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A Finite Element Approach for Analysis of a Multi Leaf Spring using CAE Tools

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Abstract

This work is carried out on a multi leaf spring having nine leaves used by a commercial vehicle. The finite element modelling and analysis of a multi leaf spring has been carried out. It includes two full length leaves in which one is with eyed ends and seven graduated length leaves. The material of the leaf spring is SUP9.The FE model of the leaf spring has been generated in CATIA V5 R17 and imported in ANSYS-11 for finite element analysis, which are most popular CAE tools. The FE analysis of the leaf spring has been performed by discretization of the model in infinite nodes and elements and refining them under defined boundary condition. Bending stress and deflection are the target results. A comparison of both i.e. experimental and FEA results have been done to conclude.

Keywords: Leaf spring, finite element analysis, FEM, CAE tools.

Introduction

Multi leaf springs used in automotive vehicles normally consists of full length leaves and graduated length leaves. The specimen under this research work consists of nine leaves, two eye pins, centre bolt with nut etc. CAE tools are being used to analyze the robustness and performance of components and assemblies. 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). Using FEA Multi leaf spring is modeled using the discrete building blocks called elements. Each element has some equations that describe how it responds to certain loads. The sum of the response of all the elements in the model gives the total response of the design. CAE depends upon actual assumptions of the assembly which acts as input data. CAE has become an important technology with benefits such as lower costs and a shortened design cycle. Studies say that any design professional can save approximate 30% of time and cost by using CAE tools. In future CAE system will be major information provider to help design professionals in decision making. I. Rajendran, S. Vijayarangan presented a formulation and solution technique using genetic algorithms for design optimization of composite leaf springs[1]. F.N. Ahmad Refngah presents about fatigue life prediction based on finite element analysis and variable amplitude loading (VAL). The finite element method (FEM) was performed on the spring model to observe the distribution stress and damage. The experimental works has been done in order to validate the FEM result[2]. Mouleeswaran Senthil Kumar describesstatic and fatigue analysis of steel leaf spring and composite multi leaf spring made up of glass fibre reinforced polymer using life data analysis. Static analysis of 2-D model of conventional leaf spring is also performed using ANSYS 7.1 and compared with experimental results. Same dimensions of conventional leaf spring are used to fabricate a composite multi leaf spring using E-glass/Epoxy unidirectional laminates[3]. Gulur Siddaramanna SHIVA SHANKAR presented a low cost fabrication of complete mono composite leaf spring and mono composite leaf spring with bonded end joints. The finite element results using ANSYS software showing stresses and deflections were verified with analytical and experimental results. The design constraints were stresses (Tsai-Wu failure criterion) and displacement[4]. M. M. Patunkar presented modeling and analysis of composite mono leaf spring (GFRP) and compare its results. Modelling is done using Pro-E (Wild Fire) 5.0 and Analysis is carried out by using ANSYS 10.0 software for better understanding[5]. J.P. Hou presents the design evolution process of a composite leaf spring for freight rail applications. Three designs of eye-end attachment for composite leaf springs are described. Static testing and finite element analysis have been carried out to obtain the characteristics of the spring. Load–deflection curves and strain measurement as a function of load for the three designs tested have been plotted for comparison with FEA predicted values[6]. M.L. Aggarwal calculated fatigue strength of shot peened leaf springs from laboratory samples. The axial fatigue strength of EN45A spring steel specimen is evaluated experimentally as a function of shot peening in the conditions used for full-scale leaf springs testing in industries[7]. Andrea Corvi demonstrated the feasibility of using the program as a tool in establishing the initial design considerations and in developing preliminary designs[8]. W.J. Yu investigated fundamental properties of dimensioning of double tapered FRP leaf

Spring made from glass fibre and epoxy to replace four leaf steel springs. GRP leaf springs showed a superior endurance and fail-safe characteristics[9]. M.L. Aggarwal described improvement in fatigue and fretting fatigue performance of leaf springs used in automotive vehicles. The fatigue strength of 65Si7 spring steel has been evaluated experimentally as a function of shot peening parameters for application in automotive vehicles[10]. The main objective of this work is to perform finite element analysis of multi leaf spring. The experimental results have been taken on a full scale static load testing machine, in which leaf spring is held under an axial load at centre till maximum deflection. These experimental results will be compared with FEA results for validation.

