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Comparative Dynamic Analysis of Upturned and Berlin Eye Mono Leaf Spring

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Abstract: *In thisresearch work, study is carried out on mono steel leaf springs used by commercial vehicles. The chief thought behind this work is to examine the dynamic behavior of two leaf springs one having Upturned eye of Maxi Truck and one having Berlin eye of Maxi T-Plus, both is having similar parameters i.e. width, thickness, eye diameter, length, radius of curvature, camber & load carrying capacity. The material used for the deuce is 0.9% carbon steel with almost similar properties. The modal analysis is accomplished theoretically for determining the natural frequency of both the springs for first five mode shapes. To validate the theoretical modal analysis, modal analysis will be conducted with aid of simulation by FEA. Modeling will be finished by using Pro-E 4.0 and analysis on Pro-E Mechanica Platform. The result of all deuce-ace analyzed operations almost coincides and compared. From the outcomes we can say that there is almost no effect of eye conditions on modal frequencies.*
Keywords-*Berlin eye,upturned eye, Finite Element Analysis,Modal analysis, Mode shapes*

I. Introduction

A leaf spring is a simple form of spring most commonly used for the suspension in wheeled vehicles. Sometimes referred to as a semi-elliptical spring or cart spring, it is one of the oldest forms of springing.In the most common configuration, the center of the arc provides location for the axle, while loops (eye) formed at either end from which one of them attached directly to the frame, usually the front, while the another end attached through a shackle. For very heavy vehicles, a leaf spring can be made from several leaves stacked on top of each other in several layers, often with progressively shorter leaves. Leaf springs can serve locating and to some extent damping as well as springing functions. While the interleaf friction provides a damping action, it is not well controlled and results in stiction in the motion of the suspension, for this reason, some manufacturers have used mono-leaf springs.

There are several types of eye comes in leaf spring but the most commonly used type of eye in leaf springs are Upturned eye and Berlin eye, for these type of springs static and dynamic analysis is done in this research work.

II. Selection Of Leaf Spring

There are two types of leaf spring used in this research work both are of steel material with 0.9% carbon, while one is upturned eye leaf spring and another is berlin eye leaf spring.
The table 01 gives an overview of properties and dimensions of selected mono leaf spring.

Table 01 Properties of the Selected Specimen

Sr. No.	Parameters	Upturned eye	Berlin eye
01	Mass Density (ρ)- kg/m^3	7850	7850
02	Moment of Inertia (I)- m^4	6.458×10^{-10}	6.458×10^{-10}
03	Young'sModulus Elasticity (E)-N/m^2	2.1×10^{11}	2.1×10^{11}
04	Poisson's Ratio	0.27	0.27
05	Outer diameter (mm)	48.5	48.5
06	Thickness (d)-mm	5	5
07	Full length (L)-mm	901.7	901.7
08	Half length (mm)	450.85	450.85
09	Width (b)-mm	62	62
10	Radius of curvature (mm)	889	889
11	Camber length (mm)	130	125
12	Angle	12°	12°
13	Mass (kg)	2.923	2.957

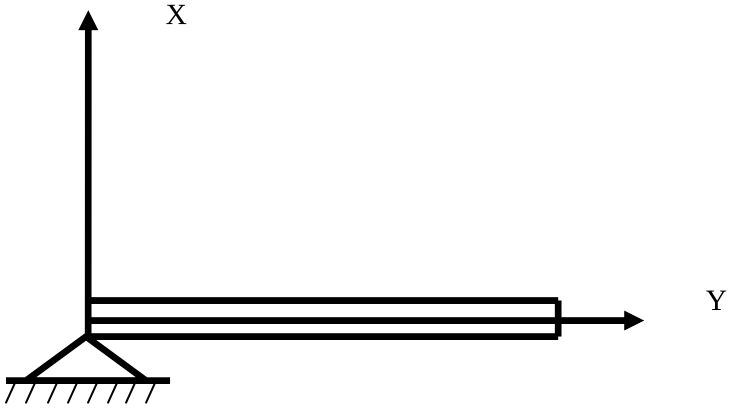
III. Research Methodology

A. Analytical Solution by Euler Bernoulli Beam Theory

Beam theory given by Euler and Bernoulli is a simplification of the linear theory of elasticity which provides a means of calculating the load carrying and deflection characteristics of beams. It covers the case for small deflections of a beam that are subjected to lateral loads only. The Euler's equation for natural frequency is given as

$$\omega_n = \frac{n^2\pi^2}{L^2}\left[\sqrt{\frac{EI}{\rho A}}\right]$$

Where,
n = Mode Shape
I = Moment of inertia of system
ρ = Density of material
A = Area of cross section
L = Length of spring
E = Modulus of Elasticity
For cantilever beam



EI, m = Constant with x

$$EI\frac{d^4W}{dx^4} + \frac{d^2w}{dt^2} = P_z$$

Boundary Conditions,

At X=0 , W=0

At X=l , $M = EI\frac{d^2w}{dx^2} = 0$

With,

$$W(x) = C_1 \sin\lambda x + C_2 \cosh\lambda x + C_3 \sin\lambda x + C_4 \cos\lambda x$$

