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A Review on Design of leaf Spring Rear Suspension for Rear Mounted Engine

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ABSTRACT

Leaf spring is major part of vehicle suspension system which is subjected to millions of varying stress cycles leading to fatigue failure. In a commercial light vehicles engine is placed at front or middle providing large space to the rear axle. Advantages of the new rear suspension design of the light commercial vehicle have been captured. In most of the vehicle Engine is placed at rear to have low engine noise and vibration inside cabin of vehicle. This research is related to overview of the design, development and validation of the leaf spring rear suspension for a light commercial vehicle for rear engine. It also explains aspects of the structural durability of the components can be evaluated by using finite element analysis and actuator testing. Vehicle dynamics stability and overall suspension design parameters can be verified by using finite element analysis and actual testing of vehicle.

Keywords— Suspension system, Structural Stability, Finite element analysis, Leaf spring, Fatigue failure.

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I. INTRODUCTION

A leaf spring is a major part of suspension system in wheeled vehicles. Semi-elliptical spring or cart spring is oldest form of 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, Tie holes called eyes are provided at one end for attaching to the vehicle body. In case of heavy loaded vehicles, a leaf spring can be made from several leaves, called as multi leaf spring.

Leaf springs can serve locating and to some extent damping as well as springing functions. 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. The shackle takes up the tendency of the leaf spring to elongate when compressed and thus makes for softer springiness.

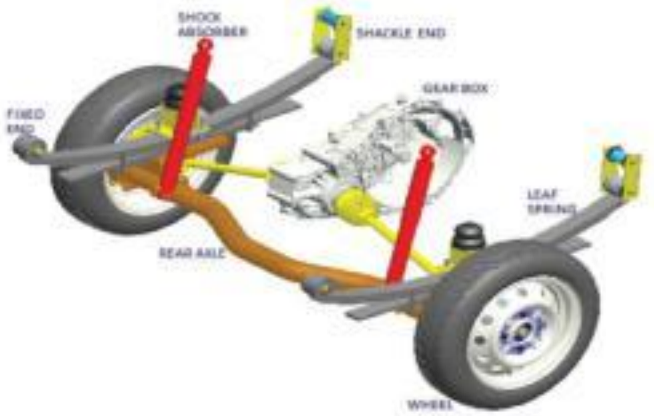

Fig.1 Rear Suspension Concept for Rear Engine.

II. LITERATUE SURVEY

Rajendran, S. Vijayarangan formulates and gives solution technique using genetic algorithms (GA) for design optimization of composite leaf springs is presented here. The suspension system in an automobile significantly affects the behavior of vehicle, i.e. vibration characteristics including ride comfort, directional stability, etc. Leaf springs are commonly used in the suspension system of automobiles and are subjected to millions of varying stress cycles leading to fatigue failure. If the unsprung weight (the weight, which is not supported by the suspension system) is reduced, then the fatigue stress induced in the leaf spring is also reduced. Leaf spring contributes for about 10–20% of unsprung weight. Hence, even a small amount of weight reduction in the leaf spring will lead to improvements in passenger comfort as well as reduction in vehicle cost. In this context, the replacement of steel by composite material along with an optimum design will be a good contribution in the process of weight reduction of leaf springs. Different methods are in use for design optimization, most of which use mathematical programming techniques. This paper presents an artificial genetics approach for the design optimization of composite leaf spring. On applying the GA, the optimum dimensions of a composite leaf spring have been obtained, which contributes towards achieving the minimum weight with adequate strength and stiffness. A reduction of 75.6% weight is achieved when a seven-leaf steel spring is replaced with a mono-leaf composite spring under identical conditions of design parameters and optimization.[1]

Alieldin proposed the first-order shear deformation plate (FSDP) model is exploited to investigate the mechanical behavior of laminated composite and functional graded plates. Three approaches are developed to transform the laminated composite plate, with stepped material properties, to an equivalent functionally graded (FG) plate with a continuous property function across the plate thickness. Such transformations are used to determine the details of a functional graded plate equivalent to the original laminated one. Functionally graded materials (FGM) are microscopically inhomogeneous composite materials, in which the volume fraction of the two or more materials is varied smoothly and continuously as a continuous function of the material position along one or more dimensions of the structure. These materials are mainly constructed to operate in high temperature environments. In this study, a first-order shear deformation plate (FSDT) model, exploited for the investigation of the mechanical behavior of composite laminated plates and functional graded plates, is introduced.[2]

