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Design and Durability Testing of Composite Mono Leaf Spring

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Abstract: A leaf spring is commonly used for the suspension in vehicles. It is an automotive component which is used to absorb vibrations induced during the motion of vehicle. Leaf springs are long and narrow plates attached to the frame of a trailer that rest above the trailer's axle. The load on the leaf spring acts on the center. The spring thus vibrates and prevents the vibrations to pass over to the other parts. There are single leaf springs and multi leaf spring used based on the application required. It also acts as a structure to support vertical loading due to the weight of the vehicle and payload. The Glass fiber reinforced plastics (FRP) composite mono leaf spring reduces weight of the machine element without any reduction of the load carrying capacity. It has high strength-to-weight ratio compared with those of steel. Also multi-leaf steel springs are being replaced by mono leaf FRP spring. The objective of this project work is to design and manufacturing of composite leaf spring.The experimentation is conducted for durability and results are compared with steel leaf spring.

Keywords : Glass fiber reinforced plastics, Leaf Spring, thermoset matrix, springs, automobile

I. Introduction

In order to conserve natural resources and economize energy, weight reduction has been the main focus of automobile manufacturer in the present scenario. Weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. 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 unsprung weight [1]. This helps in achieving the vehicle with improved riding qualities. It is well known that springs, 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 relationship of the specific strain energy can be expressed as, [1]

$$U = \frac{\sigma 2}{\rho E}$$

Where,
σ is the strength
ρ is the density
E is the Young's modulus of the spring material.

It can be easily observed that material having lower modulus and density will have a greater specific strain energy capacity. The use of composite materials 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. Also it is known that the failure nature of steel leaf springs is usually catastrophic and it is essential to replace steel leaf springs by gradually failing FRP (fiber reinforced polymer) composite material. In every automobile i.e. four wheelers and railways, the leaf spring is one of the main components and it provides a good suspension and it plays a vital role in automobile application. It carries lateral loads, brake torque, driving torque in addition to shock absorbing. The advantage of leaf spring is that the ends of the leaf spring may be guided along a definite path as it deflects to act as a structural member in addition to energy absorbing device.

Composite has received attention largely from the automotive industry due to their superior mechanical properties and relative ease of processing. The use of a thermoset matrix gives the molder the ability to modify and enhance the properties of the resin by blending additives, fillers and fire retardants depending upon the nature of the application.

In this work includes design and manufacturing of GFRP composite leaf spring with unidirectional fiber orientation angle 0^0 is considered. The implementation of composite materials for leaf springs of a suspension system can replace steel in conventional spring to reduce the weight. Its durability is tested experimentally.

PankajSaini et al. [1] studied on design and analysis of composite leaf spring. The objective is to compare the stresses and weight saving of composite leaf spring with that of steel leaf spring. The material selected was glass fiber reinforced polymer (E-glass/epoxy), carbon epoxy and graphite epoxy is used against conventional steel. A single composite leaf spring is designed and it is shown that the resulting design and simulation stresses are much below the strength properties of the material satisfying the maximum stress failure criterion. From the static analysis results it is found that there is a maximum displacement in the steel leaf spring is lower than corresponding displacements in E-glass / epoxy, graphite/epoxy, and carbon/epoxy leaf spring. Among the three composite leaf springs, only graphite/epoxy composite leaf spring has higher stresses than the steel leaf spring. E-glass/epoxy composite leaf spring can be suggested for replacing the steel leaf spring, from Composite mono leaf spring reduces the weight by 81.22% for E-Glass/Epoxy, 91.95% for Graphite/Epoxy, and 90.51 % for Carbon/Epoxy over conventional leaf spring. [1] E. Mahdi and A.M.S. Hamouda [2] shown that new composite semi-elliptical suspension spring by utilizing fiber reinforced composite. They tested three types of composites, namely, carbon/epoxy, glass/epoxy and glass/carbon/epoxy. Tests are conducted and behaviors of their compression, tension, torsion and cyclic tests showed that the fiber type and ellipticity ratio significantly influenced the spring stiffness. Y.S. Kong et.al [3] simulated the fatigue life of a parabolic leaf spring design under variable amplitude loading (VAL). VALs signal were gathered through measurements from various road conditions such as highway, curve mountain road and rough rural area road. Subsequently, fatigue life of particular leaf spring design was predicted using finite element (FE) stress–strain model together with VALs signal as load input. The results indicated that fatigue life of leaf spring is lowest during rough road mission, followed by curve mountain road and smooth highway road respectively. Yogesh G. Nadargi et.al [4] studied on comparison between steel leaf spring and composite leaf spring. In case of composite leaf spring the stresses that are much lower, the natural frequency is higher and the spring weight is nearly 85 % lower with bonded end joint and with complete eye unit.B.Vijaya Lakshmi et.al [5] compared the load carrying capacity, stiffness and weight savings of composite leaf spring with that of steel leaf spring. R D V Prasad et.al [6] deals with development of analytical formulation for Composite leaf spring and comparing the obtained results with the Conventional Steel leaf spring with 4 leaves. Composite leaf spring in this research has been developed as a mono block construction with maximum thickness at the center which is preferably glass fiber reinforced polymer. The thickness reduces towards the end in order to achieve uniform strength construction. The cross-section is constant at any section along the spring length. This condition is imposed to accommodate the unidirectional fibers and to maintain the fiber continuity from one end to the other. At first they designed a conventional Leaf spring with 4 leaves using ANSYS 11 and considered different loading conditions to obtain Stresses and Deflections.

