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VIBRATION ANALYSIS OF COMPOSITE LEAF SPRING USED FOR PASSENGER CAR

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ABSTRACT

The automobile industry has shown increased interest in the replacement of steel springs with fiberglass reinforced composite leaf springs. Therefore, the aim of this paper is to present a general study on the design and analysis of composite springs. From this viewpoint, the suspension spring of a compact car, "a jeep" was selected as a prototype. A single leaf, variable thickness spring of glass fiber reinforced plastic (GFRP) with similar mechanical and geometrical properties to the multileaf steel spring, was designed, fabricated (molded and hoop wound) and tested. The testing was performed experimentally in the laboratory and was followed by the road test. The objectives of the paper explain about Kevlar, a synthetic polymer. To Examine the structure, properties, Advantages, Disadvantages and Various Application marine sporting goods and aerospace applications of a Kevlar which is a super strong material. This material enables appreciation in various fields Such as in this paper automobile composite leaf spring.

***Keywords*: Kevlar K49 Composite, Composite Leaf Spring, Steel Leaf Spring, Euler Beam Theory,**

I. INTRODUCTION

A spring is defined as an elastic body, whose function is to distort when loaded and to recover its original shape when the load is removed. Leaf springs absorb the vehicle vibrations, shocks and bump loads (induced due to road irregularities) by means of spring deflections, so that the potential energy is stored in the leaf spring and then relieved slowly. [1]

In order to conserve natural resources and economize energy, weight reduction has been the main focus of automobile manufactures in present scenario. Weight reduction can be achieved primarily by introduction of better material, design optimization and better manufacturing processes.[2] The suspension leaf spring is one of potential items for weight reduction in automobiles as accounts for 10% - 20% of the unstrung weight. This achieves the vehicle with more fuel efficiency and improved riding qualities. The introduction of composite materials was made it possible to reduce the weight of leaf spring without any reduction on load carrying capacity and stiffness. This achieves the vehicle with more fuel efficiency and improved riding qualities. The suspension leaf spring is one of the potential items for weight reduction in automobile as it accounts for ten to twenty percent of the unstrung weight.[3] This helps in achieving the vehicle with improved riding qualities. It is well known that springs, To improve 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. This paper is mainly focused on the implication of composite materials by replacing steel in conventional leaf spring of a suspension system. The achievement of weight reduction with adequate improvement of mechanical properties has made composite a very good replacement material for conventional steel. A composite is composed of a high-performance fibers such as carbon, Kevlar, graphite or glass in a matrix material that when combined provides better properties compared with the individual materials by themselves. The composite materials are used in structural application areas, such as in aircraft, space, automotive, for sporting goods, and marine engineering .The various type of glass fibers available are Carbon fiber, C-glass, S-glass and E-glass.[4] Automobile – sector is showing an increased are designed to absorb and store energy and then release it. Hence, the strain energy of the material becomes a major factor in designing the springs. The introduction of composite materials was made it possible to reduce the weight of the leaf spring without any reduction on load carrying capacity and stiffness.Since; the composite materials have more elastic strain energy storage capacity and high strength-to-weight ratio as compared to those of steel.[5] The introduction of composite materials was made it possible to reduce the specific weight of the leaf spring without any reduction on load carrying capacity and stiffness. Since the composite materials have more elastic strain energy storage capacity and high strength-toweight ratio as compared to those of steel. Several papers were devoted to the application of composite materials for automobiles. The application of composite structures for automobiles and design optimization of a composite leaf spring has been studied by Rajendran. Great effort has been made by the automotive industries in the application of leaf springs made from composite materials. Great effort has been made by the automotive Multi leaf springs used in automotive vehicles normally consists of full length leaves and graduated length leaves.[6]

Experimentation is one of the scientific research method, perhaps the most recognizable; in a spectrum of methods that also includes description, comparison, and modeling.

II. MATERIAL PROPERTIES OF KEVLER-EPOXY

The original family of product types of Kevlar, having similar tensile properties with many deniers and finishes. Has a unique combination of high strength, high modulus, toughness and thermal stability. **Kevlar** is the trade name (registered by DuPont Co.) of aramid (poly- Para- phenylene terephthalamide) fibers.

