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Modeling and Simulation of Composite Mono Leaf Spring

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***Abstract*—The present study evaluates the capability of composite leaf spring in automobiles by considering cost effectiveness and strength. Upon introduction of composite mono leaf spring in automobiles, will reduce about 10-20% of the unsprung mass of the vehicle which in turn increases the efficiency. This study uses the E-Glass/Epoxy composite mono leaf spring having constant cross sectional area along its length and optimized geometry for static and dynamic (modal) analysis. Dynamic simulation was also carried out in order to investigate the stability of composite mono leaf spring.**

Keywords—Composite mono leafspring, E-Glass/ epoxy, Modal,static..

I. INTRODUCTION

Suspension is the term given to the system of springs, shock absorbers and linkages that connects a vehicle to its wheels and allows relative motion between the two. In recent years, researches in the area of automobile component have been receiving the considerable attention; particularly the automobile manufacturers and parts makers have been attempting to reduce the weight of the vehicles. Investigation of composite leaf spring in the early 60's failed to yield the production reality, because of inconsistent fatigue performance and absence of strong need for mass production.

P Beardmore, et al., [1] demonstrated the viability and potential of FRP (Fibre Reinforced Plastic) in automotive structural applications. The suspension system utilizing a transverse FRP leaf spring to integrate the functions of existing stamped steel lower arms and coil springs of escort vehicle rear suspension has developed. *K.H Lo, et al.,* [2] conducted a general discussion on design and analysis of constant width with variable thickness composite leaf spring for tank-trailer suspensions. *WJ Yu,et al.,* [3] has evaluated the fundamental properties of a double tapered glass fiber-epoxy leaf spring for automobile suspension. They have showed superior endurance, fail-safe characteristics and sufficient strong device for vehicle attachment. *Rajendran, et al.,* [4] has developed an optimum design of composite leaf spring using FEM. *E BreuceKirkhan, et al.,*[5] has done the development of the light flex composite spring for automobile suspension, which is a unique new product that has brought together the technologies of materials processing and design to meet the needs of today's automotive world. *P F Timmins et al.,* [6] has justified the emphasis of vehicle weight reduction in 1977 by taking a new look at composite spring. But still, extensive knowledge of the design parameters of composite materials and major innovations in fabrication technologies is needed.

The present work evaluates the capability of composite leaf spring in automobiles by considering cost effectiveness and strength. Presently, automobile industries have shown interest for the replacement of a steel spring with glass fibre composite mono leaf springs. The introduction of composite mono leaf spring in automobiles will reduce about 10-20% of the unsprung mass of the vehicle which in turn increases its efficiency. Because of high strength to weight ratio and better damping characteristics of composite mono leaf spring better riding quality and comfort can be expected. Static and Dynamic analysis of *Composite Mono Leaf Spring* has been carried out by using CATIAV5R18, HYPERMESH 11.0, OPTISTRUCT and MATLAB softwares for modelling, meshing, solving and dynamic analysis respectively.

II. METHODOLOGY

Composite mono leaf spring's model was created using optimised dimensions in CATIAV5R18 software. The constant cross-section design method was adopted because of its capability for mass production and accommodation of continuous reinforcement of fibers. The geometric model was then imported to ALTAIR HYPERMESH 11.0 software and sophisticated meshed model was generated using four noded QUAD element for the analysis purpose. The HYPERMESH model was analysed in OPTISTRUCT solver followed by Static analysis and Dynamic analysis (Modal). For Simulation of the working conditions and to obtain the dynamic response of the system (Composite mono leaf spring) MATLAB software was used. The responses such as step input response, impulse input response, and Bode diagrams were obtained. Overall comparison of analysis results with that of conventional steel spring was carried out to justify the suitability and feasibility of *Composite Mono Leaf Spring*.

III. PRE-PROCESSING

A. *Geometry optimization*

With the design variables as thickness and width at the center and at ends, the optimization of the geometry has been carried out by selecting constant cross-selection area design concept by series of iterations. In each iteration one particular combination of width and thickness at center and ends chosen and corresponding values of stresses and deflection values were obtained using ANSYS. Detailed view of optimized geometry of composite mono leaf spring is shown in the Fig: 1.