II. Design of composite leaf spring

Specific Design Data

Here Weight and initial measurements of "TATA ACE HT" light vehicle are taken.

Gross vehicle weight = 1770 kg

Taking factor of safety (FS) = 1.4

Acceleration due to gravity (g) = 9.81 m/s²

There for; Total Weight (W) = 1770*9.81*1.4 = 24310 N

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

F = 24310/4 = 6077 N

Steel Leaf Spring Specifications of TATA ACE

Total Length (L) 1060 mm

Length of leaf spring from Eye to Eye 990 mm

Thickness (t) 8 mm

Width (b) 60 mm

No. of leaf =2

Material Properties of 55Si2Mn90 Steel [10]

1. Ultimate tensile strength - 1962 Mpa
2 .Yield tensile strength - 1470 Mpa
3. Modulus of elasticity (E) – 210 Gpa
4. Poisson ratio 0.3

Design of Composite Leaf spring

Since the leaf spring is fixed with the axle at its centre, only half of it is considered for analysis purpose. From the material point of view a unidirectional E-glass/Epoxy composite material is selected. It is selected due to its relative advantages stated in the literature review above, mainly high strength to weight ratio and high capacity of storing strain energy in the longitudinal direction of the fibres. Optimum volume fraction of matrix phase selected to be 40% and for the fiber phase it is 60%.

We have to find t=? And b=?

$$\sigma_{max} = \frac{6WL}{bt^2}$$

$$\delta_{max} = \frac{4WL^3}{Ebt^3}$$

$$t = \frac{\sigma_{max} L^2}{E\delta_{max}}$$

Since we consider half of the leaf spring we substitute 'L/2' instead of 'L' to calculate 't' and 'b'. As the end of leaf spring is hinged, the entire leaf spring will only be loaded under tension. Therefore, we consider only the longitudinal properties.

For E-glass/Epoxy

Maximum stress (σ_{max})=473 MPa

Maximum deflection (δ_{max})=105 mm

Measured data of the above stated light weight 4-wheeler vehicle

Length of the leaf spring (L) = 1060mm

Parameter	At center	At end
Leaf thickness (mm)	28	14
Leaf width (mm)	52	99

Table: 1 Composite leaf spring specification

Hence, we have selected the dimensions for GFRP composite mono leaf spring and it is manufactured with specific material and Hand lay-up technique is used for manufacturing.

III. Experimental set up

One end of the composite leaf spring is fixed to the rigid frame and other end is movable. Load on the leaf spring acts on the center and is then distributed along longitudinal direction. The spring thus vibrates and prevents the vibration to pass over to the other assembled parts and body. The load is given by using cam follower mechanism to the leaf spring at center by considering different road conditions. Cam follower mechanism is placed right below the leaf spring and it gives the vibrations that will takes place on the leaf spring. The frequency of the vibrations generated by the cam follower mechanism set up. Vibrations given to the spring are given on the basis of the road conditions.

Experimental Setup Consist of 1)Leaf spring

- DC motor
- Cam and follower mechanism
- Variable frequency drive.
- Accelerometer

The experimental test rig is used for testing of leaf spring. Test is conducted for specific frequency of vibration considering road conditions and durability is evaluated for steel and composite leaf spring. Experimental setup diagram is as follows: Durability is defined as the ability of material to staying strong and in good condition over a long period of time without any breakage or significant deterioration. As usual after long period of working of leaf spring the stiffness of steel leaf spring deteriorates, it results in comfort of vehicle reduces.

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Fig: 1 Experimental set up

To find the durability of leaf spring, it is tested for particular time interval on experimental set up and stiffness calculated by UTM machine.For all the above purpose we need to design the setup on which composite and steel leaf spring should be mounted which gives us the expected results.

IV. Selection of frequency of vibration considering road conditions

Road conditions are majorly depending upon the roughness of road surface. So roughness is the parameter which is most important in consideration of road condition for the leaf springs. Roughness is the surface irregularities in 0.5 – 50 m wavelength. This corresponds to the frequency range which induces relative motion in road vehicle suspension system over a reasonable range of operating speeds. Consider general road conditions in India where the wavelength of normal road in city ranges from 0.5m-33m.

Let, considering average road condition of wavelength $\lambda = 6$ m

Now we know that

$V=\lambda f$

Where,

V-velocity of vehicle

λ- Wavelength

f - frequency of vibration of road surface.

If we consider average speed of vehicle i.e V= 40 Km/Hr

f= V/ λ=1.85 Hz.

This is frequency of vibration of road surface .So select this frequency as frequency of vibration for leaf spring and adjusts speed of cam accordingly.

