International Journal of Theoretical and Applied Mechanics.
ISSN 0973-6085 Volume 7, Number 2 (2012) pp. 87-94

http://www.ripublication.com/ijtam.htm

Optimal Design of Automobile Leaf Spring using Finite Element Analysis

A. Chennakesava Reddy, M. Vidya Sagar
and G. Satish Babu

Department of Mechanical Engineering,
JNTUH College of Engineering Hyderabad 500085,
Andhra Pradesh, India
E-mail: dr_acreddy@yahoo.com

Abstract

Effect of width, length and thickness of leaves on the optimal design of the leaf spring has been investigated with the help of the commercial FEM package ANSYS. The stress induced in the leaf spring decreases with increase in the thickness and width of leaves. The results obtained from the finite element analysis are in good agreement with those of conventional design procedure.

Keywords: Leaf spring, Width, thickness, Finite Element Analysis

Introduction

Semi-elliptical leaf springs are universally used for suspension in light and heavy commercial vehicles. The laminated spring consists of number of leaves called blades. The blades are varying in length. The blades are usually given an initial curvature so that they will tend to straighten under the load. The leaf spring design is based upon the theory of beams of uniform strength. Leaves are made up of laminated strips of curves steel. The chassis supports the two ends and middle of the leaf spring is connected to the axle. As the leaf spring is compressed, the steel leaves bend acting as springs, and the leaves slide across each other dissipating energy through coloumb friction. The multi-leaf spring has more than one leaf in its assembly. It consists of a center bolt that properly aligns the leaves and clips to resist its individual leaves from twisting and shifting. Accurate modeling of the leaf springs is necessary in evaluating ride comfort, braking performance, vibration characteristics, and stability.

The suspension systems are modeled by typical multi-body system elements like rigid bodies, links, joints and force elements [1]. Influences of the shapes of spring leaves in a progressive multi-leaf spring were investigated using the semi-analytic model based on the Euler beam theory and the finite element modeling using ABAQUS. The trends in shifting of the location of the contact point were found to change with the shapes of spring leaves. A change in the shapes of the spring leaves caused a change in the transition load of the stiffness of a progressive multi-leaf spring [2]. Based on the characters of the explicit time integration algorithm, node-to-point contact element strategy was proposed and applied to handle the strategic or quasi-static multi deformation body contact with friction [3].

Though simple in appearance, a leaf spring suspension causes many problems in modeling. The establishment and evolution of the finite element method (FEM) has contributed greatly to the solution of many engineering problems, particularly in situations where analytical methods become too complex, and experimental techniques appear inappropriate because of either difficulties in application or instrumentation, or of the high costs which may be involved. There is currently much interest in deformation analysis of multiple bodies in contact. In order to accurately model the deformation and vibrations of the leaf springs, nonlinear finite element procedures are need to be employed. Thus, it is appropriate to have perfect nonlinear FEM to analyze the leaf springs.

Effect of varying parameters like width, length and thickness of the leaf spring are to be investigated with the help of the commercial FEM package ANSYS. The mathematical leaf spring model used in this study is the semi-analytic model based on the Euler beam theory.

Finite Element Modeling of the Leaf Spring

In order to perform 2-Dimensional contact analysis, the geometric model was developed. PLANE182 element was chosen to mesh the leaves. To allow each individual leaf for sliding and bending on its own taking the load from top laef and distributing to the bottom leaves, each leaf should be joined to the top and bottom leaves with contact elements after meshing all the leaves separately. Contact pairs between surfaces were created using CONTA172 and TARGE169 elements [4]. The finite element contact modeling was based on a master-slave relation between the contact surfaces, where the nodes on the slave surface were not allowed to penetrate the surface elements of the master thus the top leaf was taken as source and lower leaf as the target as shown in figure 1. In order to study the effect of contact pairs at different positions, the contact analysis was performed by creating one-to-one contact pair successively between the leaves. This was performed in the following two ways:

- Contact pairs were formed between adjacent leaves from bottom to top.
- Contact pairs were formed between adjacent leaves from top to bottom.

