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Parametric modeling and fea analysis of automobile leaf spring

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ABSTRACT

A leaf spring is a simple form of spring, commonly used for the suspension in wheeled vehicles. Leaf Springs are long and narrow plates attached to the frame of a trailer that rest above or below the trailer's axle. Leaf springs are mainly used in suspension systems to absorb shock loads in automobiles like light motor vehicles, heavy duty trucks and in rail systems. It carries lateral loads, brake torque, driving torque in addition to shock absorbing. The advantage of leaf spring over helical spring is that the ends of the spring may be guided along a definite path as it deflects to act as a structural member in addition to energy absorbing device. Present article addresses the problem using FEA approach, in this Parametric CAD model is developed and this parametric model is further provided to ANSYS workbench. Variation of parameters such as length of leaf, width of leaf and thickness of leaf is analyzed and results of FEA are further compared with analytical formulations from design data book. It is observed there is close match between FEA results and analytical formulations. Further we have carried out the experiment on leaf spring to determine its deformations and stresses under static loading using standard UTM machine. Experimental results are having close match with FEA results and involve error not more than 8%.

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I. INTRODUCTION

In order to provide satisfactory comfort, shocks from bumps in the road surface must not be transmitted to the cab and superstructure. Springs are therefore provided between wheels and the chassis frame.

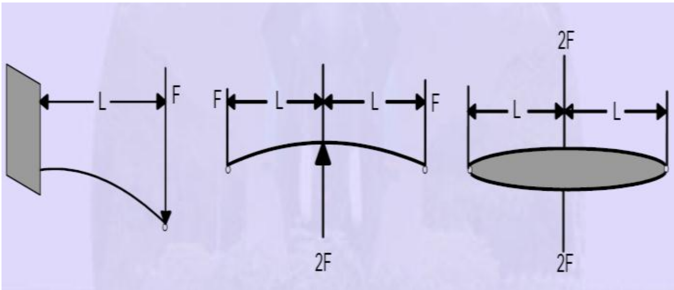
Leaf springs are mainly used in suspension systems to absorb shock loads in automobiles like light motor vehicles, heavy duty trucks and in rail systems. It carries lateral loads, brake torque, driving torque in addition to shock absorbing. The advantage of leaf spring over helical spring is that the ends of the spring may be guided along a definite path as it deflects to act as a structural member in addition to energy absorbing device. According to the studies made a material with maximum strength and minimum modulus of elasticity in the longitudinal direction is the most suitable material for a leaf spring.

Recently, automotive industry requires higher level of design and calculation almost in every part in both fabrication and testing which make it possible to improve and develop products.

Currently, the design of multi-leaf spring and the prediction of behaviors are more efficient when using finite elements method. The purposes of this research are to analyze, develop and validate finite element models of multi-leaf spring.

II. DESIGN OF LEAF SPRING

Multi-leaf springs are widely used for automobile and rail road suspensions. It consists of a series of flat plates, usually of semi- elliptical shape as shown in figure.



The objective of the present work is to design, analyze, fabricate and testing Conventional leaf spring. Identify the stresses and deformations in the leaf spring under static and dynamic loading conditions and decide a mode of failure in the leaf spring.
Parameters of the steel leaf spring used in this work are shown in Table 1
In every automobile, i.e. four wheelers and railways, the leaf spring is one of the main components and it provides a good suspension and it plays a vital role in automobile application. It carries lateral loads, brake torque, driving torque in addition to shock absorbing. The advantage of leaf spring over helical spring is that the ends of the spring may be guided along a definite path as it deflects to act as a structural member in addition to energy absorbing device. The geometry of the Steel leaf spring is shown in Fig. 1.