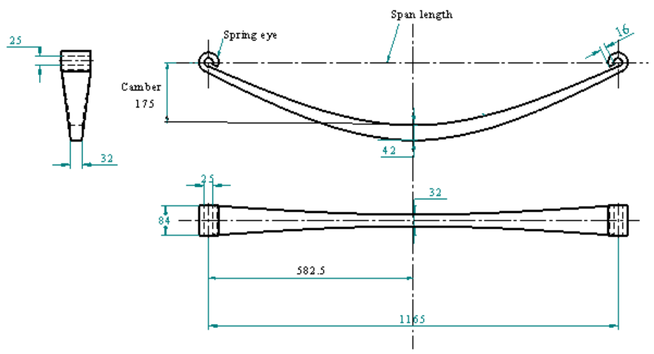

Fig. 1: Detailed View of Optimized Geometry of Composite Mono Leaf Spring.

B. Material Selection

The commonly used fibers are Carbon, Glass, Kevlar, etc. Among these, E-Glass fiber was chosen for our work because of its high stiffness, high strength, and low density with intermediate cost. In a Fiber Reinforced Plastic (FRP), the interlaminar shear strength is controlled mainly by the matrix system used. Since there are no reinforcement fibers in the thickness direction, fibers do not influence inter laminar strength. Therefore the matrix system should have good inter laminar shear strength characteristics compatibility to the selected reinforcement fiber. Many thermostat resins such as polyester, vinyl ester and epoxy resin are being used for fiber reinforced plastics fabrication. Among these resin systems, epoxies show better inter laminar strength and good mechanical properties.

C. Meshing

4 node Quad element meshing has been carried out to get the finite element model in HYPERMESH. The meshed model is shown in fig. 2.

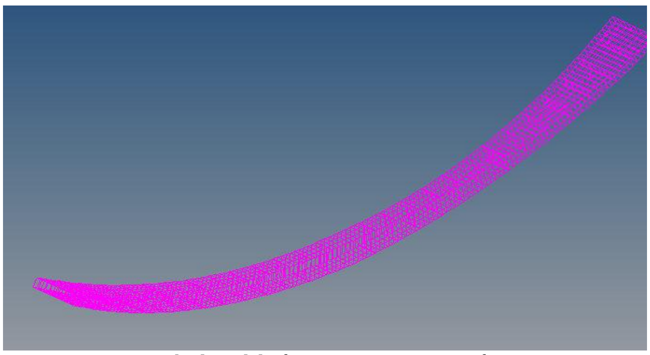

Fig. 2: Meshed model of Composite Mono Leaf Spring.

The mesh details are shown below in table 1.

Table 1: Mesh Details.

Specification	Parameters
Number of elements	688
Type of element	4 Node, QUAD
Number of nodes	836
Type of mesh	QUAD Mesh

D. Boundary Conditions

According to boundary conditions nodes were constrained in all directions and a load of 1925 N was applied at the center in upward direction as shown below in fig. 3.

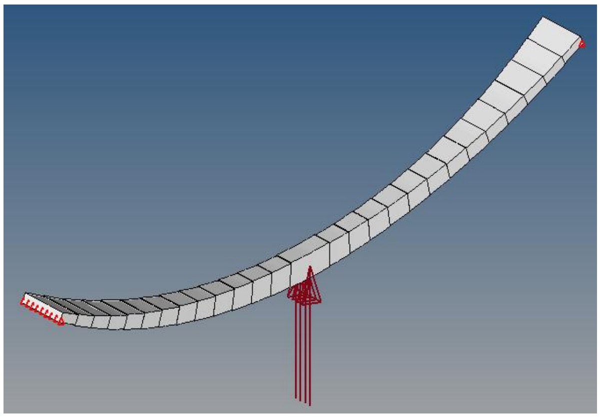

Fig. 3: Boundary conditions.

IV. RESULTS and DISCUSSIONS

A. Static Ananlysis

The results of the static analysis of *Composite Mono Leaf Spring* are illustrated in figures 4 to 6.

