Determination of Camber and Leaf Span of a Parabolic Leaf Spring for Optimized Stress and Displacement Using Artificial Neural Networks

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Abstract : *This work has been carried out on a parabolic leaf spring of a mini loader truck. The spring has been analyzed by applying a load of 3800 N and the corresponding values of stress and displacement are computed. In this work, Design of experiments has been applied under various configurations of the spring (i.e by varying camber & eye distance). Camber and Leaf span of a Parabolic Leaf Spring was found for Optimized Stress and Displacement value using Artificial Neural Networks. Various networks with different architecture were trained and the network giving the best performance was used for optimization.*

Keywords*: Artificial neural networks (ANN), Computer Aided Design (CAD), Camber, Design of Experiments (DOE), Eye Distance, Finite Element Analysis (FEA), Parabolic Leaf Spring (PLS).*

I. Introduction

Parabolic Leaf sprigs are essential suspension elements used on mini loader trucks necessary to minimize the vertical vibrations, impacts and bumps due to road irregularities and to ensure safety of the loaded cargo. Parabolic Leaf springs are widely used for automobiles. The Parabolic leaf spring absorbs the vertical vibrations and impacts due to road irregularities by means of variations in the spring deflection so that the potential energy is stored in spring as strain energy and then gradually released to maintain comfort. The finite element analysis (FEA) is a computing technique that is used to obtain approximate solutions to the boundary value problems in engineering. It uses a numerical technique called the finite element method (FEM). It is now accepted by major industries across the world and a company that is able to verify a proposed design will be able to perform to the clients specifications prior to manufacturing or construction. In the present work, leaf spring has been analyzed for static strength and deflection using 3D finite element analysis. CATIA V5 R20 has been utilized in the creation of the three dimensional model and its static structural workbench for analysis when subjected to vertical loads. The variation of bending stress and displacement values are computed. To add on the different combinations of input parameters (camber & eye distance) have been taken into account & its influence on bending stress and max deflection has been studied.

II. Parabolic Leaf Spring & Dimensions

A more modern implementation of old leaf springs is the parabolic leaf spring for automobiles. The new innovative design is characterized by the use of less leaves whose thickness varies from the center to the outer side following a parabolic pattern. The mathematical equation between the thickness & the length of the spring is that of a parabola & hence it has been named as parabolic leaf spring.

1. Camber – 90.81mm
2. Distance between eyes(Eye Distance) : 1025mm
3. Thickness at the central part : 10.81mm

Note: The above dimensions have been taken with the help of an inextensible measuring tape and a vernier caliper and then the procedure of modeling the spring was initiated. The basic views of the considered parabolic leaf spring are shown in fig. 1.

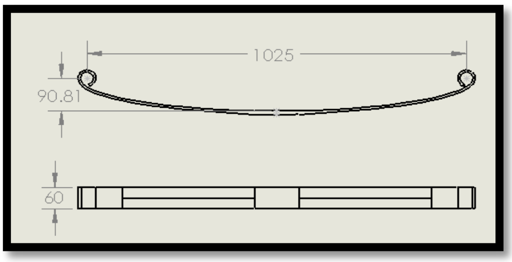


Fig.1 Front & Top view

Note : All dimensions are in mm

III. Existing Material

The material used for experimentation is EN45 and its mechanical properties has been mentioned in Table-1

Table--1

Material		Youngs Modulus (E) Gpa	Poisson's Ratio (M)	Density (Kg/M^3)	Yield Strength (Mpa)
EN	IS(Old)				
EN 45	55Si2 Mn90	200	0.3	7850	1500

IV. Result And Analysis Using Method Of Finite Elements

4.1 Meshing

Meshing is basically the process of breaking the CAD model into very small elements. It is also known as piecewise approximation. Meshing are of different types, it may be comprising of 1D, 2D or 3D elements. In present case selected is shown in Table-2

Table--2

Mesh			Element type	
S. N.	**Entity**	**Size**		
1	**Nodes**	**12084**	**Connectivity**	**Statistics**
2	Elements	5905	TE10(Tetrahedron element)	5905 (100.00 %)

4.2 Boundary Conditions

As shown in Fig. 2, one eye of the leaf spring will be fixed and the other eye will have certain degree of rotation to allow the leaf spring to deflect by some amount. It has been mathematically calculated that the maximum load which the spring will be subjected to 3800 N. This particular calculation has been done on the basis of GVW (Gross Vehicle Weight), which may be defined as the total weight of the loaded vehicle. This includes the vehicle itself and the cargo that is loaded within that vehicle.

