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Static Free Vibration Analysis of Composite Leaf Springs

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***Abstract*— The following work deals with the free vibration analysis of composite leaf springs clamped on one side. This has been done using a three dimensional finite element model in ANSYS version 12. The effects caused by the variation of width, friction between the leaves of the spring, relative movement of the leaves and the changes that occur in the natural frequency of the spring when the orientation of the fiber stacks in the leaves is varied have been discussed.**

***Index Terms*—Free vibration, Composite Leaf Spring, FEM.**

I. INTRODUCTION

Leaf springs probably are the oldest automobile suspension gadgets still in active use. Their simplicity and effectiveness might be contributing to this. The fact that a staggering amount of load is managed well while reducing the subsequent discomfort substantially adds to their reliability. As they rank very high under the header of effective dampers, leaf springs have been observed to be rather intriguing and have been taken into study in this paper.

Many papers have implemented various procedures to emulate the effectual prowess of leaf springs. In the paper "Analysis of Vibrations of the Simplified Model of the Suspension System with a Double Spring and a Fluid Damper" [1], Wieslaw Krason discusses the effect of leaf springs as effective dampers when compared to other suspension gadgets. Kae Nam Song, in the paper titled "Elastic stiffness analysis of leaf type hold down spring Assemblies" [2], proves experimentally that leaf springs, in general, are stress withstanding over a wide range of stress magnitudes. Jadhav Mahesh V, in the paper "Performance Analysis of Two Mono Leaf Spring Used for Maruti 800 Vehicle" [3] underlines the advantages of composite leaf springs when used for light vehicles and strives to prove them cost effective. So does in the paper "Development of a Composite Leaf Spring for a Light Commercial Vehicle", [4], Vivek Rai has discussed in full detail about composite efficiency, underlining the importance of choosing the correct material in order to obtain maximum output. In the present work, free vibration response of a composite leaf spring is simulated in ANSYS software in order to estimate the effect of various parameters such as width, friction, layer sequence etc. on the natural frequencies.

II. PROCEDURE

In order to study the behavior of a leaf spring as it vibrates freely and to determine this course over a range of effects, a Solid Layered 46 element of ANSYS software [5] has been used. This facilitates the rearrangement of various fibers in the composite, which makes up the leaves and a thorough examination of the effects caused by the same. The present study has been done considering five nodes, constraining the leaves at one end and allowing free movement longitudinally and transversely at the other (Fig. 1).

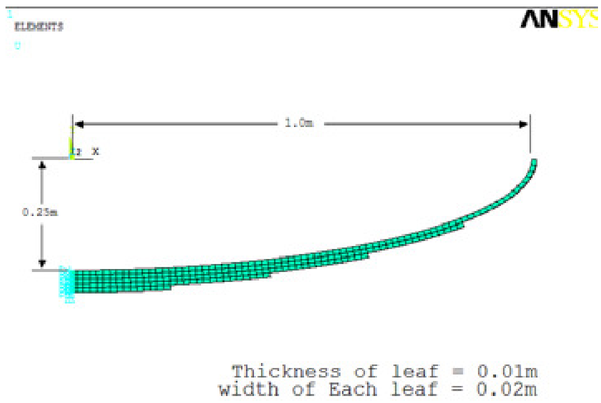

Fig. 1: 2-D View of Geometry of Leaf Spring with FE Mesh

A. *Material Properties*

The following orthotropic material properties of Carbon/Epoxy (AS4/3501-60) have been used.

Young's moduli, $E_1 = 147.0$ GPa
$E_2 = 10.3$ GPa
$E_3 = 10.3$ Gpa

Poisson's ratios, $\nu_{12} = 0.27$
$\nu_{23} = 0.54$
$\nu_{13} = 0.27$

Moduli of rigidity, $G_{12} = 7.0$ Gpa
$G_{23} = 3.7$ Gpa
$G_{31} = 7.0$ Gpa

Density, $\rho = 1.6e3$ kg/m3

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III. Results And Discussions

The results have been noted from a converged mesh. The effect of various parameters on natural frequencies of the considered leaf spring has been discussed in this section.