Kevlar K49 – high modulus used in aerospace, automotive and marine applications.

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Sr.No	Properties	Value
1	Tensile modulus along X-direction	73000 Mpa
2	Tensile modulus along Y-direction	6550 Mpa
3	Tensile modulus along Z-direction	6550 Mpa
4	Tensile strength of material	900 Mpa
5	Compressive strength of the material	450 Mpa
6	Poisson ratio along XY-direction	0.217 MPa
7	Poisson ratio along YZ-direction	0.0366 MPa
8	Poisson ratio along ZX-direction	0.217 MPa
9	Mass density of the material	$1.44*10^3$ gm/mm^3

III.THEOROTICAL ANALYSIS

1.1. BEAMTHEORY

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 c the above eq (1) can be modified as

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

An elegant technique known as "Mode superimposition" technique exists for the continuous system with linear behaviour. The technique will be discussed in detail with an example. To apply the mode superimposition technique, it is necessary first to know the natural frequencies and corresponding mode shapes.

1.2 Natural Frequencies and Mode Shapes

The natural frequencies and mode shapes are obtained considering the homogeneous solution of the beam vibration equation. We consider the undamped mode in bending vibration of the beam with uniform sectional property. For free vibration let f(x,t)=0 and assume that the response is given by

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

in which $\Phi(x)$ is the mode shape function and ω is the circular natural frequency.

Substituting (49) in eq. (47), one has

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

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

In order to solve Eq. 3.7 the following boundary conditions for Cantilever Beam are needed:

1. At x=0 → W=0

2. At x=0 → W|=0

3. At x=L→ WII=0

4. At x=L→ WIII=0

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

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

$$[\sin h\beta l - \sin \beta l]C_3 + [\cos h\beta l + \cos \beta l]C_4 = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad 3.8$$

We can write Eq. 3.8 in matrix form as

$$\begin{bmatrix} \cos h\beta l + & \cos \beta l + & \sin h\beta l + \sin \beta l \\ \sin h\beta l - & \sin \beta l - & \cos h\beta l + \cos \beta l \end{bmatrix} \begin{bmatrix} C_3 \\ C_4 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad 3.9$$

For solving matrix of Eq. 3.9, we get determinant

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

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

Hence we get,

$\cos \beta L \cosh \beta L = 1$

This transcendental Eq. has an infinite number of solutions $\beta i = 1,2,3 \ldots n.$

Corresponding giving an infinite number of natural frequencies,

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

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

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

Where,

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

I = Moment of inertia of system

P = Density of Material

A = Area of cross section

L = Length of spring

Beam Condition	$(\beta_1 l)^2$ fundamental Mode	$(\beta_2 l)^2$ second Mode	$(\beta_3 l)^2$ third Mode
Clamped-Clamped	22.4	61.7	121.0

The end conditions for system are same as that of suspension connected to vehicle body. Both ends are fixed.

By Calculation-

1. Modes For Steel Leaf Spring-

Sr. No	Modes of Vibration	Frequency in Hz
1	$1^{st\ Mode}$	85.56
2	$2^{nd\ Mode}$	235.67
3	$3^{rd\ Mode}$	462.18

2. Modes For Composite Spring-

Sr. No	Modes of Vibration	Frequency in Hz
1	$1^{st\ Mode}$	95.51
2	$2^{nd\ Mode}$	263.08
3	$3^{rd\ Mode}$	515.93

IV.EXPERIMENTAL ANALYSIS

Experimental studies carried out by using FFT Analyzer. Specifiction the FFT Analyzer are as followes.