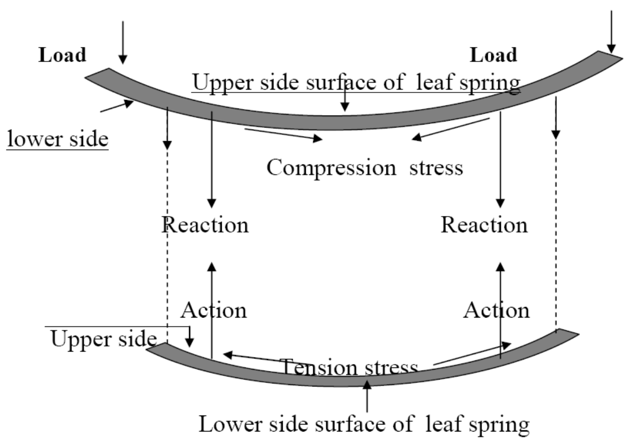


Fig indicates (the upper and lower side), (the action and reaction forces) and (tension and compression stress)
If the curvature beam is free there is a bending stress at lower side of curvature beam which has the same stress as on upper side of curvature beam with different signs. But in this research the upper and lower sides of curvature beam

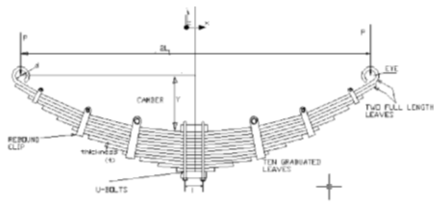


Figure 1: Leaf spring

are not free since there are contacts between the points on two adjacent leaves. This contact causing different force distribution on two sides upper and lower surfaces of leaf spring as shown in Fig.

It can be seen that the stresses on the lower surface are bending stress combined with compression stress and they are in the same direction which make the stresses at lower side greater than that on upper surface which has bending stress combined with tensile stress. Then the deflection in lower side will be greater than that on upper side.

The leaf spring has a bending stress which must be equally distributed along the structure. In mathematical point of view, the leaf spring can be considered as a cantilever beam. The bending stress in the arbitrary distance x can be expressed with the equation,

$$\sigma_t = \frac{M_t}{W}$$

Where Mt is bending moment and W is bending resistance. This equation qualifies for a spring which has regular cross-section area. Bending stress at for the parabolic leaf spring can be expressed with the equation,

$$\delta_t = \frac{M_x h_x}{I_x^2}$$

Where M_x is the bending moment, h_x is the thickness of the leaf and I_x is the second moment of area. I_x and h_x are usually expressed as functions in the parabolic leaf. I_x=f(x) and h_x=f(x).

Table 1 Parameters of Leaf Spring

Parameter	Value
Material selected – Steel	55Si2Mn90
Tensile strength (N/mm^2)	1962
Yield strength (N/mm^2)	1470
Young's modulus E (N/mm^2)	$2.1 \cdot 10^5$
Design stress (σ_b) (N/mm^2)	653
Total length (mm)	1190
The arc length between the axle seat and the front eye (mm)	595
Arc height at axle seat (mm)	120
Spring rate (N/mm)	32
Normal static loading (N)	3850
Available space for spring width (mm)	60 – 70
Spring weight (kg)	26

III.MODELING & ANALYSIS

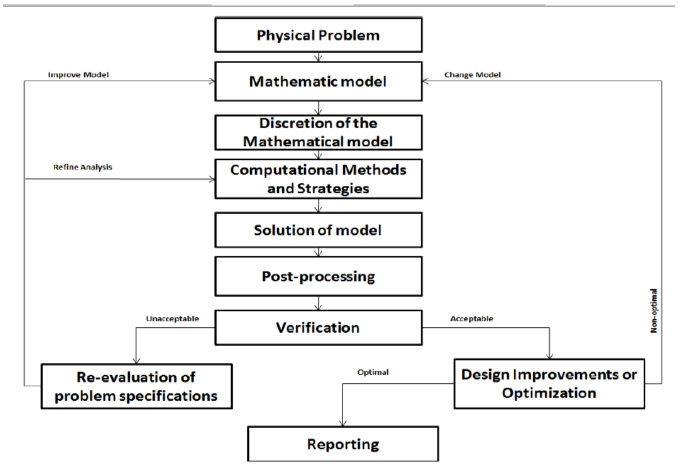
In this research, the analysis of multi-leaf spring was performed using finite elements method for determining stress distribution with following assumptions:

- The material properties are homogeneous.
- The effect of residual stresses such as heat treatment stress peeing, or center clamp are omitted.
- Spring shackle are not modeled.
- No inter leaf friction is considered.
- Only vehicle and payload were applied vertically.