Material and Methods

Material properties and Design parameters: The table-1 below is showing the different parameters related to material properties;

Table-1
Material Properties

Parameter	Value
Material selected- steel	65Si7/SUP9
Young's Modulus, E	$2.1 * 10^5$ N/mm^2
Poisson's Ratio	0.266
BHN	400-425
Tensile strength Ultimate	1272 MPa
Tensile strength Yield	1158 MPa
Spring stiffness	221.5 N/mm
Mass	54.165 kg
Normal Static loading	35000 N
Density	0.00000785 Kg/mm^3
Behavior	Isotropic

Design parameters of the multi leaf spring used in this work are:
Total span length (eye to eye): 1450mm
Number of full length leaves: 02
Length of full length leaves (L-1 and L-2): 1450 mm each
Width of all leaves: 70mm
Thickness of all leaves: 12mm
Number of graduated length leaves: 07
Length of graduated length leaves;
(L-3, L-4, L-5, L-6, L-7, L-8 and L-9): 1320mm, 1140mm, 940mm, 800mm, 640mm, 464mm & 244mm respectively.

Multi Leaf Spring Geometery and Boundary Conditions: The two dimensional drawing of the multi leaf spring is shown in the figure-1 below;

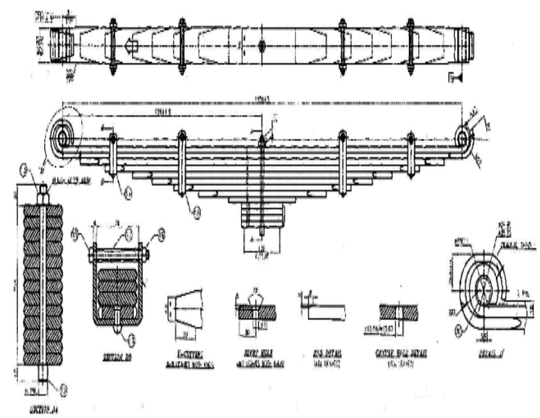

Figure-1
Drawing of Multi Leaf Spring

The multi leaf spring is modelled in position having maximum deflection i.e. flat position[11] & will be loaded in reverse direction to attain its original shape i.e. semi-elliptical.

The boundary condition is the collection of different forces, pressure, velocity, supports, constraints and every condition required for complete analysis. As per specifications the spring is drawn at flat condition, therefore the load is applied in downward direction to achieve initial no load condition. As no load camber is 153°, a joint rotation of 27° is considered for both revolute joints, during static analysis. The boundary conditions for the experimental results are shown in the figure-2 below;

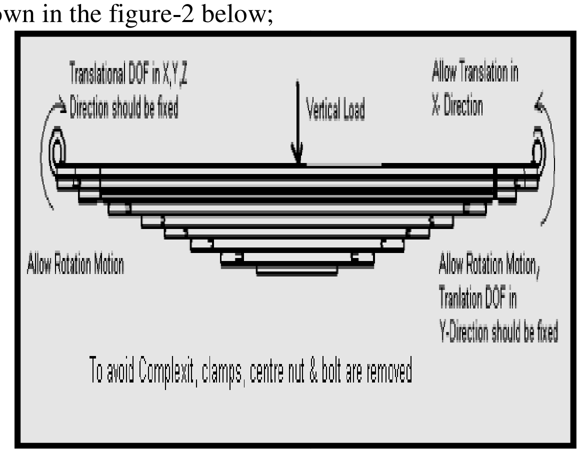

Figure-2
Experimental Boundary Conditions

Modeling & Finite Element Analysis: CAD Modeling: CAD modeling software is dedicated for the specialized job of 3D-modeling. The model of the multi leaf spring structures also includes many complicated parts, which are difficult to make by any of other CAD modeling as well as Finite Element software. CAD modeling of the complete Multi Leaf Spring structure is performed by using CATIA V5 R17 software. CATIA is having special tools in generating surface design to construct typical surfaces, which are later converted into solid models. Solid model of all parts of the structures are then assembled to make a complete structure. The process of assembly is very much analogous to general process of fabricating structures while real production. The CAD model of multi leaf spring used for FE Analysis during assembly is shown in figure-3 and figure-4. The assembled CAD model has been prepared from various part modeling drawings.