Dipendra Kumar Roy et al studied the numerical analysis of large deflection of prismatic cantilever beams for various types of material properties with a transverse load at free end, to study the displacement response of leaf springs. Besides the free end displacement, the variation of stress, strain and the bending moment of the beam having variable material properties with the beam length are obtained by the technique of minimization of total potential energy. The mathematical formulation is based on a variational principle using

Galerkin's assumed mode method. The displacement functions are approximated by linear combination of sets of orthogonal coordinate functions, developed through Gram-Schmidt scheme and substituted in the governing equilibrium equation. The final solution of the large displacement geometric nonlinear problem is obtained iteratively with the help of MATLAB computational simulation.[4]

Vladimír Goga et al said that main purpose of vehicle suspension is to achieve good driving stability and passenger comfort regardless of road surface. These requirements are often contradictory. Further studied to show the possibilities offered by a combination of modeling in a virtual environment and evolutionary computation in the process of optimization. Mathematical half-car model was created in Matlab/Simulink.

He will focus on the use of the genetic algorithms to optimization of passive suspension parameters with respect to these requirements. The aim of his study was optimized passive suspension parameters with using genetic algorithms. Optimization criteria were passenger comfort (vertical and angular accelerations of vehicle body) and driving stability (contact wheels with road). Each criterion had the same priority. Optimization was performed use with Matlab/Simulink via mathematic model of half car model. Results for model with optimized parameters show significant decreasing of amplitudes and faster stabilization of measured quantities against results of model with original parameters. Generally passive suspension is not ideal to achieve good driving stability and passenger comfort therefore semi-active and active suspensions are more expanded. Future work will be oriented to use genetic programming for design and optimization parts of semi-active and active suspensions. [5]

Ramu I et al published Different methods for performing static and dynamic analysis of plate like structures. The finite element method (FEM) is widely used and powerful numerical approximate method. The finite element method involves modeling the structure using small inter connected elements called finite elements. The finite element method of structural analysis enables the designer to found stress, vibration and thermal effects during the design process and to evaluate design changes before the construction of a possible prototype. Thus assurance in the acceptability of the prototype is improved.[6]

Mahmood M Shokrieh Davood Rezaei studied optimization of leaf spring. A four-leaf steel spring used in the rear suspension system of light vehicles is analyzed using ANSYS V5.4 software. The finite element results showing stresses and deflections verified the existing analytical and experimental solutions. Using the results of the steel leaf spring, a composite one made from fiber glass with epoxy resin is designed and optimized using ANSYS. He concluded from the results obtained that an optimum spring width decreases hyperbolically and the thickness increases linearly from the spring eyes towards the axle seat. Compared to the steel spring, the optimized composite spring has stresses that are much lower, the natural frequency is higher and the spring weight without eye units is nearly 80% lower.[7]

M.A. Osipenko proposed a work regarding contact problem in the theory of leaf spring bending. The weak joint bending (unbounded contact without friction) of the stack of slim non-uniform curved beams (leaves) with rectangular cross-sections is considered. Each leaf has one end clamped and the other free. The leaves have the same widths and different lengths (the lengths decrease upwards). The given loading is applied (upwards) to the lower leaf. This structure is the model of a leaf spring. The basic problem is to find the shapes of the leaves under bending. This problem is reduced to the problem of finding the densities of the forces of interaction between the leaves. The uniqueness of the solution of the problem is proved. The analytical solution is constructed in the special case of two uniform straight leaves.[10]

A. Project Need

To sustain in the today's competitive market it is necessary to have low cost sustainable design of suspension systems which will satisfy the customer demands with desired life. To fulfill this requirements many automotive industry keeps their focus on developing their own design methodology which gives better outcomes with available resources. Many test rigs are also required to verify and validate design parameters along with high end software's which consumes a major part of financial assistance.