With the successful formulation of contact pairs between all the leaves, six contact pairs were perfectly formed between seven leaves, the contact pairs are shown in figure 2.

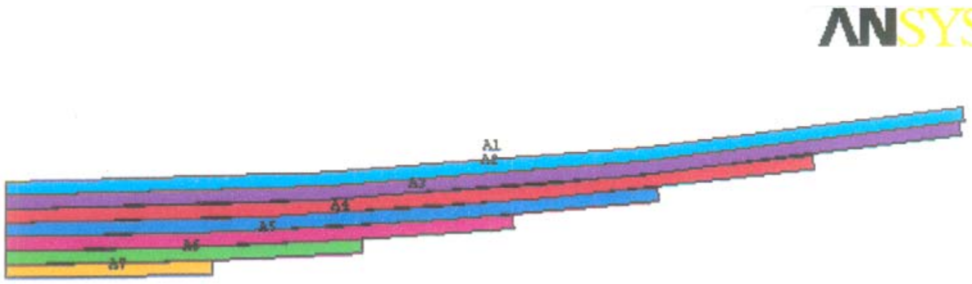

Figure 1: Specification of source and target

For the formulation of contact pairs between bottom leaf to top leaf successively, the first contact pair was formed between the last two leaves of the laminated leaf spring. Then, contact pairs were increased one by one sequentially in the same process from bottom to top as shown in figure 2a. The first contact pair was formed between the first two leaves of the laminated leaf spring for the formulation of contact pairs between to top leaf to bottom leaf successively. Then, the contact pairs were increased one by one sequentially in the same process from top to bottom as shown in figure 2b.

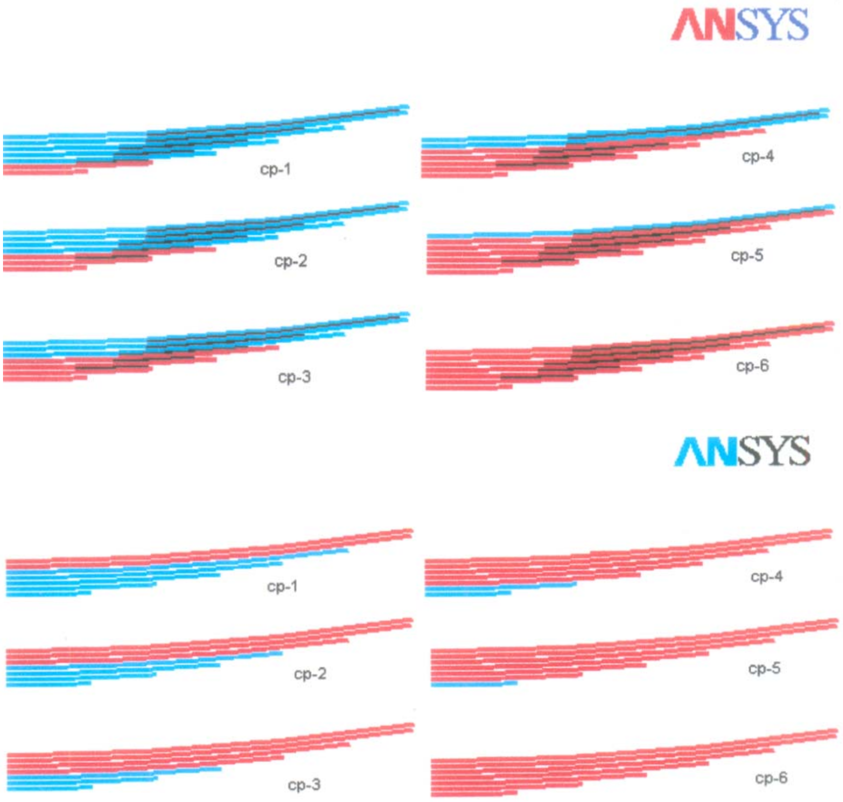

Figure 2: Formulation of contact pairs between bottom leaf to top leaf: (a) bottom to top and (b) top to bottom

The effect of thickness and width of leaves on stress and stiffness of the leaf spring has been also studied in the finite element analysis.

