: www.ijera.com

[25] M. Raghavedra, Syed Altaf Hussain, V. Pandurangadu, K. PalaniKumar (July-August 2012) "Modeling and Analysis of Laminated Composite Leaf Spring under the Static Load Condition by using FEA'' (IJMER) vol.2, issue 4 ISSN: 2249-6645 Available: www.ijera.com

.