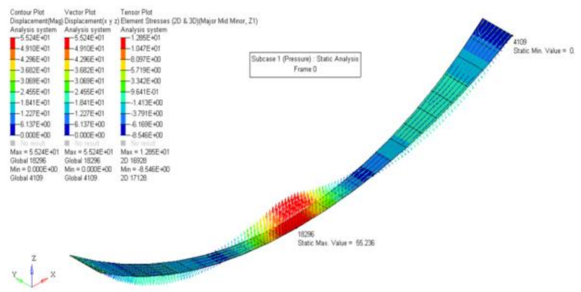

Fig. 4: Contour Plot of the Displacement Analysis System

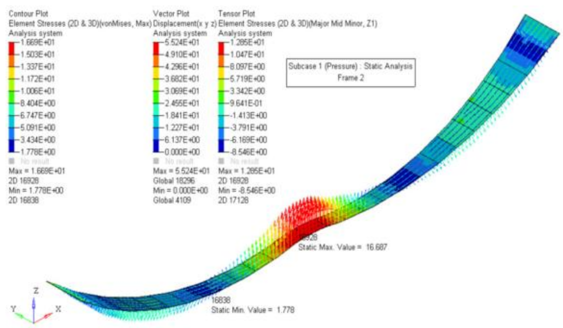

Fig. 5: Contour Plot of the VonMises Stress in Model

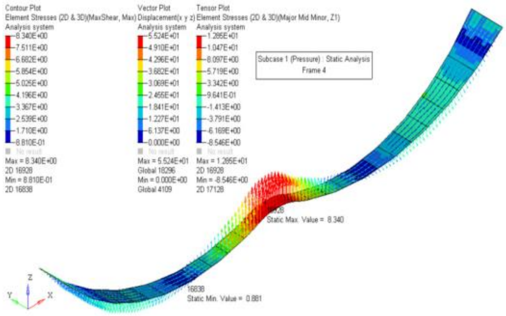

Fig. 6: Contour Plot of the Max Shear Stress in Model.

It is observed from the above figures that the maximum deflection is 55.24 mm, stress along Z direction is 12.85 N/mm^2, Von Mises stress is 16.69 N/mm^2 and Max shear stress is 8.34 N/mm^2.

B. Dynamic/Modal Ananlysis

The importance of the study of dynamic characteristics such as mode shapes and natural frequencies are critical for composite mono leaf spring. Thus mode shape gives necessary information and data regarding the damping behavior of the system. To better understand a structural vibration problem, it is needed to characterize the resonances of a structure. A common and useful way of doing this is to define its modes of vibration. Each mode is defined by a modal frequency, modal damping, and a mode shape.

The modal analysis results for 0.6 fibre volume fraction are presented for the first seven modes. The corresponding mode shapes of modal analysis of composite spring are shown in fig. 7 to 13.

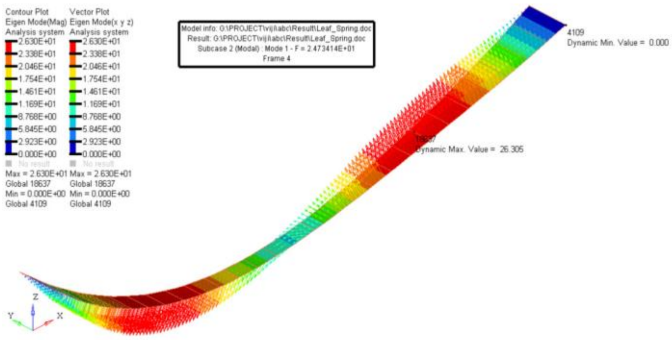

Fig. 7: Mode Shape 1.

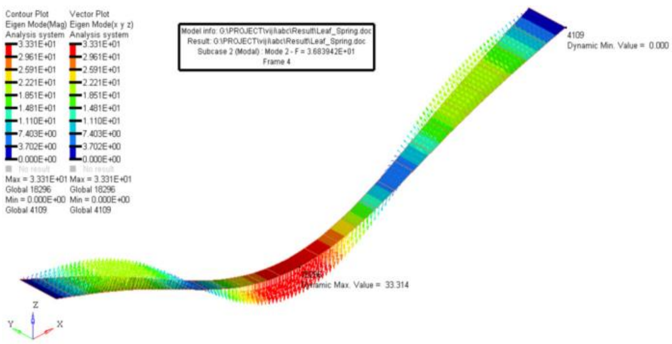

Fig. 8: Mode Shape 2.

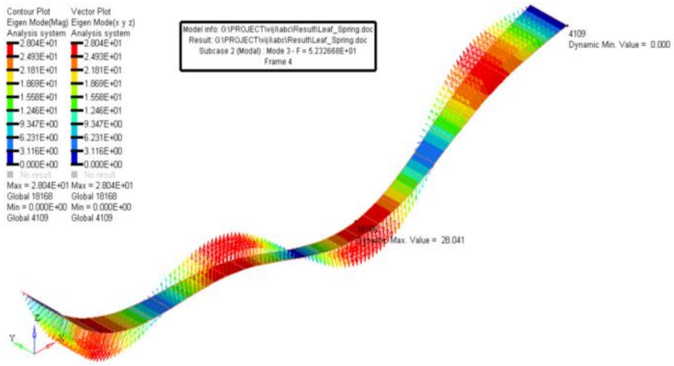

Fig. 9: Mode Shape 3.