Results and Discussion

The variation of deflection, stress and stiffness with increasing the number of contact pairs creating between leaves from bottom to top is given Table-1. As recorded in Table-1 it is clear that each leaf is experiencing successively tensile and compressive stresses. It is also observed that the leaves are held together and are acting as perfect spring. The load is carried by all the leaves together. The stress and the deflections are with in the limits.

Table-1: Deflection, Stiffness and stress with contact pairs formed from bottom to top

S.No.	Contact pair between leaves from bottom to top		Deflection, mm	Stiffness, N/mm	Stress, N/mm^2
	No contact pair	--	2.13	1421.80	87.09
	6-7	Cp-1	2.39	1269.68	87.55
	5-6-7	Cp-2	3.11	972.73	87.55
	4-5-6-7	Cp-3	4.95	610.04	118.95
	3-4-5-6-7	Cp-4	9,89	305.14	183.95
	2-3-4-5-6-7	Cp-5	25.53	122.86	278.90
	1-2-3-4-5-6-7	Cp-6	50.084	60.16	353.58

Table-2: Deflection, stiffness and stress with contact pairs formed from bottom to top

S.No.	Contact pair between leaves from bottom to top		Deflection, mm	Stiffness, N/mm	Stress, N/mm^2
	1-2-3-4-5-6-7	Cp-6	50.084	60.16	353.58
	2-3-4-5-6-7	Cp-5	41.07	70.04	409.04
	3-4-5-6-7	Cp-4	29.42	101.96	395.39
	4-5-6-7	Cp-3	18.67	160.66	362.41
	5-6-7	Cp-2	10.30	291.29	309.41
	6-7	Cp-1	4.71	636.40	198.90
	No contact pair	--	2.13	1421.80	87.09

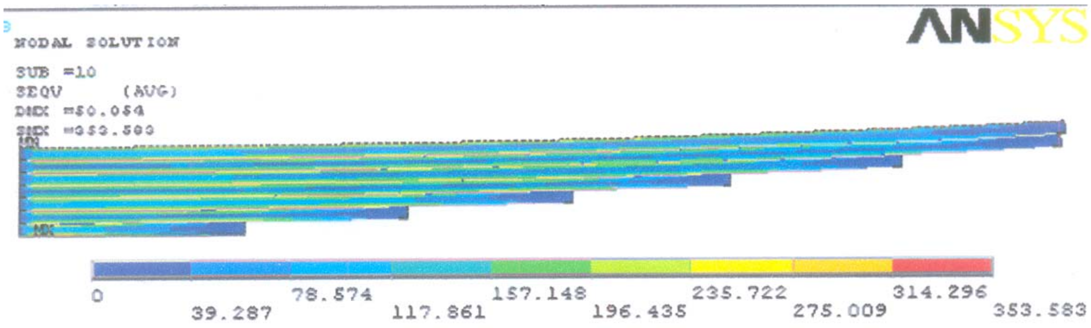

Figure 3: Deflection and stress distribution in the leaf spring

Effect of Thickness and width of springs on Deflection, stress and stiffness

The effect of thickness and width of leaves on the deflection of leaf spring is shown in figure 4. The deflection of leaf spring decreases with increase in thickness and width of leaves. The cross-sectional area of the leaves increases with increase in the thickness and width of leaves. The stiffness of the leaf spring increases with increase in the cross-sectional area of the leaves. This phenomena is proved to be true with results plotted in figure 5.