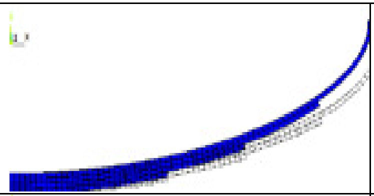
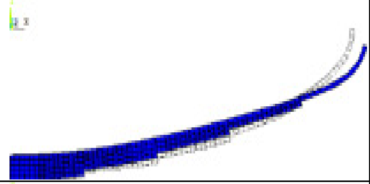
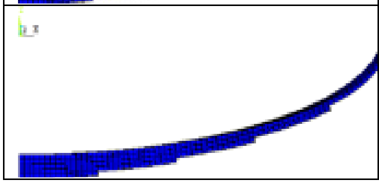
	0/90/90/0 μ=0.2 , b=0.02m Mode-2,f=60.746 Hz
	0/90/90/0 μ=0.2, b=0.02m Mode-4, f=185.5 Hz
	0/90/90/0 μ=0.2 , b=0.02m Mode-5, f=270.44 Hz

Fig. 2: Mode Shapes of Leaf Spring

A. Effect of Friction on Natural Frequency

The effect of friction has been studied by varying the values of friction in augmented method with the layer specification being no separation (always) for a 0|90|90|0 angular stack arrangement of fibers. Analyzing the results over 5 modes, one can observe that with the gradual increase in friction over a range permissible for the material in question, the natural frequency varies, albeit very slightly, nonetheless emphasizing that the resistance offered by friction affects the overall stiffness of leaf springs structure (Table 1 & Fig. 3).

Table 1: Variation of 'Frequency' w.r.t. Friction

μ	Mode-1	Mode-2	Mode-3	Mode-4	Mode-5
0.1	29.995	60.576	113.1	184.5	267.55
0.2	30.132	60.746	114.93	185.5	270.44
0.3	30.184	60.807	115.65	185.9	271.63
0.4	30.211	60.84	116.04	186.1	272.29
0.5	30.227	60.859	116.04	186.3	272.71

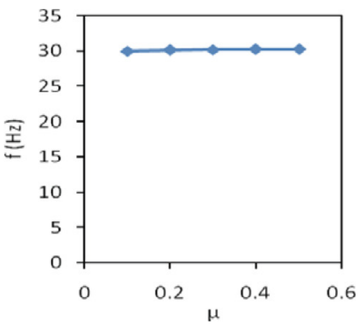


Fig. 3: Variation of 'f' w.r.t. Friction (Mode-1) at b=0.02m

B. Effect of Stacking Angles on Natural Frequency

When the same element conditions applied to the leaf spring at a constant friction value μ=0.2 and the various stacking arrangements as mentioned in Table 2 are studied, it has been observed over 5 modes, that the natural frequency of the material is at the highest at the 0|0|0|0 arrangement of the fibers while the same is at the lowest at the 90|90|90|90 arrangement, with the rest only changing infinitesimally with respect to each other (Table 2 & Fig. 4).

Table 2 Variation of 'frequency' w.r.t. stacking sequence

Stacking	Mode-1	Mode-2	Mode-3	Mode-4	Mode-5
0|0|0|0	39.727	77.985	142.06	224.2	336.57
90|90|90|90	11.997	23.784	50.876	67.22	122.11
0|90|90|0	30.132	60.746	114.93	185.5	270.44
90|0|0|90	30.098	55.925	114.33	133.6	269.01
0|90|0|90	30.114	58.711	114.25	165.4	269.33
90|0|90|0	30.074	58.106	114.61	162.6	269.26

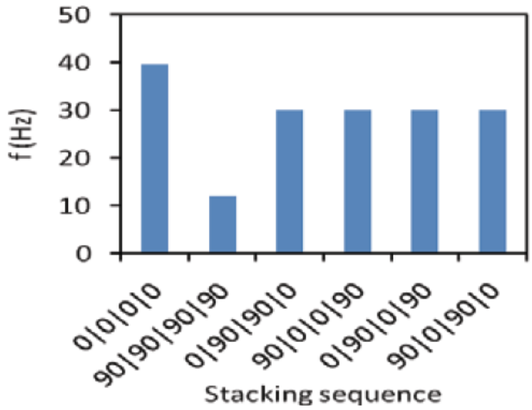


Fig. 4: Variation of 'f' w.r.t. Stacking Sequence (Mode-1) at b=0.02m

C. Variation in Natural Frequency When the Leaves are bonded Together

When the leaves in the spring are bonded together, characterizing the entire object as a singular entity, the values of the natural frequency have been observed to vary with respect to stacking angles in a fashion that is much similar to that observed in case of separated leaves. While the parallel and the orthogonal arrangements showed the maximum and minimum values respectively, the rest were almost similar in disposition. The overall magnitude does not change very significantly (Table 3 & Fig. 5).