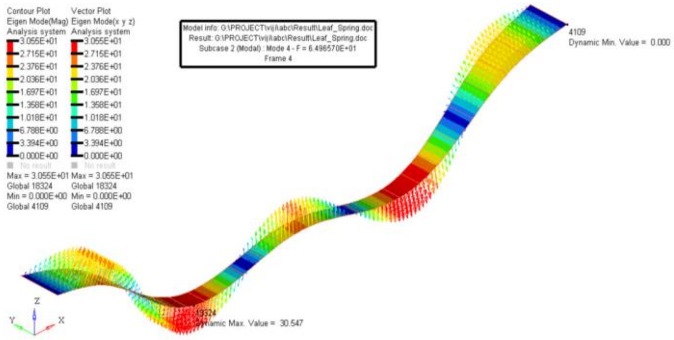

Fig. 10: Mode Shape 4.

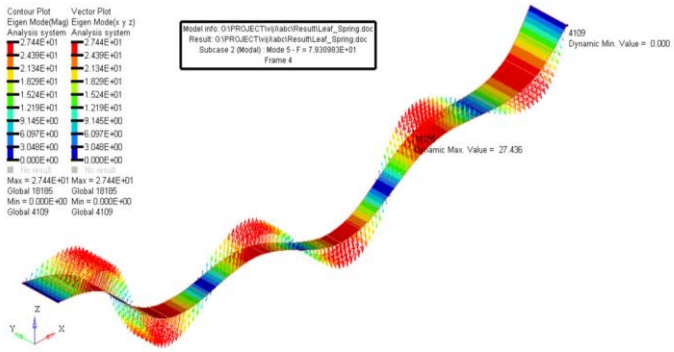

Fig. 11: Mode Shape 5.

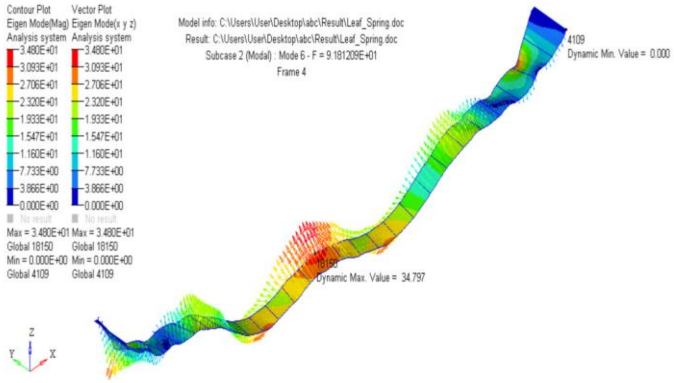

Fig. 12: Mode Shape 6.

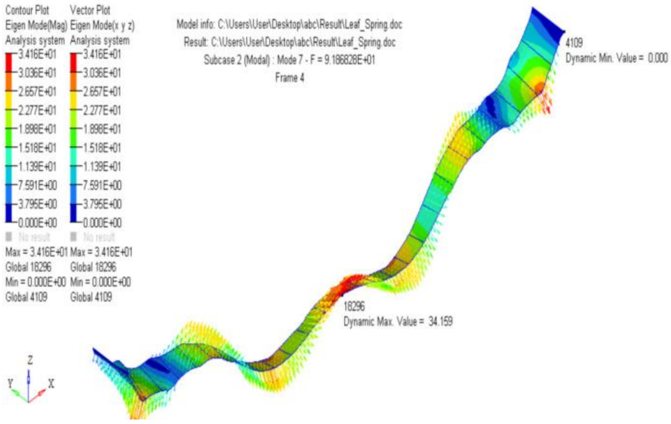

Fig. 13: Mode Shape 7.

The results of Modal analysis are tabulated in table 2.

Table 2: List of Natural Frequencies for different modes

Mode	Fiber volume fraction V_f= 0.6
	Natural frequency (Hz)
1.	24.73
2.	36.84
3.	52.33
4.	64.97
5.	79.31
6.	91.81
7.	91.87

C. *Dynamic Simulation Results*

A block diagram of Dynamic Model is shown in figure 14.