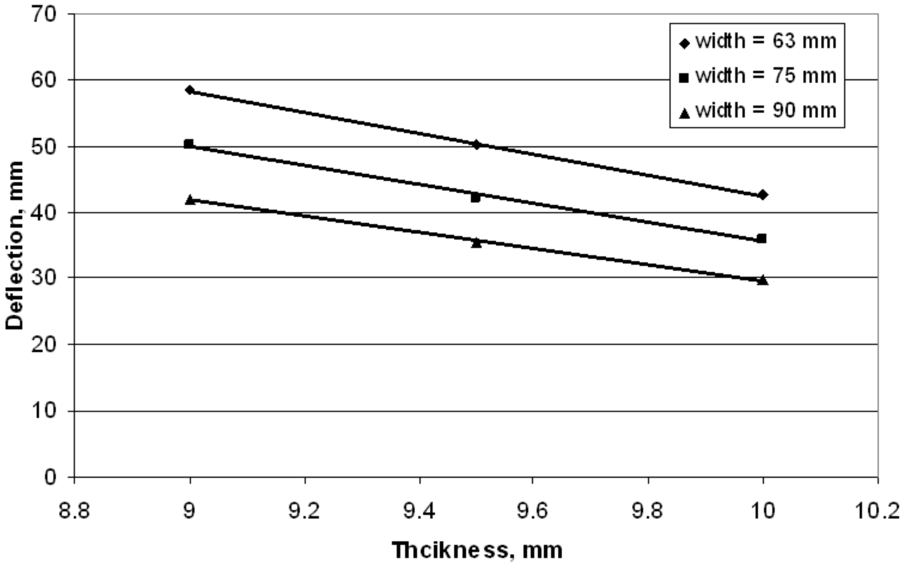

Figure 4: Effect of thickness and width on the deflection of the leaf spring

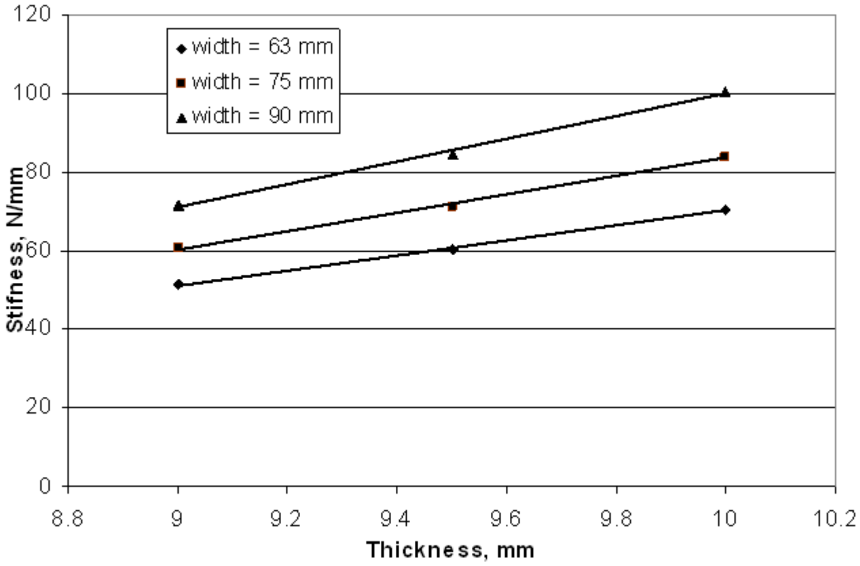

Figure 5: Effect of thickness and width on the stiffness of the leaf spring

The effect of thickness and width of leaves on the stress of leaf spring is shown in figure 6. The stress induced in the leaf spring decreases with increase in the thickness and width of leaves. The required stress in the leaf spring is 377.5 MPa. From the graph 6, some combinations which are experiencing more stress than the working stress of 377.5 MPa are neglected and the remaining combinations may be considered to satisfy the safe design criteria. The safe design of leaves are given in Table-3.