The classical finite elements method is used with modification where all points (nodes) from points of contact, (between any two nodes on contact leaves) regarded to have the same displacement and the same internal forces.

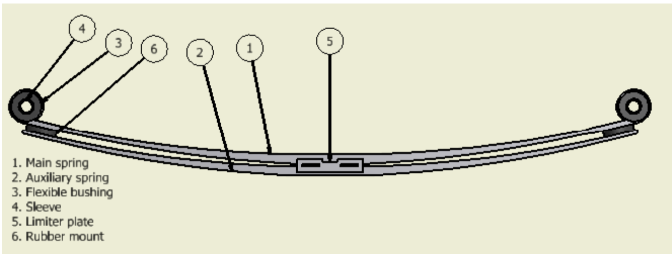
The finite element method (FEM) or the finite element analysis (FEA) is an analysis method to solve complex problems that cannot be described in the traditional engineering science. Fundamentals of the FEA are to divide a complex problem to several smaller problems and then use mathematics as a tool to bind solutions. The combined solution will give approximate determination for the complex solution. The development of the FEA was originated in 1960 by civil and aeroplane engineering industries. When the civil aviation started to grow up the need for safe structures increased. This led to the research of numerical modeling methods using the computers.

The typical flowchart of the FEA is shown in Figure. This process can be applied to any kind of analyses which are performed by using the FEA. The process starts of the determination of the physical problem. The FEA can be considered as a powerful tool to solve issues related to the engineering science, but it requires understanding of the physical problem. After the determination of the physical problem the mathematical model can be created. This means definitions of mathematical formulations and the problems physical outlines. The discretion of the model is usually defined in FEA programs by the automatic tool. Programs are capable to create elements without the user definitions. Even though, the automatic meshing and elements are implemented to programs, they are not able to predict where the finer mesh is needed. Refining of the mesh is usually done by using the information from the determination of the physical problem. Computational methods and strategies are mostly based on the user experience. Definitions are required when selecting solution methods, time steps or load steps for non-linear analysis. The solution of the model is processed when all definitions are done. The product from the solution is a result or an error. The post-processing offers information for rejecting or acceptance of the analysis. Processing of the data is usually done within the limits of knowledge of the physical problem. For example, common procedures in practical analyses are comparing the stress levels to material properties or inspect allowed displacements. Verifications can be done by using the previous information or experience. The data can be validated also via measurements if possible.

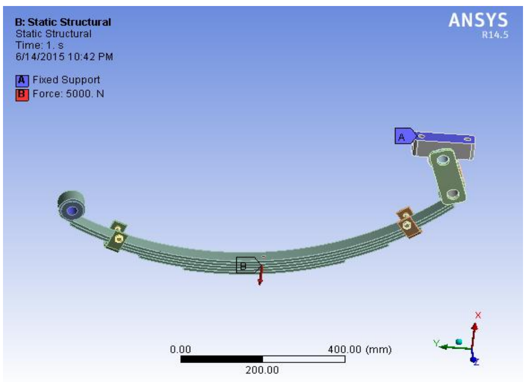


Process flowchart of typical FE-analysis.

The FE-model was created from the 3D model of the spring. Modeling was done by using the PROE Creo CAD program. The analysis was done with the Ansys WorkBench 14.0. The assembly was determined with components which were essential for calculations. Interesting points for the analysis were the thinnest cross section areas in the spring profile. The 3D model is presented in Figure. Simplifications of the model were that elasticity of flexible bushings (3. in Figure) and rubber mount (6. in Figure) are not taken into account in the FE model. The contact friction between the rubber mount and the main spring is not modeled.



Boundary conditions are modeled into the spring's eyes by using the cylindrical and remote displacement supports. Supports and the global coordinate system are introduced in Figure. The cylindrical support in the point A allows rotation over the z-axis with respect to the global coordinate system. The remote displacement allows rotation over the z-axis and displacement along the x-axis in the global coordinate system.



The mesh was generated by using the Ansys workspace automatic tool. The tool generated automatic elements to solid bodies. The mesh was refined in examination and contact areas. Refining was also done for flanks of the spring. Figure below shows a meshed model for leaf spring under consideration.