Hence it is necessary to develop a methodology which gives an optimized design with minimum mathematical computation, minimum resources for testing and validation and with less consumption of time and money for above mentioned unique design.

B. Problem Definition

In traditional design the engine was placed at the front, it require huge space so resulting in vibration in cabin & high engine noise. The design of rear mounted engine reduces this defect i.e. noise & vibration in cabin at the same time it also eliminates the propeller shaft which is used to transfer drive from power pack to axle housing in traditional one. At the same time there is a need of high load carrying rear suspension to suit market requirement so necessary to use leaf spring type rear suspension.

III. DESIGN CALCULATIONS

Considering Material of the spring is 50 Cr 1or oil tempered carbon steel.

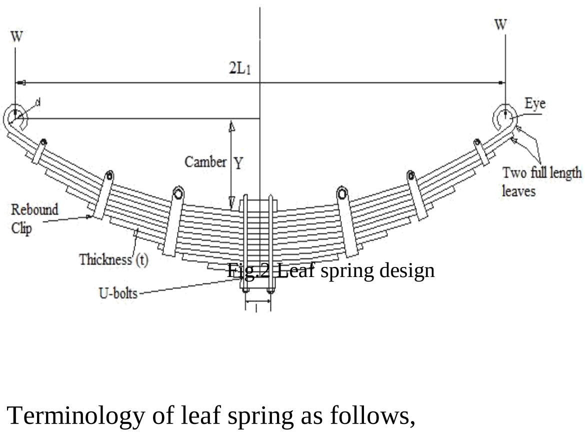

Fig.2 Leaf spring design

Terminology of leaf spring as follows,

1. Thickness of Leaves = t
2. Width of Each Leaf = b
3. No of Leaves = n
4. Maximum Load = W
5. Length of Cantilever Spring = L
6. Modulus of Elasticity of Material = E
7. Maximum Bending Moment in the Centre (M) = W.L

A. Length Of Semi-Elliptical Leaf Spring Leaves:

The length of the leaf springs leaves may be obtained as discussed below:

1. 2L1 = Length of span or overall length of the spring
2. ℓ = Width of Band or distance between centers of U-Bolts. It is the ineffective length of the spring
3. nf = Number of full length leaves
4. ng = Number of graduated leaves
5. n = Total number of leaves
   = (Full length leaves + Graduated leaves)

Effective length of the spring,

2L = 2L1- ℓ (When band is used)… (1) =
2L1 - ℓ (When U-bolts are used) …(2)

When there is only one full-length leaf (i.e. master leaf only), then the number of leaves to be cut will be n and when there are two full length leaves (including one master leaf), then the number of leaves to be cut will be (n-1) if a leaf spring has two full-length leaves, then the length of leaves is obtained as follows:

Length of smallest leaf = $\frac{\text{Effective length}}{}$ + Ineffective Length ... (3)

$$\text{Length of next leaf} = \frac{\text{Effective length}}{n-1} \times 2 + \text{Ineffective Length} \quad \ldots (4)$$

Similarly,

$$\text{Length of (n-1) the leaf} = \frac{\text{Effective length} \times}{n-1}\text{(n-1)} + \text{Ineffective Length} \quad \ldots (5)$$

The n[th] leaf will be the master leaf and it is of full length. Since the master leaf has eyes on both sides, therefore

Length of Master Leaf = 2L1 + π (d + t) × 2 … (6)

Where,
d = Inside diameter of eye
t = Thickness of master leaf

The relation between the radius of curvature(R) and the camber (y) of the spring is given by :

$$y\,(2R + y) = (L1)^2 \quad \ldots (7)$$

Where,
L1 = Half span of the spring.

The maximum deflection (δ) of the spring is equal to camber (y) of the spring.