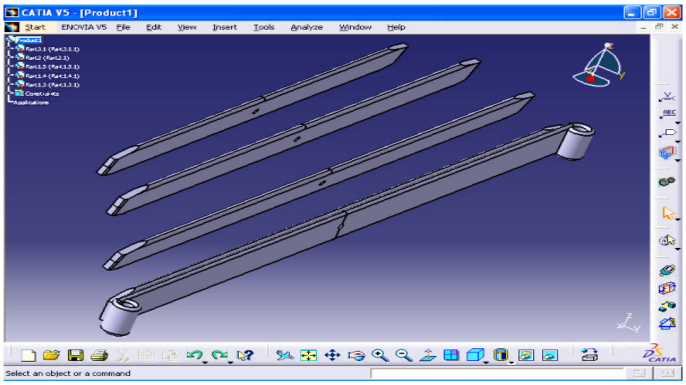

Figure-3
Assembly Design in CATIA

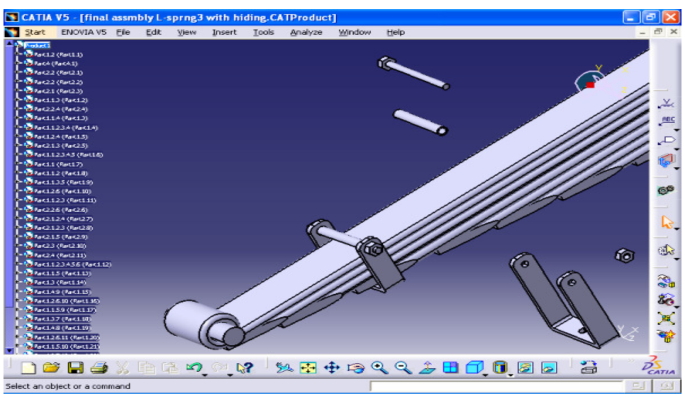

Figure-4
Assembly Design in CATIA

Finite Element Analysis: A stress-deflection analysis is performed using finite element analysis (FEA). The complete procedure of analysis has been done using ANSYS-11. To conduct finite element analysis, the general process of FEA is divided into three main phases, preprocessor, solution, and postprocessor.

Preprocessor: The preprocessor is a program that processes the input data to produce the output that is used as input to the subsequent phase (solution). Following are the input data that needs to be given to the preprocessor: i. Type of analysis ii. Element type iii. Real constants iv. Material properties v. Geometric model vi. Meshed model vii. Loading and boundary conditions.

Solution: Solution phase is completely automatic. The FEA software generates the element matrices, computes nodal values and derivatives, and stores the result data in files. These files are further used by the subsequent phase (postprocessor) to review and analyze the results through the graphic display and tabular listings.

Postprocessor: The output from the solution phase is in the numerical form and consists of nodal values of the field variable and its derivatives. For example, in structural analysis, the output is nodal displacement and stress in the elements. The postprocessor processes the result data and displays them in graphical form to check or analyze the result. The graphical output gives the detailed information about the required result data.

The multi leaf spring with all boundary conditions and material properties is imported in ANSYS-11, showing in figure-5, figure-6, figure-7 and figure-8.

The material used for the leaf spring for analysis is structural steel, which has approximately similar isotropic behavior and properties as compared to SUP9.