Put the resulting four equations in matrix form

$$\begin{bmatrix} 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & -1 \\ \sin\lambda l & \cos\lambda l & \sin\lambda l & \cos\lambda l \\ \sin\lambda l & \cos\lambda l & -\sin\lambda l & -\cos\lambda l \end{bmatrix} \begin{Bmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{Bmatrix}$$

From above matrix

$$w(0) = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

$$\frac{d^2w}{dx^2}(0) = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(2)$$

$$w(l) = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3)$$

$$\frac{d^2w}{dx^2}(l) = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(4)$$

Solution of determinant matrix generally yields values of λ which then yield frequencies and associated modes (as was done for multiple mass systems in a somewhat similar fashion)
In this case, the determinant of the matrix yields:

$$C \sin\lambda l = 03$$

Note: Equations (1 & 2) give $c_2 = c_4 = 0$

Equations (3 & 4) give 2 $c_3 \sin\lambda l = 0$

⇒ Non trivial: $\lambda l = n\pi$

The nontrivial solution is:

$$\lambda l = n\pi \text{ (Eigen value problem) Recalling that,}$$

$$\lambda = \left[\frac{\mathrm{m}\omega^2}{\mathrm{EI}}\right]^{\frac{1}{4}}$$

$$\frac{m\omega^2}{EI} = \frac{n^4\pi^4}{l^4} \quad \text{(Change n to r to be consistent with previous notation)}$$

$$\omega_n = \frac{n^2\pi^2}{L^2}\left[\sqrt{\frac{EI}{\rho A}}\right]$$

(Natural frequency)

The natural frequencies obtained by using analytical method for upturned and berlin eye leaf spring is shown in table 02,

Table 02 Natural Frequency of Leaf Spring by Analytical Method

Number of Modes	Upturned Eye		Berlin Eye	
	rad/sec	Hz	rad/sec	Hz
1	90.616	14.421	90.616	14.421
2	362.464	57.688	362.464	57.688
3	815.544	129.798	815.544	129.798
4	1449.857	230.752	1449.857	230.752
5	2265.402	360.550	2265.402	360.550

B. Finite Element Method (FEM) Analysis

The check of aftereffects of explanatory strategy appeared table 02 is done through Pro-E wild fire 4.0. Modelling is finished utilizing Pro-E Wild Fire 4.0 and examination is done utilizing Pro-E Mechanica programming.