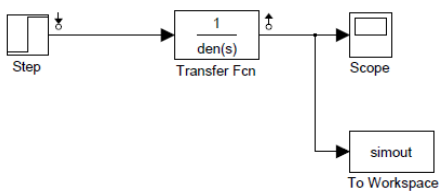

Fig. 14: A block diagram of Dynamic Model.

The governing equation for the dynamic simulation of a composite mono leaf spring is given by,

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=\{f\} \quad (1)$$

The performance of *Composite Mono Leaf Spring* is compared with *Steel Multi Leaf Spring* as validation for the variables mentioned in table 3.

Table 3: Specifications of Leaf Spring.

Variables	Mono leaf composite spring	Multi leaf steel spring
Total Mass	6.36 kg	17.83 kg
Damping Coefficient	0.9604 N s/ m	0.1051 N s/ m
Stiffness	32.7 N/mm	38.72 N/mm

Figures 15 to 20 show the step response plot, Bode diagram plot and impulse response plot for both the leaf springs.

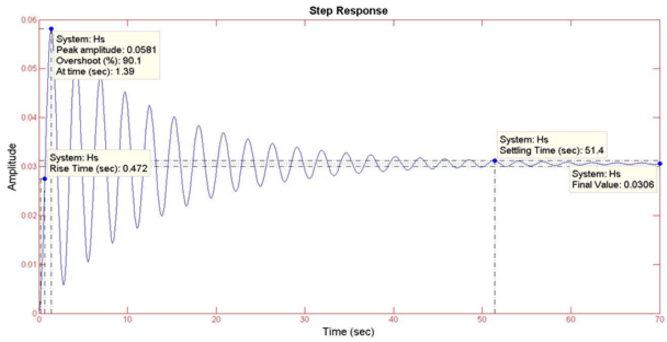

Fig. 15: Step response plot of mono leaf composite spring.

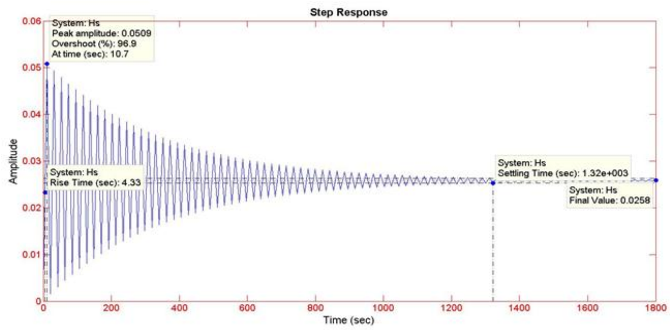

Fig. 16: Step response plot of multi leaf spring.

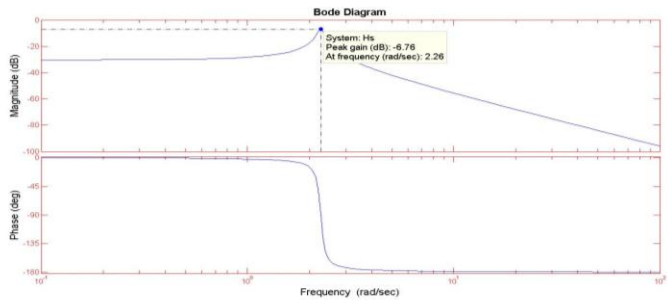

Fig. 17: Bode Diagram Plot of Composite Mono Leaf Spring.

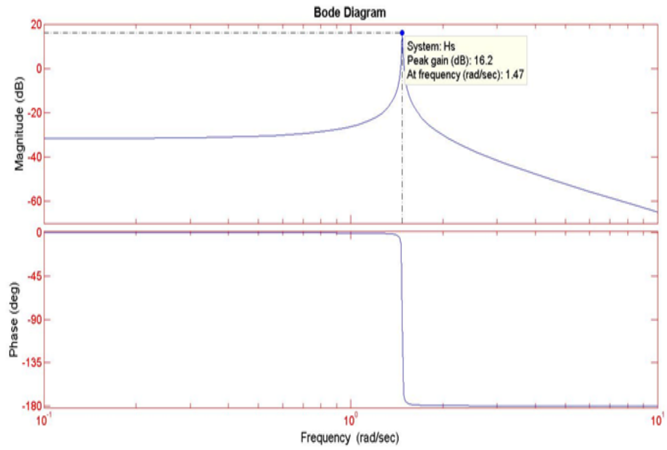

Fig. 18: Bode Diagram Plot of multi leaf steel spring.