Table 3: Variation of 'f' w.r.t. Stacking Sequence (Single Stepped Leaf)

Stacking	Mode-1	Mode-2	Mode-3	Mode-4	Mode-5
0|0|0|0	40.242	78.652	149.17	229	347.36
90|90|90|90	12.024	23.849	51.378	67.59	123.89
0|90|90|0	30.371	61.082	118.98	188.2	278.5
90|0|0|90	30.355	56.37	118.77	135.6	277.76
0|90|0|90	30.373	59.13	118.44	168.5	277.54
90|0|90|0	30.309	58.45	118.78	164.8	277.54

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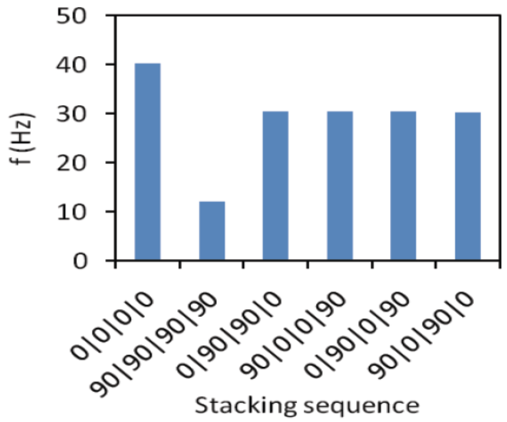

Fig. 5: Variation of ‘f’ w.r.t. Stacking Sequence (Mode-1) When Leaves are Bonded at b=0.02m

D. Variation of Natural Frequency on Frictionless Leaves

When the leaves in the spring are assumed to be frictionless and the change in natural frequency for the various arrangements in the stacks are observed, different trend has been noted this case with a pronounced slump in the magnitude. In uni-directional fiber arrangement, longitudinal fibers exhibit maximum frequency and transverse fibers show minimum frequency. In symmetric layer arrangement, leaves with longitudinal outer layers have more frequency. The value of frequency is almost same in ant symmetric cases (Table 4 & Fig. 6).

Table 4: Variation of ‘f’ w.r.t. Stacking Sequence (Frictionless Leaf)

Stacking	Mode-1	Mode-2	Mode-3	Mode-4	Mode-5
0|0|0|0	21.139	25.124	40.739	72.73	93.482
9|90|90|90	5.9504	7.166	11.16	19.66	25.669
0|90|90|0	18.982	19.948	30.175	53.68	88.05
90|0|0|90	9.4307	18.977	30.171	41.27	53.672
0|90|0|90	14.509	18.964	30.159	53.65	64.o56
90|0|90|0	14.504	18.981	30.171	53.67	63.914

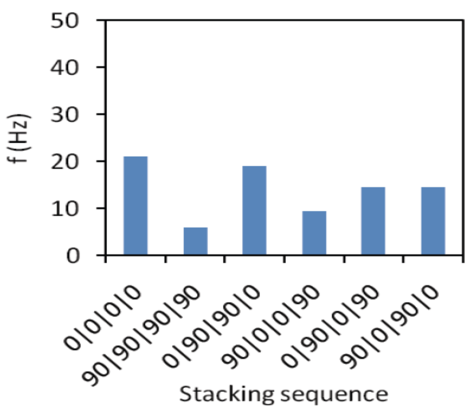

Fig. 6: Variation of ‘f’ w.r.t. Stacking Sequence (Mode-1) When Leaves are Frictionless at b=0.02m

E. Variation of natural frequency with change in Leaf Width

The entire structure has been redesigned with a standard friction value of 0.2 and with augmented and separated layers for an orientation of 0|90|90|0 for different width values of individual leaves. The increase in the leaf width over four steps depicts a substantial increase in the natural frequency at every mode (Table 5 & Fig. 7).

Table 5: Variation of ‘f’ w.r.t. Leaf Width

b(m)	Mode-1	Mode-2	Mode-3	Mode-4	Mode-5
0.01	15.74	62.092	63.873	148.75	186.8
0.02	30.132	60.746	114.93	185.52	270.44
0.03	46.544	66.25	170.72	198.08	378.61
0.04	61.204	66.223	197.81	212.18	427.89

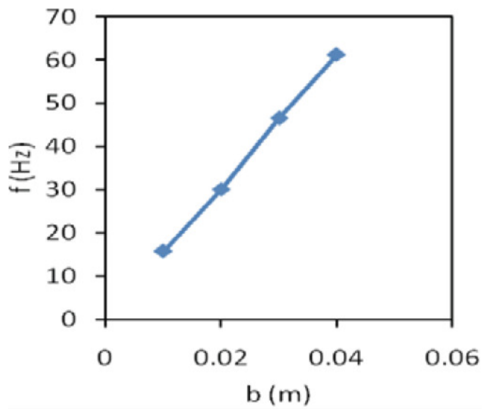

Fig. 7: Variation of ‘f’ w.r.t. Leaf Width (Mode-1)

IV. CONCLUSION

By these results, it has been concluded that

1. No significant effect of friction coefficient is noticed.
2. Springs with more number of longitudinal layers and when they are placed outer exhibit higher frequencies.
3. No significant variation between friction and bonding cases.
4. Frictionless surfaces causes for reduction in frequencies.
5. Increase in leaf width improves natural frequencies.

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