i. 3D MODEL AND MODE SHAPES OF UPTURNED EYE LEAF SPRING

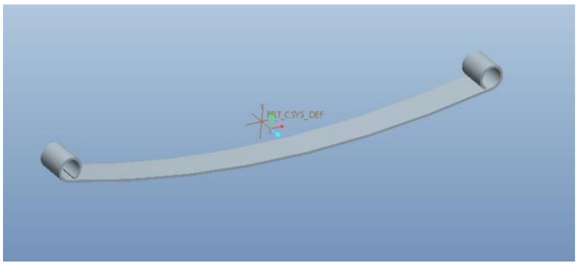


Fig 01: Model of Upturned Eye Leaf Spring

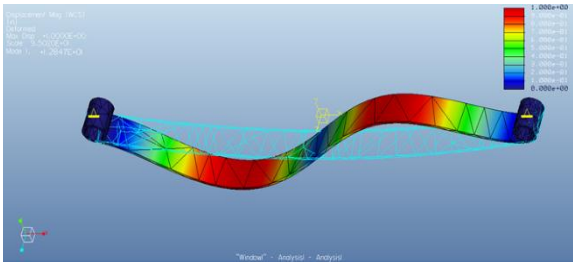


Fig 02: Mode Shape 1

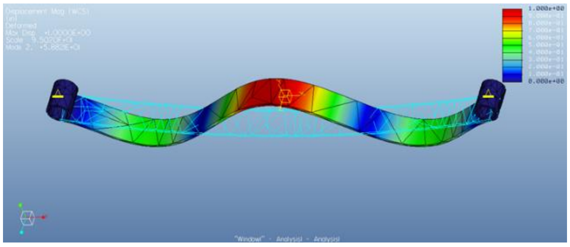


Fig 03: Mode Shape 2

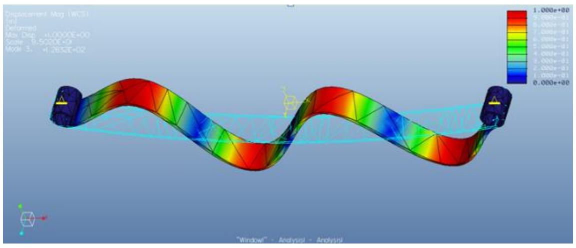


Fig 04: Mode Shape 3

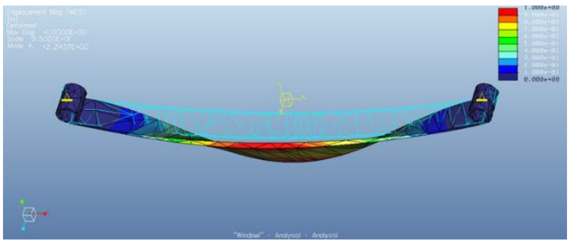


Fig 05: Mode Shape 4

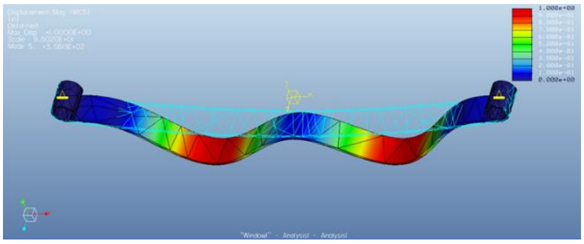


Fig 06: Mode Shape 5

ii. 3D MODEL AND MODE SHAPES OF BERLIN EYE LEAF SPRING

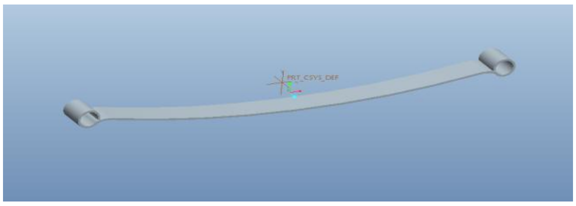


Fig 07: Model of Berlin Eye Leaf Spring

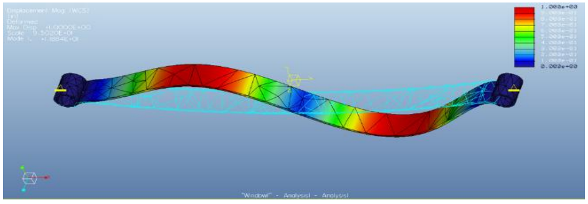


Fig 08: Mode Shape 1

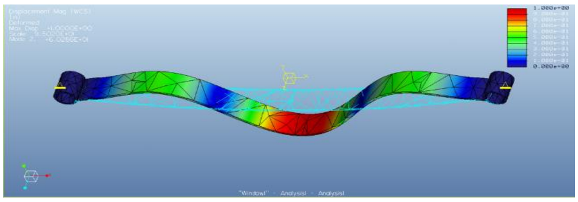


Fig 09: Mode Shape 2

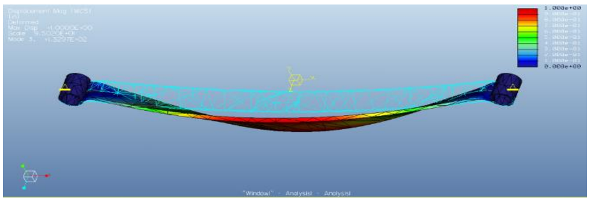


Fig 10: Mode Shape 3

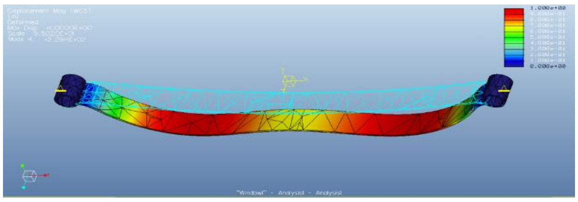


Fig 11: Mode Shape 4

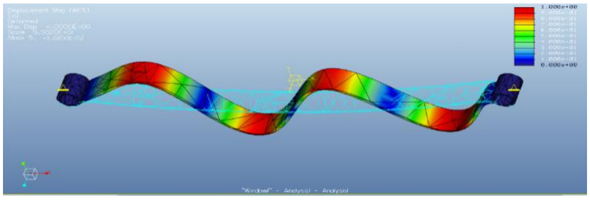


Fig 12: Mode Shape 5

The natural frequencies obtained by using FEAmethod for upturned and berlin eye leaf spring is shown in table 03.

Table 03 Natural Frequency of Leaf Spring by FEM Method

Number of Modes	Upturned Eye		Berlin Eye	
	rad/sec	Hz	rad/sec	Hz
1	80.720	12.847	75.109	11.954
2	369.583	58.821	378.780	60.286
3	806.258	128.320	835.475	132.970
4	1409.758	224.379	1439.729	229.140
5	2250.197	358.130	2312.212	368.000

IV. Results And Discussion

As the mode frequencies got from both the methodology for the two sorts of eye conditions are coordinating with one another so we can presume that there is no impact of eye conditions on mode frequencies. The mode shape frequencies gotten by utilizing FEA we can likewise infer that the most encouraging eye is Berlin eye as their modular frequencies are high relatively

The relative outcomes got from Euler Bernoulli and FEA strategy is appeared table 04,

Table 04 Comparative Results

Number of Modes	Euler Bernoulli Method		FEA Method	
	Upturned Eye	Berlin Eye	Upturned Eye	Berlin Eye
1	14.421	14.421	12.847	11.954
2	57.688	57.688	58.821	60.286
3	129.798	129.798	128.320	132.970
4	230.752	230.752	224.379	229.140
5	360.550	360.550	358.130	368.000

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