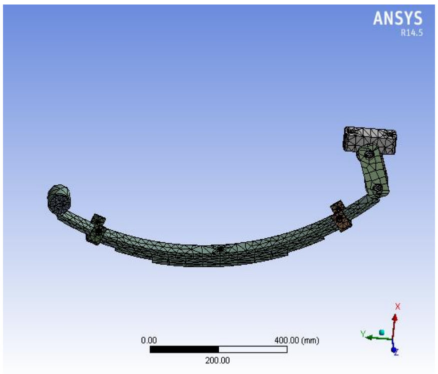


Figure below shows a deformed model for multi-leaf spring under specified load. Deformation is maximum 0.24 mm and is observed at central part of leaf spring.

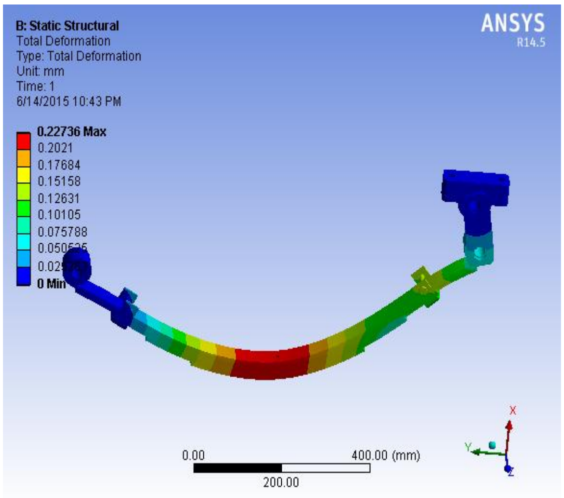
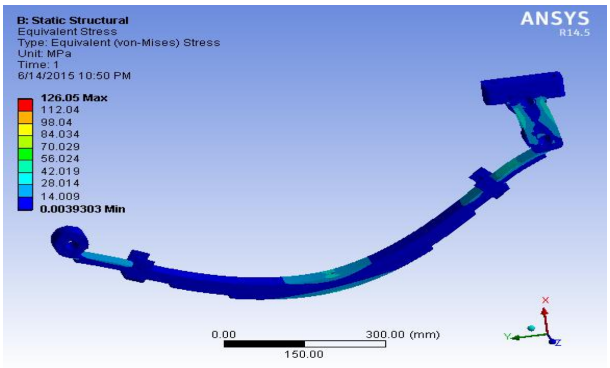


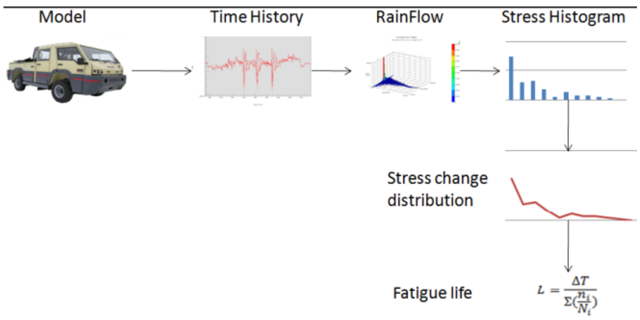
Figure below shows stresses induced in leaf spring, it is observed the maximum equivalent stress is 126 N/mm2 and which is within safe limit of material property of steel.



Stress analysis of multi – leaf spring were considered when the spring is subjected to maximum load at 1000N to determine the stress distribution and critical region of high stress which could cause failure to five leaves "7".

Fatigue analyses are done to determine the fatigue strength of the structure. Analyses can predict the life cycles of elements which are under the variable amplitude loading. Most of the structural failures in machines are caused by the fatigue phenomena.

The fatigue life calculations usually require known loading history. Most of the fatigue analyses are adaptable for the loading which has constant amplitude. In this case, the spring was under the random cyclic loading. Figure shows the process of the universal fatigue analysis in the time domain. The process can be applied to any kind of random loading fatigue analyses in time domains.