B. Theoretical Calculations For Steel Leaf Spring

Deflection,

$$\delta = \frac{6WL^3}{nEbt^3(2n} \ldots \quad (8)$$

+2n)
g f

Where,

W = Load on leaf spring = 500 N
L = length of leaf spring = 595 mm
n = Number of Leaves = 1
E = the modulus of elasticity = 2e5 N/mm^2
b = Width of Leaves = 50 mm
t = Thickness of Leaves = 8 mm

$$\delta = \frac{6 \times 500 \times 595^3}{1 \times 2e5 \times 50 \times 8^3}$$

= 12.42 mm

Bending stress,

$$\sigma_b = \frac{3WL}{nbt^2}$$

$$\sigma_b = \frac{6 \times 500 \times 595}{1 \times 50 \times 8^2}$$

= 69.75 N/mm^2

The stored elastic strain energy in a leaf spring varies directly with the square of maximum allowable stress and inversely with the modulus of elasticity both in the longitudinal and transverse directions according to

Strain energy,

$$= \frac{\sigma^2}{2 \ldots} \qquad (9)$$

Where,

σ = allowable tensile stress, ρ is the density.

=
1962^2
2 x 7.85 − 6 x 2 5

= 1.226e6 J

Stress developed in the full length leaves is 50% more than that in the graduated leaves.

Step1: Bending stress and displacement in the graduated leaves

For analysis half the spring can be considered as a cantilever. It is assumed that the individual leaves are separated and the master leaf placed at the center. Then the second leaf is cut longitudinally into two halves, each of width (b/2) and placed on each side of the master leaf. A similar procedure is repeated for rest of the leaves The graduated leaves along with the master leaf thus can be treated as a triangular plate of thickness as shown in figure 3.

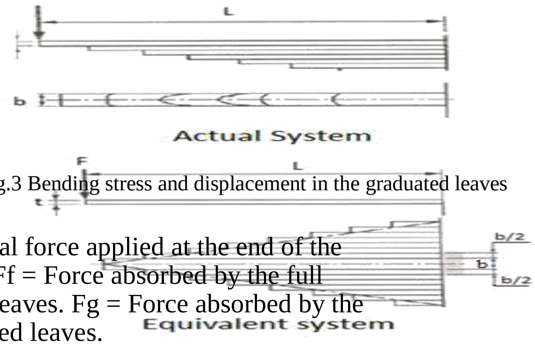

Fig.3 Bending stress and displacement in the graduated leaves

Let,

F = Total force applied at the end of the spring Ff = Force absorbed by the full length leaves. Fg = Force absorbed by the graduated leaves.

The bending stress developed in the graduated leaves will be:

$$\sigma_{bg} = \frac{M_b y}{I} = \frac{F_g L(\frac{t}{2})}{\frac{1}{12}(i_g b)t^3} = \frac{6F_g L}{i_g bt^2} \qquad \ldots\ldots (10)$$

For cantilever triangular plate, the deflection at the point of application of force is given by:

$$\delta_g = \frac{F_g L^3}{2EI_{max}} = \frac{6F_g L^3}{Ei_g bt^3} \qquad \ldots\ldots(11)$$

Step 2: Bending stress and displacements in full length leaves It is assumed that the individual leaves are separated and the full length leaf is placed at the center. Then the second full length leaf is cut longitudinally into two halves, each of width (b/2) and placed on each side of the first leaf. A similar procedure is repeated for the rest of the leaves. The resulting cantilever beam of thickness'' is shown in the figure 4.

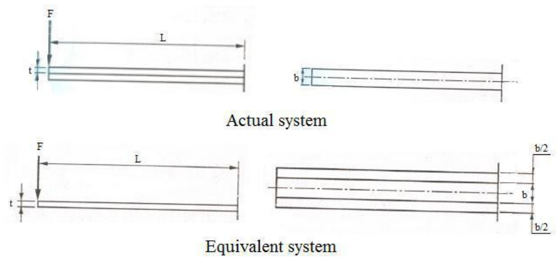

Fig.4 Resulting cantilever beam

The bending stress developed in the full length leaves will be:

$$\sigma_{bf} = \frac{M_b y}{I} = \frac{F_f L(\frac{t}{2})}{\ldots} = \frac{6F_f L}{\ldots}$$

$bf \quad I \quad \frac{1}{12} \quad (i_f b)t^3 \quad t_f\, bt^2$

For a cantilever rectangular plate, the deflection at the point of application of force is given by:

$$f \quad Ť \frac{F L^3}{3EI_{max}} \quad Ť \frac{4F L^3}{E i_f bt^3} \quad f \quad f$$

…. (13)

Step 3:

Since the graduated leaves and the full leaves are clamped together the deflection for both should be the same.