In order to perform static structural analysis it is very essential to restraint the CAD model in the same manner as it is done physically. As far as parabolic leaf springs are concerned it has two eye ends, one of which is fixed with the upper body of the mini loader truck, while the other end is attached to a shackle which allows the spring to expand along its leaf span thereby causing some degree of rotation in the shackle.

Similarly we have applied constraints to our CAD model of parabolic leaf spring shown in Fig. 3 & 4.

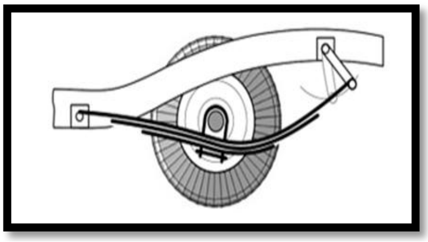


Fig.2 Suspension and Constraints

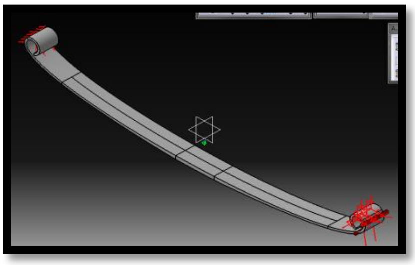


Fig.3 Applying Constraints.

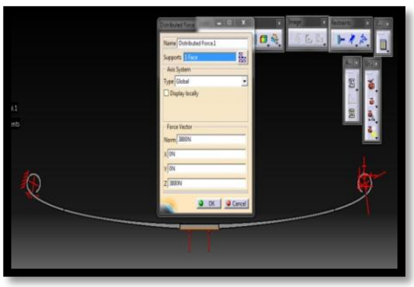


Fig.4 Applying Load

As shown in Fig. 4, the leaf spring is being treated as a simply supported beam which has a central load of 3800 N directed upwards.

4.3 Static Structural Analysis in CATIA V5 R20

After applying the boundary conditions the maximum von mises stress and maximum displacement is shown in Fig. 5 & 6.

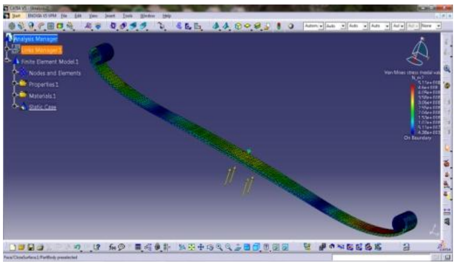


Fig.5 Von Mises Stress

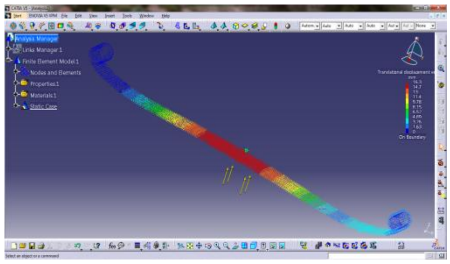


Fig.6 Displacement

Outputs on the basis of existing dimensions has been mentioned in Table-3 :

Table--3

S.N.	Output Parameter	Value
1	Maximum Displacement	16.3079mm
2	Maximum Von mises stress	5.11017e+008 N_m2
3	Energy	30.008 J
4	Mass	4.549kg

V. Design Of Expirements

The Design of experiments (DOE) is a tool for determining the significance of different factors affecting process quality and for calculating optimal settings for controllable factors. For example we may believe that operating temperature and wave height affects the number of defects from a wave solder machine. DOE provides a fast & efficient means for determining the values of these parameters that would produce the fewer number of defects.

