Static Analysis of a Leaf Spring using Probabilistic Methods and Finite Element Analysis

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1. Abstract

In this project work, the static analysis of the leaf spring will be performed by using two methods namely, probabilistic analysis and finite element analysis. The CAD model of the leaf spring is designed using the Computer Aided Design tool CATIA and it will be analyzed using the finite element tool ANSYS Workbench 19 R2 under the static structural analysis system. The probabilistic model will be analyzed using all the data from the sample of values of random parameters. And, there will be a comparison between the results of both the methods to analyze the effect of random variables on the output parameters.

Keywords: Leaf spring, CATIA, ANSYS, static analysis, von mises stress, deflection

2. Introduction

Spring is a coil or an elastic body that distorts when a load (either compression or tension) is applied on it and stores some energy and then retain its original shape after the load is removed by releasing the stored energy. For this purpose, leaf spring is mainly used because it has various characteristics such as uniform load distribution, rough use, lower manufacturing & maintenance cost, and it can be tightly attached to the working frame. To ensure a compliant suspension system in the automobile, leaf spring play a vital role as it absorbs the vibrations that occur and impacts due to irregularities of the roads, store it as strain energy and release it slowly.

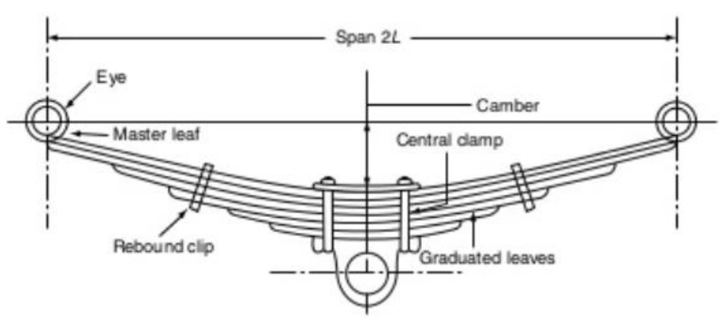

Figure 1 Laminated Leaf Spring

2.1 Literature Review

Jei, Y.-G., et al., [1] introduced a new lateral vibration damper using leaf springs and oil. The stiffness of the leaf spring damper depends on the stiffness of the leaf spring which was varied with the thickness, effective length, and the number of leaves in spring groups. It was found out that the damping was viscous due to oil pressure build-up in the oil spaces and was frictional due to O-rings and small slips between leaf springs.

Shiva Shankar G.S., et al., [2] designed and manufactured a unidirectional E-Glass fiber/Epoxy mono composite leaf spring without end joints and composite leaf spring using bonded end joints using hand lay-up technique. The steel and composite leaf springs were tested by leaf spring test rig for defects like cracks, surface abnormalities, etc. and stress analysis was done using ANSYS under static loading for stresses and deflection. Composite leaf spring weight was reduced by 85% compared to steel leaf spring. Adhesively bonded end joints enhance the performance of composite leaf spring for delamination and stress concentration when compared with bolted joints.

Sorathiya M., et al., [3] compared load carrying capacity, stiffness and weight reduction of composite leaf spring with that of steel leaf spring. They modeled three different composite mono leaf springs by considering uniform cross-section & unidirectional fiber orientation angle for each lamina of a laminate and considered stress & deflection as the design constraints. Static analysis was performed using ANSYS 10.0. A weight reduction of 79.617% was achieved for composite leaf spring and 90.09% for mono leaf spring.

Ishtiaque M.T., et al., [4], designed the conventional flat profile leaf spring and a parabolic shape leaf spring. They considered structural steel as the base material & SAE 5160 steel as second material and obtained the deformation, stress, and fatigue life using ANSYS Workbench. They modified the number of leaves for the same simulation conditions and obtained the optimized design which incorporates the better fatigue life, reduced deformation, reduced weight of the spring, and increased factor of safety.