$= \quad = \quad ….$ (14)

$6 F L^3 \quad 4F L^3$ g f Ť

$Et^3\ bt \quad Et^3\ bt$ g f

$F \quad 2t$ Ť g g

$F \quad 3i$ f f

$F Ť F \quad Ǵ F$ g $\frac{F}{2i}$

$F Ť F \quad (1 Ǵ \frac{g}{3i_f})$ f

On solving we get,

$$F_f \; Ť \left(\frac{3Fi_f}{3i_f \; Ǵ \; 2i_g}\right) \text{ and } F_g \; Ť \left(\frac{3Fi_g}{3i_f \; Ǵ \; 2i_g}\right)$$

….. (15)

Substituting the values of Ff and Fg in the equations of ····bf and ····bg we get;

$$\sigma_{bf} \; Ť \frac{18FL}{(3i_f \; Ǵ \; 2i_g)bt^2} \text{ and } \sigma_{bg} \; Ť \frac{12FL}{(3i_f \; Ǵ \; 2i_g)bt^2}$$

…. (16)

Taking the ratios of both stresses and solving we get;

$$\frac{\sigma_{bf}}{\sigma_{bg}} \; Ť \; 1.5$$

…. (17)

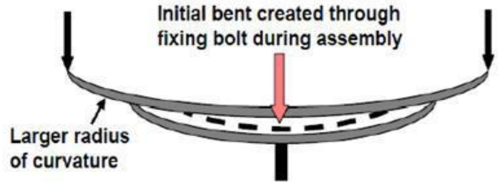

Fig. 5 Equalized stress in spring leaves (Nipping)

The stress in the full length leaves is 50% greater than the stress in the graduated leaves. To distribute this additional stress from the full length leaves, pre-stressing is done. This

is achieved by bending the leaves to different radii of curvature, before they are assembled with the centre bolt.

The full length leaves are given in greater radii of curvature than the adjacent one. Due to the different radii of curvature, when the full length leaves are staked with the graduated leaves, without bolting, a gap is observed between them. This gap is called Nip. The nip eliminated by tightening of the center bolt due to these pre-stresses is induced in the leaves. This method of pre-stressing by giving different radii of curvature is called as nipping. By giving a greater radius of curvature to the full length leaves than graduated leaves before the leaves are assembled to form a spring.

NipC:

The value of the initial Nip C is nothing but the difference in deflection between the full length and the graduated leaves

$c \; Ť \; \delta_g \; Ή \; \delta_f$

Solving, we get;

$$c \; Ť \frac{2FL^3}{tb'h^3E}$$

…… (18)

IV. EXPERIMENTAL METHODOLOGY

Suspension design for rear engine, consist of following steps:

A. Vehicle Layout Making

Rear suspension layout done by using two point deflection method using 3 link mechanisms. Using various formulas Calculations are made to get front and rear suspension roll centers and corresponding roll axis. In this concept level stage, different suspension parameters like, spring stiffness and camber, spring mountings, bump stop stiffness etc are fine tuned and finalized.

B. Rear axle design

Due to rear engine mounting, Engine is coming in between rear suspension making the design complicated. Considering all packaging constraints, rear axle is designed by bending center tube at offset position with wheel center.

Spring design becomes complicated for target load and stiffness.

C.Finite Element Analysis of Rear axle

Rear axle analysis done to get optimized size and thickness of different parts to withstand overloading. Initially analysis is done with complete vehicle model of rear axle, spring, to get effect of leaf spring & bush stiffness on stress level of rear axle. With the help of above works reference small reduced model is developed to make different iterations to design, cost effective rear axle with minimum time.

D. Dynamic calculations

Transient analysis done to get acceleration levels for ride comfort calculations from straight line stability test.

E. Design Verification

We are validating Strain data at critical locations while vehicle running on different roads and track. Stress levels measured with the help of software and actuator testing are found matching. Acceleration levels on axle and frame is acquired and found reasonably matching with calculated.