V. Durability testing of steel and composite mono leaf spring

The stiffness of steel and composite leaf spring is tested by using UTM as shown in Figs. The spring is loaded from zero to the maximum deflection and back to zero. The load is applied at the Centre of spring; the vertical deflection of the spring at Centre is recorded.

Procedure of Durability Testing

1) Find the stiffness of leaf spring by using UTM before the experimentation.
2) As vibrations are given to leaf spring by using cam follower mechanism, adjust the speed of cam which is equal to the frequency of vibration for leaf spring considering the road condition.
3) Vibrations are given to the leaf spring continuously for one hour and then stiffness is calculated by using UTM.
4) Again Vibrations are given to the leaf spring continuously for two hours, three hours, four hours and corresponding stiffness is calculated by using UTM.

Sr.no	Time,(Hr)	Stiffness of steel leaf spring (N/mm)	Stiffness of composite leaf spring (N/mm)
1	0	39.56	56.62
2	1	38.01	55.95
3	2	37.08	55.00
4	3	35.95	54.56
5	4	35.08	54.01

Table: 2 Stiffness of steel and composite leaf spring at particular time interval of vibrations

VI.Results and discussions

Stiffness deterioration of springs

As we know that stiffness is the ability of material to resist the deformation. In above graph we have seen that the stiffness of steel and composite leaf spring decreasing slowly when tested for continuous vibrations for specific time intervals. So we need to find the stiffness deterioration of steel and composite leaf spring.

Stiffness deterioration can be finding by following formula:

For one hour vibrations of leaf spring:

% Stiffness deterioration $= \frac{K_0 - K_1}{K_0}$

For two hour vibrations of leaf spring:

% Stiffness deterioration $= \frac{K_0 - K_2}{K_0}$

Similarly this formula is used for next specific time intervals of vibrations

Where,

K_0 – Stiffness of leaf spring at zero hour of vibrations to the leaf spring (Before experimentation)

K_1- Stiffness of leaf spring after one hour of vibrations to the leaf spring.

K_2- Stiffness of leaf spring after two hour of vibrations to the leaf spring.

The calculations of stiffness deterioration tabulated as follows:

Sr.no	Time, (Hr)	Stiffness of steel leaf spring (N/mm)	% Stiffness deterioration	Stiffness of composite leaf spring (N/mm)	% Stiffness deterioration
1	0	39.56	0.00	56.62	0.00
2	1	38.01	3.92	55.95	1.18
3	2	37.08	6.27	55.00	2.86
4	3	35.95	9.12	54.56	3.64
5	4	35.08	11.32	54.01	4.61

Table: 3 Stiffness deterioration of steel leaf spring at particular time interval of vibrations

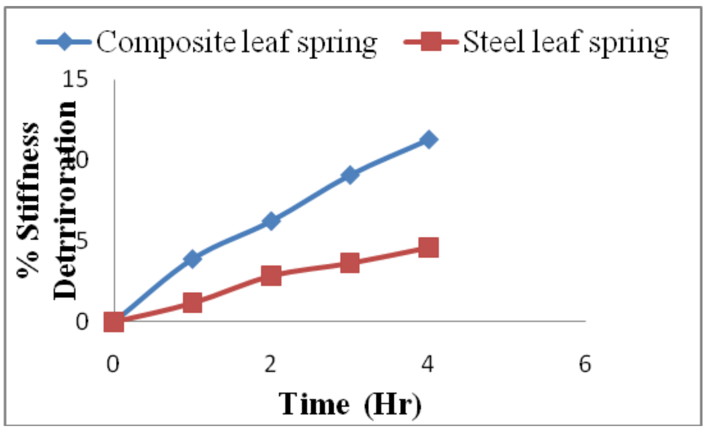

Fig.:2Percentage stiffness deterioration of steel and compositeleaf springs
Vs. particular time interval of vibration

Above graph of percentage stiffness deterioration of steel and composite leaf springs verses particular time interval of vibration reveals that the percentage stiffness deterioration of steel leaf spring is higher than the composite leaf spring when tested for continuous vibrations for specific time intervals. It means the ability of steel material to resist the deformation is lower than the composite material. This results shows when we run the vehicle for long time the composite leaf spring gives the better results than the conventional leaf spring.

VII. Conclusion

1. Composite mono leaf spring reduces the weight by 68% for E-Glass/Epoxy over conventional steel leaf spring.
2. Comparison of composite leaf spring and steel spring is done based on their working on actual road condition. The stiffness of both leaf springs is determined and it is seen that composite leaf spring gives better result compare to conventional steel leaf spring
3.When we run the vehicle for long time the percentage stiffness deterioration of steel leaf spring is higher than the composite leaf spring. It means the ability of steel material to resist the deformation is lower than the composite material. When we run the vehicle for long time the composite leaf spring gives the better results than the conventional leaf spring.
4. Also percentage deterioration in natural frequency of steel leaf spring is higher than the composite leaf spring when tested for continuous vibrations for specific time intervals. It means steel leaf spring is more prone to resonance than the composite leaf spring.

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