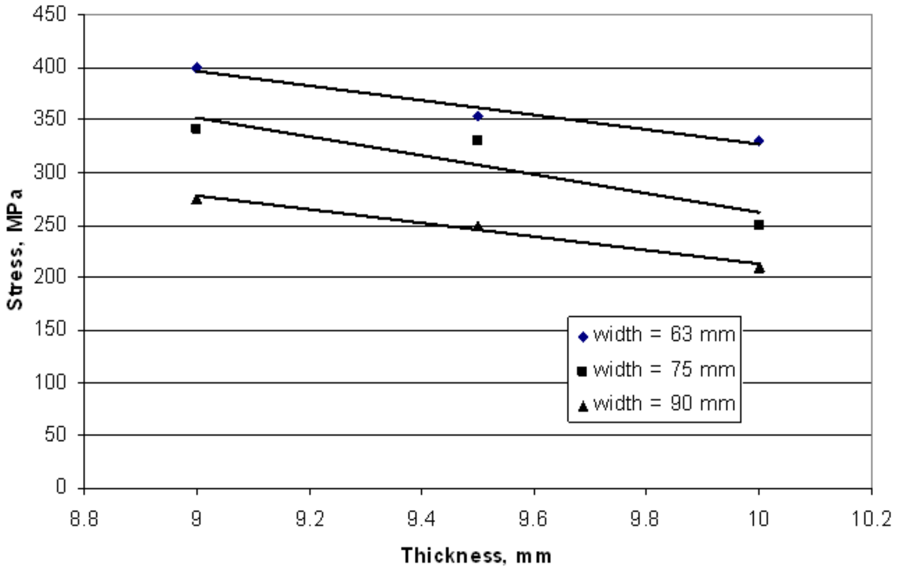

Figure 6: Effect of thickness and width on the stress of the leaf spring

Table 3: Cross-sectional area of leaves

Thickness, mm	Width, mm		
	63	75	90
9	--	675	810
9.5	598.5	712.5	855
10	630	750	900

In order to reduce the weight of the vehicle, the leaves with cross-sectional area of 598.5 mm^2 may be considered for manufacturing leaf spring.

Verification of Results

Leaf springs are designed to withstand a maximum load of 6000 N.

Length of leaf (2*L*) is 1320.8 mm

Effective length of leaves is $2L - \frac{2}{3}l$ = 620.4 mm, where *l* is the distance between the centers of U – bolt.

Width of leaf (*b*) is 65 mm.

Thickness (*t*) of the leaf is 9.5 mm.

Number of leaves, n (i.e., $n_g + n_f = 5 + 2$) is 7, where n_f is the number of full length leaves and n_g is the number of graduated leaves.

Young's modulus of the material is 2.08 x 10^5 N/mm^2

Density is 7.86x 10^6 N/mm^3

Poisson's ratio is 0.3

Stress in the leaves, $\sigma = \frac{18 \times P \times L}{\left[b \times t^2 \left(3n_f + 2n_g\right)\right]}$ = 368.27 N/mm^2

Spring deflection, $\delta = \frac{12 \times P \times L^3}{\left[b \times t^3 \times E\left(3n_f + 2n_g\right)\right]}$ = 49.73 mm

Stiffness, $k = \frac{\text{Load}}{\text{Deflection}}$ = 60 N/mm

The results obtained from the finite element analysis are compared with those of conventional design procedure. The error is very small. Therefore, the use of ANSYS software can save the time and in fact, the detailed design is possible with one solution.

Design procedure	Deflection, mm	Stiffness, N/mm	Stress, N/mm^2
Conventional	49.87	61.28	368.27
ANSYS	50.01	60.16	353.58
Error, %	0.28	- 1.86	- 4.15

Conclusions

The leaf is experiencing successively tensile and compressive stresses. The deflection of leaf spring decreases with increase in thickness and width of leaves. The cross-sectional area of the leaves increases with increase in the thickness and width of leaves. The stiffness of the leaf spring increases with increase in the cross-sectional area of the leaves. The stress induced in the leaf spring decreases with increase in the thickness and width of leaves. The results obtained from the finite element analysis have negligible error as compared with those of conventional design procedure.

References

[1] Shigley, J.E., 1972, “Mechanical Engineering Design”, 2nd Edition, McGraw-Hill.

[2] Timoshenko, S.P., and Goodier J.N., 1970, “Theory of Elasticity”, 3rd Edition, McGraw-Hill.

[3] Fischer, Grubisic, V.V., 1998, “Durability approval of leaf springs under operational loading”, SAE paper.

[4] ANSYS 5.5 Elements Reference Manual, 10ty edition, ANSYS Inc.