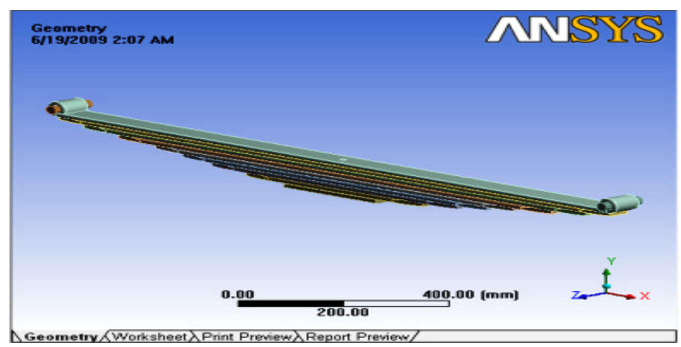

Figure-5
Multi Leaf Spring Assembly

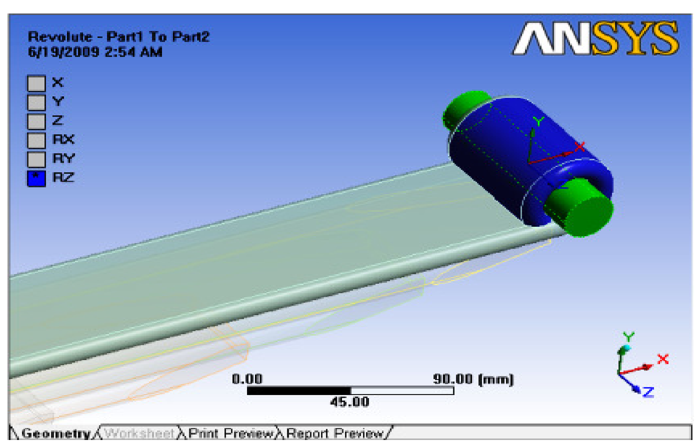

Figure-6
Eye end with pin

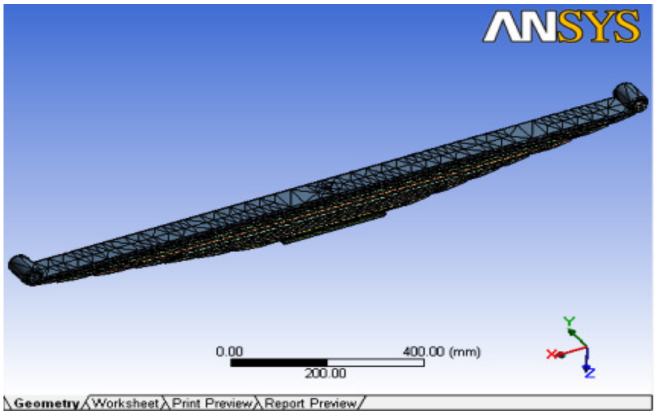

Figure-7
Meshing of Assembly

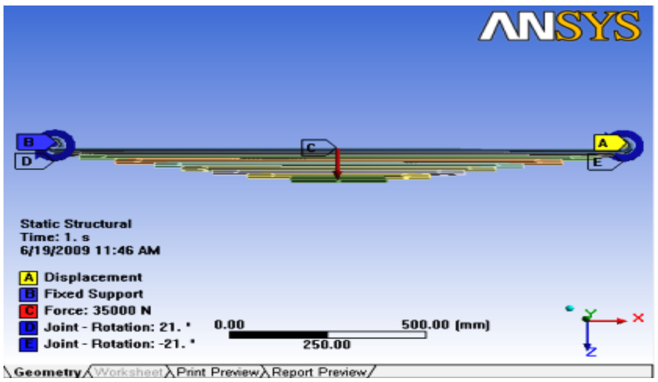

Figure-8
Boundary Conditions in ANSYS-11

Result and Discussions

As the finite element analysis of multi leaf spring is performed using ANSYS-11 detailed above, in which all conditions are considered which were also considered for results taken by experimental testing. The multi leaf spring showing deflections under full & half rated loads are shown in figure-9 and figure-10, as well as in tabular form taken from ANSYS-11.