F. Validation:

To reduce testing time, sub system level testing is done in actuator lab. Test setup consist of rear axle, spring, frame etc is made. Frame fixation and actuator loading point in this sub system is finalized using FEA to match the stress levels on rear axle between complete vehicle and sub system. Only damaging load is extracted from pave track and applied to actuators in test lab to reduce testing time. Testing is successfully completed for targeted kilometers. Due to FEA & design verification activities no failure occurred during testing.

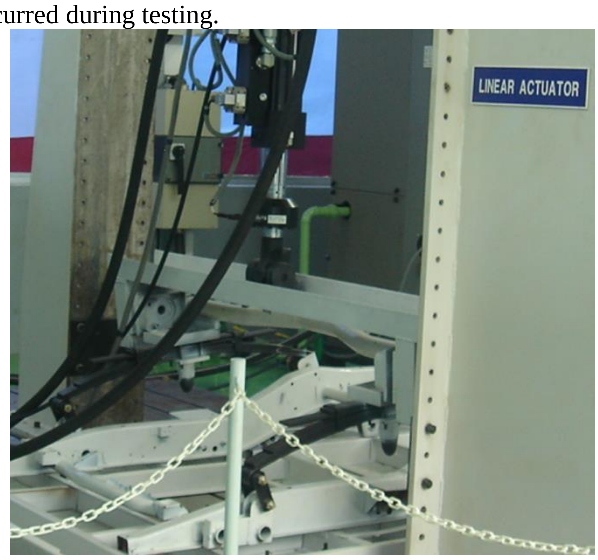

Fig.6 Test setup of rear suspension system testing.

At the final stage the complete rear suspension system we will test in actuator lab. And FEA analysis has done with the help of software.

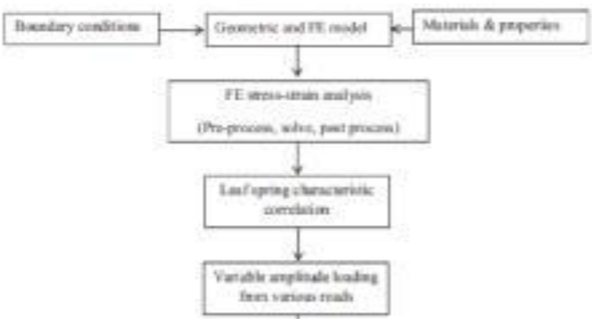

Fig.7 FEA procedure

V.MODEL BUILDING

A finite element analysis may be carried out for a number of different purposes, and the modeling requirements depend on its intended use. For fatigue analysis, the results are very sensitive to the accuracy of the calculated stresses and strains in localized regions of a component. To achieve acceptable levels of accuracy, the following are essential requirements.

A. Model Creation:

Initially analysis is done with complete vehicle model as shown in Fig 3 consists of rear axle, spring, spring bushes, frame etc. To get effect of all components on stress level of rear axle. Based on this, small reduced model is developed and correlated with full vehicle model to give similar values of stresses to make different iterations to design, cost effective rear axle with minimum time.

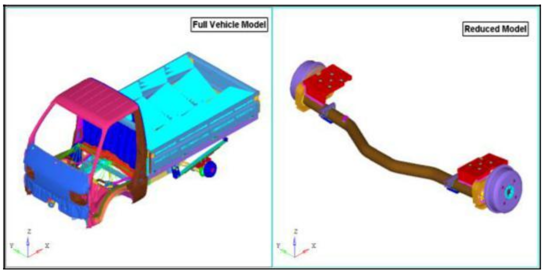

Fig. 8 Full Vehicle Model & Reduced Model.

Component	Full Vehicle	Reduced Model
Centre Tube	373	400
Wheel Support Plate	256	302
Spring Support Plate	137	168

Table 1 Stress comparison between Full Vehicle Model & Reduced Model.

Table 1 show, stress levels at full model and reduced model for critical locations. As stress levels are matching in full model and reduced so possible to use reduced model to save analysis time.

VI. EXPECTED OUTCOMES

This paper gives an overview of the design, development and validation of the leaf spring rear suspension for a light commercial vehicle for rear engine. Aspects of the structural durability of the components can be evaluated by using finite element analysis and actuator testing. Vehicle dynamics stability and overall suspension design parameters can be verified by using finite element analysis and running vehicle on road.

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