Qureshi H.A. [5], designed, analyzed and performed experimental investigations of composite leaf spring. Single leaf spring with varying thickness and made of glass fiber reinforced plastic material was tested physically. It was concluded that the GFRP leaf springs have more flexibility and hardness with the reduction in noise parameters as compared to conventional steel leaf springs. Also, the natural frequency and weight were reduced up to 80%.

Gebremeskel S.A. [6], designed, simulated and manufactured a single composite leaf spring for light-weight vehicles. E-Glass/Epoxy material was used for manufacturing the leaf spring. The maximum stress failure criterion was considered for analysis and the hand layup technique was considered for manufacturing. It was found out that the fatigue life of E-Glass/Epoxy leaf spring is 221.16x103 cycles.

Ghag M.D., et al., [7] performed static and dynamic analysis of steel and laminated composite leaf spring using ANSYS 14.5, keeping their objective to compare displacement, frequencies, deflections, and weight reduction. The aluminum alloy unidirectional laminates leaf spring was analyzed by using the layer stacking method for composites by changing reinforcement angles from 3 layers, 5 layers, and 11 layers. A weight reduction of 27.5% was achieved by using composite leaf spring.

The purpose of this project is to implement the concepts of probabilistic methods to analyze the effects of parameters such as the thickness of the leaf, material variation, effective length, and the number of leaves, on stiffness, stress, and deflection in the spring. The objective is to reduce the overall stress in the spring with minimal deflection.

The random variable, material for leaf, can take various inputs but generally the leaf spring is made up of conventional steel, aluminum alloys, and composites. Similarly, the effective length can vary by keeping the radius of the spring to be constant. Number of leaves is a discrete random variable, and the thickness of the leaf & length are the continuous random variables. As there are few materials with the properties lying in a range, it is a continuous variable.

3. **Models/Methodologies**

The spring is designed using the CAD software CATIA and the analysis will be performed using the finite element code ANSYS. For now, the sample values of the dimensions and number of leaves are taken for designing the spring. For the calculations, as it is a semi-elliptical leaf spring, the effective length is calculated by finding the distance between two eyes. But, practically the distance between the eye and the center bolt is calculated to get the exact length of the spring. The cross-section of the leaf is rectangular.

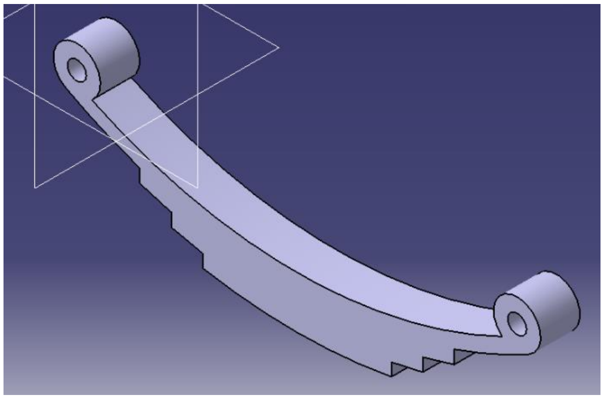

Figure 2 CAD Model of Leaf Spring

3.1 Calculations

The following calculations are performed to calculate the bending stress generated in the leaf spring and the deflection due to the load application at the center of the spring:

Nomenclature:

L = length/span of the spring

t = thickness of the leaf

b = width of the leaf

n = number of leaves

W = load acting on the spring

I = moment of Inertia

σ = maximum bending stress developed

δ = deflection

R = radius of the spring

M = maximum bending moment

A and B = two ends of the leaf spring

C = center point of the leaf spring

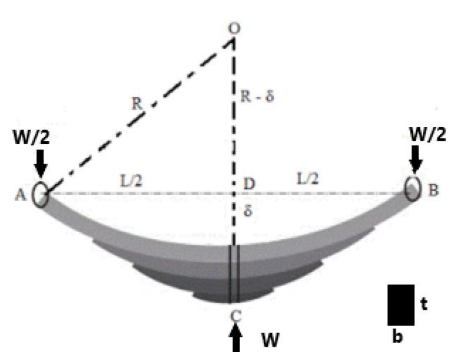

Figure 3 Labeled Leaf Spring

Now, from Figure 3,

$$\text{Maximum Bending Moment, } M = \frac{WL}{4}$$

Using the bending equation,

$$\frac{M}{I} = \frac{\sigma}{y}$$

$$y = \frac{t}{2} \quad and \quad I = \frac{bt^3}{12}$$

$$M = \frac{\sigma b t^2}{6}$$

Total Bending moments for ‘n’ plates = $\frac{\sigma b t^2 n}{6}$

After calculations,

$$\text{Bending stress in the leaf spring, } \boldsymbol{\sigma = \frac{3WL}{2bt^2 n}}$$

From the geometry of leaf spring,

For the deflection,

$$\delta = \frac{L^2}{8R}$$

Using bending equation,

$$R = \frac{Ey}{\sigma}$$

On solving,

$$\text{Deflection in the leaf spring, } \boldsymbol{\delta = \frac{3WL^3}{8bt^3 nE}}$$

3.2 Methodology

The CAD model will be simulated in the ANSYS and the von-mises & deflection in the spring will be analyzed using the static structural analysis system. The model for the probabilistic analysis is yet to study. Finally, the comparison will be made between both the processes and the results will be analyzed accordingly.

4. Discussion

The number of samples is yet to be decided as the range of values for the random variables is not fixed now. One of the errors that may or may not occur depends on calculation or consideration of values of selected random design parameters which can be termed as design errors where limits and tolerances are a good fit to be implicated. The leaf spring design should have utmost limits and tolerances in order to sustain for a longer period.

One of the major advantages of using leaf spring in a vehicle is the suspension it offers. With contemplation on the leaf size and other parameters, it would be interesting to understand all the variables effectively and precisely. On the other hand, the disadvantage that may incur is not able to consider the exact flexibility and rigidity of the leaves which do undergo many critical irregularities on the road. The inter friction between the leaves may also result in failure of the leaf spring during the heavy load conditions.

5. Team Organization and management

Most of the work has been done collaboratively. Hope the same would be continued during the progression of the project. The organization is above the par and the management is expected to be as on time.

6. References

[1] Jei, Y.-G., Kim, J.-S., Hong, S.-W., & Jung, S.-Y. (1999). A New Lateral Vibration Damper Using Leaf Springs. *Journal of Vibration and Acoustics*, *121*(3), 343–350. doi: 10.1115/1.2893986

[2] Shiva Shankar G.S., & Vijayarangan S. (2006). Mono Composite Leaf Spring for Light Weight Vehicle – Design, End Joint Analysis and Testing. *ISSN 1392-1320 Materials Science (Medziagotyra)*, Vol. 12, No. 3. 2006

[3] Sorathiya M., Shah D.B., & Bhojawala V. (2013). Various Numerical Analysis of Composite Leaf Spring for Light Vehicle Mini Truck. *International Conference on Engineering (NUiCONE 2013)*, doi: 10.13140/2.1.2135.8080

[4] Ishtiaque M.T. & Joo S.-W. (2018). Optimized Modeling and Fabrication of a Parabolic Leaf Spring with Finite Element Analysis. *International Mechanical Engineering Congress & Exposition*, IMECE2017-71180, V009T12A052

[5] Qureshi H.A. (2001). Automobile Leaf Spring from Composite Material. *Journal of Material Processing Technology 118*, 58-61

[6] Gebremeskel S.A. (2012) Design, Simulation, and Prototyping of Single Composite Leaf Spring for Light Weight Vehicle. *Global Journal of Researches in Engineering (Mechanical and Mechanics Engineering)*, Volume 12 Issue 7 Version 1.0

[7] Ghag M.D., Nikam M., Ghadigaonkar P.P., & Teli S.N. (2018). Design and Material Optimization of Jeep Leaf Spring. *Global Meet on Advances in Design, Materials & Thermal Engineering [GMADMT-2018]*

[8] Khurmi R.S., Gupta J.K. (2000). A textbook of Machine Design