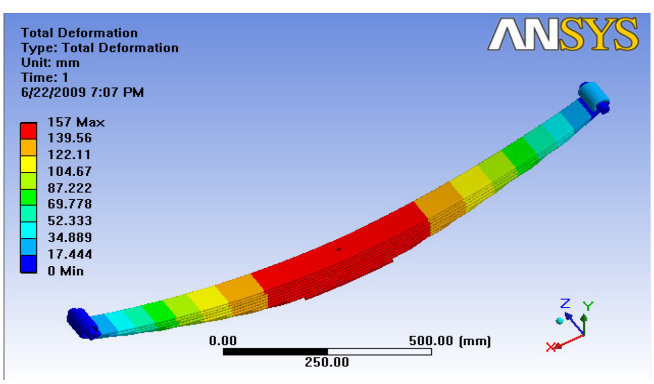

Figure-9
Deformation at Full Load

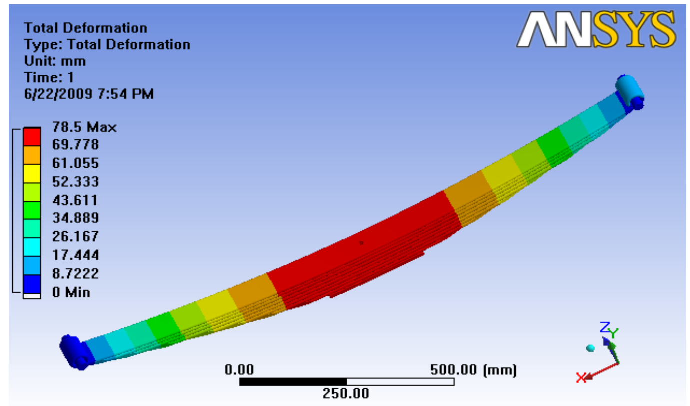

Figure-10
Deformation at Half Load

Result Comparison & Discussions:

Table-2
Result Comparison at Full Load

Parameters	Experiment Results	FEA Results	Variation
Normal Static Load	35000 N	35000 N	Nil
Deflection	158 mm	157 mm	0.632 %
Spring Rate	221.5 N/mm	222.92 N/mm	0.641 %
Bending Stress	101.8 Kgf/mm^2	113.25 Kgf/mm^2	10.11 %

As shown in the above table-2 deflection and the bending stress are compared for experimental and FEA results. The experimental deflection value is 158 mm and the FEA value is 157 mm i.e. a negligible difference is detected. On the other hand the bending stress is increased from 101.8 Kgf/mm^2 to 113.25 Kgf/mm^2 i.e. again a negligible difference is detected.

Table-3
Result Comparison at Half Load

Parameters	Experimental Results	FEA Results	Variation
Normal Static Load	17500 N	17500 N	Nil
Deflection	79 mm	78.5 mm	0.632 %
Spring Rate	221.5 N/mm	222.92N/mm	0.641 %
Bending Stress	48 Kgf/mm^2	56.62 Kgf/mm^2	17.95 %

As shown in the above table-3 the deflection and the bending stress with half rated load are compared for experimental and FEA results. The experimental deflection value is 79 mm and the FEA value is 78.5 mm i.e. a negligible difference in Experimental and FEA value. On the other hand the bending stress is increased from 48 Kgf/mm^2 to 56.62 Kgf/mm^2 i.e. the experimental value is lower than the FEA value but not far away.

The load vs deflection curve is also plotted here for FEA results.

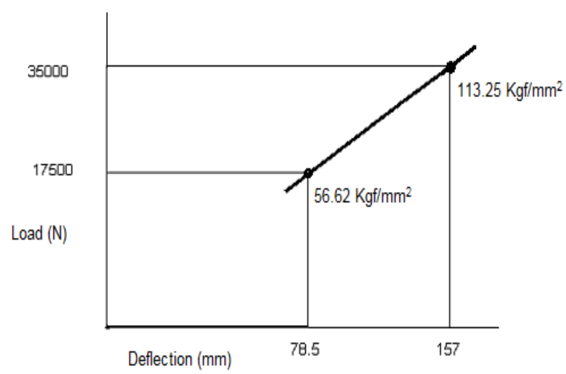

Figure-11
Load-Deflection curve for FEA Results

Conclusion

Design and stress-deflection analysis of a multi leaf spring is carried out by finite element approach using CAE tools (i.e CATIA, ANSYS). When the leaf spring is fully loaded, a variation of 0.632 % in deflection is observed between the experimental and FEA result, and same in case of half load, which validates the model and analysis. On the other hand, bending stress in both the cases is also close to the experimental results. The maximum value of equivalent stresses is below the Yield Stress of the material indicating that the design is safe from failure.

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