DOE Procedure:

a) Select factors to be tested & a measure of process outcome.
b) Select test setting for each factor.
c) Select the appropriate orthogonal array.
d) Run the tests.
e) Analyze the results.
f) Calculate optimum setting for each factor.
g) Run confirmation test(s).

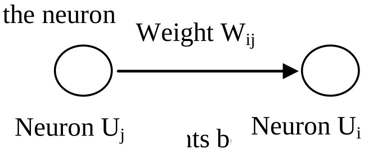
In this work camber and eye distance are selected as input parameters and max displacement, max von mises stress as output parameters. Design of experiments has been implemented by varying camber from 90 mm to 95 mm in steps of 10 and by varying eye distance from 1020 mm to 1030 mm in steps of 10.

VI. Artificial Neural Networks And Training

An Artificial Neural Network (ANN) is an information processing paradigm that is inspired by the way biological nervous systems, process information. An artificial neuron is composed of five main parts: inputs, weights, sum function, activation function and outputs. Inputs are information that enters the neuron from other neurons or from the external world. Generally connections between the units are defined by a weight w_{ij}. Weights are adaptive coefficients inside the network and they determine the intensity of the input signal as registered by the artificial neuron. Sum function is a function that calculates the effect of inputs and weights totally on this process element. This function calculates the net input that comes to a cell. The weighted sums of the input components is calculated by using Eq. 1

$$(net)_j = \sum_{i=1}^{n} W_{ij} I_i + b \quad .... (1)$$

Where $(net)_j$ is the weighted sum of the j neuron for the input received from the preceding layer with n neurons, W_{ij} is the weight between the j^{th} neuron in the preceding layer and i^{th} neuron in the layer, I_i is the input to the preceding layer and b is a fix value as an internal addition known as bias. Figure 7 shows the connection between the neuron



6.1 Training by Artificial Neural Networks.

Training has been with the help of neural network tool box in MATLAB 2009b. Different combinations were taken into account to create the network which best suits our need. The neural network created is two layered and consists of 10 neurons in layer 1. The network initialization has been done below:

Feed forward back propagation network

a) Training Function- TRAINLM
b) Adaptive Learning Function- LEARNGDM
c) Architecture- 2X10X2
d) Hidden Layer- Tansig
e) Output Layer- Purelin

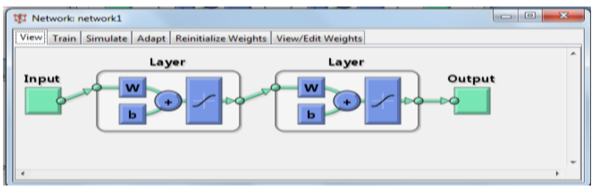


Fig.8 Neural Network Model

Several neural network models with different arcitecture were trained and tested using different configurations but the one in shown in Fig.8 above showed minimum Mean square error amongst all.

6.2 Performance

The assessment of any neural network model is done with the help of Mean Square error and it is found that amongst all the different configurations trained and tested, the minimum value of MSE was 0.91786.

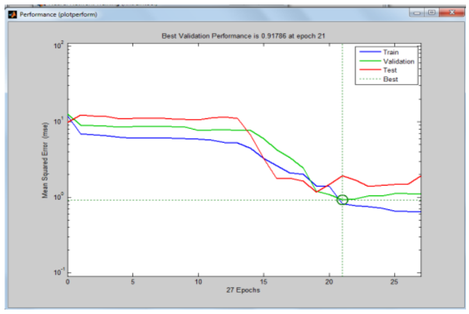


Fig.9 Mean Square Error is 0.91786 at epoch 21

VII. Conclusion

After successful creation of the neural network model it is imperative to optimize the stress and displacement in order to achieve the corresponding values of camber and leaf span. Following conclusion has been derived from the Neural Network Model:

Table--3

Min Stress (N/m^2)	Max Displacement(mm)	Camber (mm)	Leaf Span(mm)
507400000	16.596	90.8623	1029.1062

The values of camber and leaf span for optimized stress and displacement are shown in table-3 above.

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