Input Channels:	• 4 AC, ICP® power supply on/off • 4 DC for process values • 1 TACHO for external trigger
Input Range:	• AC +/- 12 V peak-peak • DC +/- 24 V
AD Conversion:	• 24 bit, 64 bit internal signal processing No AutoGain function

Dynamic Range S/N:	Dynamic range S/N: • 120 dB
Frequency Ranges:	• Max. 76 kHz (1 Ch, 196 kHz sampling) • Max. 25 kHz (4 Ch, 64 kHz sampling) • Min. 25 Hz (4 Ch, 64 Hz sampling)
Sampling Mode:	• fully simultaneous for 4 channels
FFT Resolution:	• Min. 100 lines • Max. 25 600 lines
Data Processing:	• FFT real time analysis • ENVELOPE analysis • ACMT - low speed bearing analysis • order analysis • user band pass analysis • RPM measurement • DC measurement • Orbit measurement
Signal Recorder:	• 64 kHz sampling frequency • 4 Ch memory consumption 3 GB/hour • 4 Ch total recording - 35 hours
Communication:	• USB
Temperature Range:	• -10°C to +50°C
Power:	• Battery 5 hours operation, AC 230 V

V.RESULTS AND DISCUSSION

To determined natural frequency and mode shape of both Steel Leaf Spring and Composite Leaf Spring. Results obtained from FFT Analyzer in graphical

Bump Test For Steel Leaf Spring-

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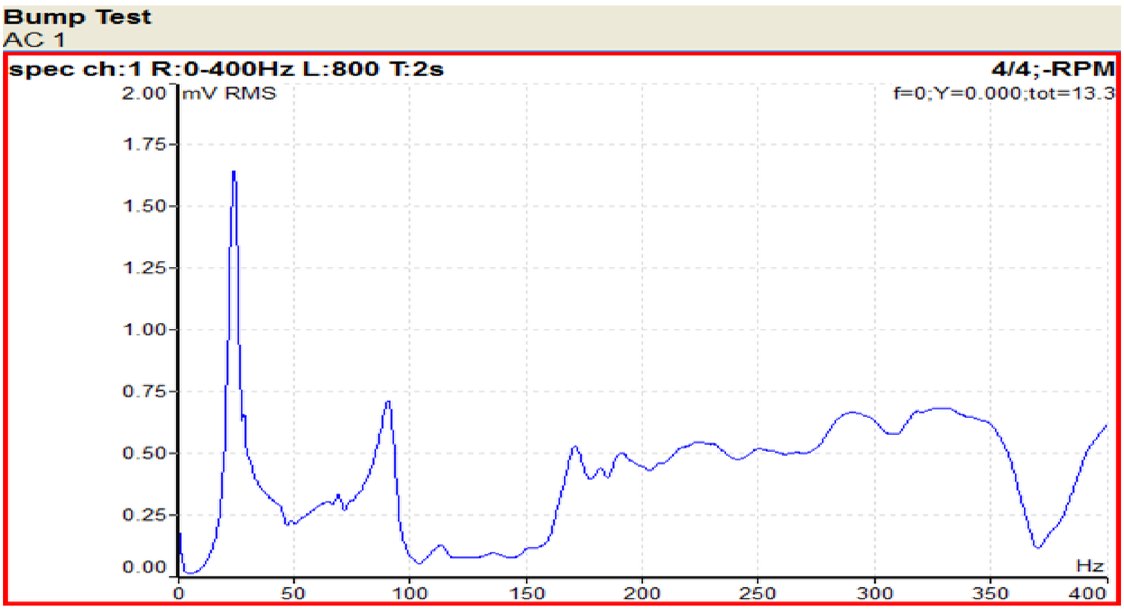
Bump Test For Composite Leaf Spring-



VI. CONCLUSION

The research demonstrated that composites can be used for leaf springs for light weight vehicles and meet the requirements, together with substantial weight savings. A comparative study has been made between composite and steel leaf spring with respect to weight and strength. From above experimentation, it is obtained that the natural frequencies of the composite leaf spring is more than the steel leaf spring with similar design specifications but not always is cost- effective over their steel counterparts. Due to high natural frequency less vibration occurs in composite leaf spring. Hence more comfort provided. Due to weight Reduction, Direction stability achieved. Composite materials have more elastic strain energy storage capacity and high strength to weight ratio as compared with those of steel.

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