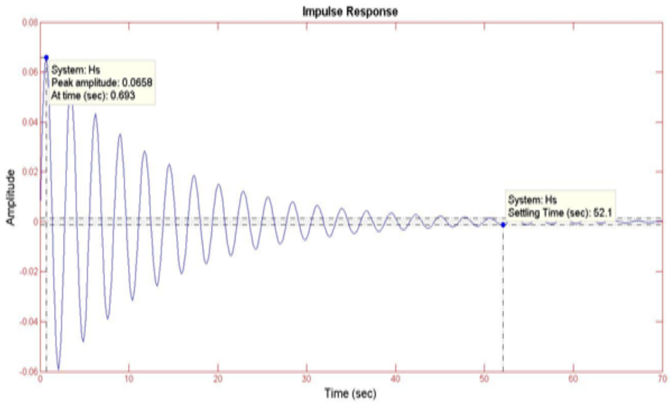

Fig. 19: Impulse response plot of composite mono leaf spring.

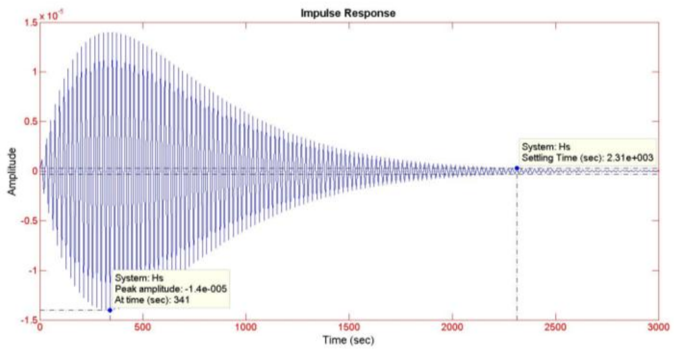

Fig. 20: Impulse response plot of multi leaf steel spring.

The linearized results of dynamic simulation of *Composite Mono Leaf Spring* and *Multi Leaf Steel Spring* are tabulated in the table 4. Although the peak amplitudes of both springs in step response and impulse response are almost similar, there is a difference in settling time which is of prime concern. The results show that the *Composite Mono Leaf Spring* has less settling time in comparison with *Multi Leaf Steel Spring*. From the Bode Diagram plots, it can be observed that the *Mono Leaf Composite Spring* is more stable as the magnitude of its peak gain is negative, where as it is higher in *Multi Leaf Steel Spring*. The dynamic simulation results indicate that the *Composite Mono Leaf Spring* is more stable and feasible.

Table 4: Results of Dynamic Simulation.

Plot	Specification	Composite Mono Leaf Spring	Steel Multi Leaf Spring
Step Response	Peak Amplitude (mm)	0.0581	0.0509
	Over Shoot (%)	90.1	96.9
	Rise Time (s)	0.472	4.33
	Settling Time (s)	51.4	1320
Bode Diagram	Peak Gain (db)	-6.76	16.2
	Frequency (Rad/Sec)	2.26	1.47
Impulse Response	Peak Amplitude (mm)	0.0658	1.4 x e-5
	Settling Time (s)	52	2310

V. CONCLUSION

The E-Glass/Epoxy composite mono leaf spring having constant cross sectional area along its length and optimized geometry has been considered for static and dynamic (modal) analysis. Dynamic simulation was also carried out in order to investigate the stability of composite mono leaf spring.

The geometric modeling was carried out using CATIA V5R18 and meshing by HYPERMESH tool using 4 noded QUAD elements. OPTISTRUCT solver was used to perform static and dynamic (modal) analysis. The deflection and stress results of static analysis were well within the safer limits for composite mono leaf spring.

The modal (dynamic) analysis for the same FE model was carried out using OPTISTRUCT. The modal shapes and frequencies up to seven modes were obtained which ranges from 24.73 Hz to 91.87Hz. The first natural frequency obtained (24.73 Hz) was well away from the vehicle operating frequency and give safe riding characteristics.

Dynamic Simulation of Composite Mono Leaf Spring and Multi Leaf Steel Spring were carried out using Simulink in MATLAB tool. The amplitude, magnitude and settling time parameters as observed in Step response, impulse response and Bode plot of Composite Mono Leaf Spring were well acceptable compared to Multi Leaf Steel Spring.

To accomplish, the overall study demonstrates that E-Glass epoxy composite mono leaf spring can be used in place of conventional multi leaf steel spring for light motor vehicles to meet the strength and stiffness requirements together with substantial weight savings that eventually leads to fuel efficiency.

ACKNOWLEDMENT

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