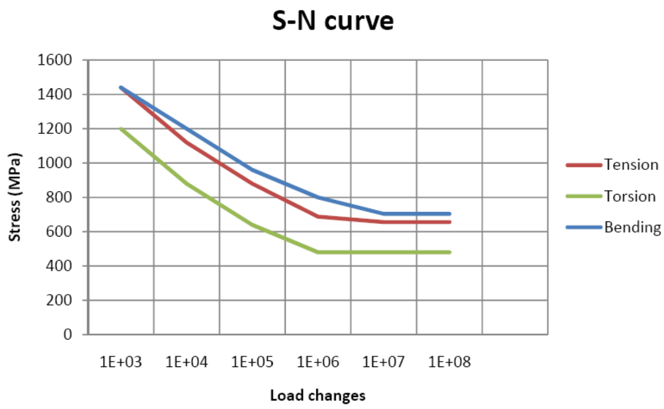
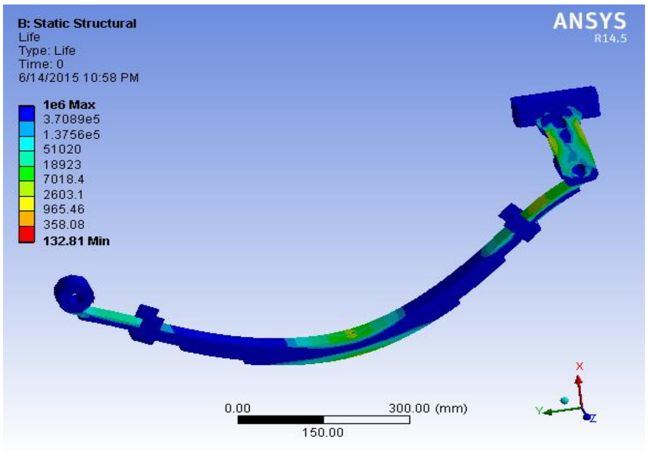


Figure above shows an S-N curve considered from fatigue analysis point of view. This data is provided to FEA software ANSYS Workbench as a Material properties and further fatigue life estimation is carried out under cyclic loading condition.

The fatigue analysis was carried out by using the von Mises stress, maximum principal stress and maximum principal strain. Evaluations were done with respect to bending. The idea was to compare results from different kind of methods. The maximum principal stress gave the shortest life time. The von Mises stress and the maximum principal strain gave approximately the same life time for the spring. Differences between fatigue analyses were that the strain life based approach used more accurate material information. The stress life based calculations were done from the S-N curve.

Figure below shows fatigue life of multi-leaf spring under consideration. It is observed that life of component is vary at different cross-section and different at different leafs. Middle leafs are having higher fatigue life where as inner and outer leafs have lower fatigue life.



Loading parameter of multi-leaf spring is varied from 1KN to 10 KN with step of 1KN. Table shows a comparison between theoretical and FEA results which are more close to each other.

Force in N	Total Deformation Maximum (mm)		Equivalent Stress Maximum (N/mm2)		Life Minimum (Cycles)
	Theory	FEA	Theory	FEA	
-1000	0.0401	0.0446	18.7014	20.7793	341260.1735
-2000	0.0714	0.0892	33.2469	41.5586	22280.3583
-3000	0.1097	0.1338	51.1171	62.3380	5846.2822
-4000	0.1586	0.1784	73.8820	83.1173	2402.7323
-5000	0.1784	0.2230	83.1173	103.8966	1306.3163
-6000	0.2141	0.2676	99.7407	124.6759	813.0856
-7000	0.2810	0.3122	130.9097	145.4552	544.5529
-8000	0.2775	0.3568	129.2935	166.2345	384.7965
-9000	0.3206	0.4014	149.3680	187.0139	283.2750
-10000	0.3524	0.4460	164.1566	207.7932	215.3848

IV. CONCLUSION

Stress analysis of multi leaf spring were considered, when the spring is subjected to maximum load of 1000N to determine the stress distribution and critical region of high stresses which could cause failure to the spring. Von Mises stresses on each leaf from first to fifth were calculated for different radii of curvature.

The magnitude of stress in lower side surface for all leaves of spring is more than stress in upper side surface. The maximum stresses are equals for all leaves except that on the last leaf (where last leaf is fixed). Lastly comparison between theoretical and FEA results are presently in tabular form. It is observed that theory and numerical simulations are close to each other.

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