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Design and Parametric Optimization Of Heavy Duty Leaf Spring

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ABSTRACT

The project deals with the analysis of a leaf spring, which is employed in heavy duty vehicle belonging to the medium segment of the Indian automotive market. In the design of this kind of spring both the elastic characteristics and the fatigue strength have to be considered as significant aspects. In addition to this particular elastic property, as a consequence of the research effort in reducing the mass of components typical of the automotive industry, these springs have to face very high working stresses. The structural reliability of the spring must therefore be ensured. So for this purpose the static stress analysis using finite element method has been done in order to find out the detailed stress distribution of the spring. In this spring is analyzed for stresses and deflection and same as plotted. Nine different parameters have chosen for the analysis. In this project main aim is to improve the fatigue strength by reducing shear stress of the spring, so each material is analyzed for its displacements and stresses. The material with the lowest displacement and stress is selected. The software used for the finite element meshing is ANSYS. Result values obtained for deflection and stresses are compared for each material. This project deals stress variations for all the set of parameters, and to pick the best spring among the rest.

Keywords: Leaf spring, structural reliability, static stress analysis

1. INTRODUCTION

A leaf spring is a simple form of spring, commonly used for the suspension in wheeled vehicles. It is also one of the oldest forms of shock absorption system. Leaf spring consists of flat bars of varying lengths clamped together and supported at both ends, thus acting as a simply supported beam. This can also be referred to as a semi-elliptical spring or cart spring; it has the form of a slender arc-shaped length of spring steel of rectangular cross-section [6].

The center of the arc provides location for the axle, while tie holes are provided at either end for attaching to the vehicle body. For 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. All the leaves are clamped using U-bolt. 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 friction in the motion of the suspension system. For this reason manufactures have experimented with mono-leaf springs [7].

A leaf spring can either be attached directly to the frame at both ends or attached directly at one end, usually the front, with the other end attached through a shackle, a short swinging arm. The shackle takes up the tendency of the leaf spring to elongate when compressed and thus makes for softer springiness. Some springs terminated in a concave end, called a spoon end, to carry a swiveling member. The spring consists of number of leaves, which are held together by U-clips. The long leaf fastened to the supported is called master leaf. Remaining leaves are called as graduated leaves. By giving greater radius of curvature to the full length leaves than the graduated leaves, before the leaves are assembled to form a spring thus a gap or clearance will be left between the leaves. This initial gap is called nip [7].

In order to conserve natural resources and economize energy, weight reduction has been the main focus of automobile manufacturers in the present scenario. Weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. The suspension leaf spring is one of the potential items for weight reduction in automobiles as it accounts for 10% - 20% of the unstrung weight. This achieves the vehicle with more fuel efficiency and improved riding qualities. [7].

Clerke C.K, Borowski G.E [3] estimates the reduction in strength in the spring resulting from cracks existing before the accident and the mid plane segregation. The Leaf Spring were suggested that leaf spring for heavy duty vehicles having l=600mm, w=90mm, n=15 to withstand load of 30tons. In Leaf spring, the static analysis is performed using ANSYS to find the maximum safe stress and the corresponding pay load. After geometric modelling of the leaf spring with given specifications it is subjected to analysis. The Analysis involves the following discrimination called meshing, boundary conditions and loading. However model analysis does not need loading.

Shiva Shankar G, Vijayarangan S [2] suggested Harmonic analysis has been done on composite leaf spring to find the modal frequency. The first five natural frequencies are listed in the Table 6. The natural frequency of composite leaf spring is higher than that of the steel leaf spring and is far enough from the road frequency to avoid the resonance. Stress calculations to estimate the effect of the prior cracking yielded residual strength levels in the spring that could be reasonably expected in travel over a dirt road. Thus conditions for spring rupture existed prior to the start of the accident sequence. Location of the point of rupture of the spring should therefore be placed at the beginning of the accident sequence, because the stresses for rupture were present at that point.

Senthil Kumar M, et al [1] analysed the composite multi leaf spring using glass fibre reinforced polymer are carried out using life data analysis.The reduction of weight, the fatigue life of composite leaf spring is predicted to be higher than that of steel leaf spring. Life data analysis is found to be a tool to predict the fatigue life of composite multi leaf spring. It is found that the life of composite leaf spring is much higher than that of steel leaf spring. The main factors that contribute to fatigue failures include number of load cycles experienced, range of stress and mean stress experienced in each load cycle and presence of local stress concentrations. Testing of leaf springs using the regular procedure consumes a lot of time. The results of the accelerated tests can be extrapolated to get the actual fatigue life under normal working conditions. The steel leaf spring was replaced with a composite one. The objective was to obtain a spring with minimum weight which is capable of carrying given static external forces by constraints limiting stresses (Tsai-Wu criterion) and displacements. The weight of the leaf spring is reduced considerably about 85 % by replacing steel leaf spring with the composite leaf spring. Thus, the objective of the unstrung mass is achieved to a larger extent. The stresses in the composite leaf spring are much lower than that of the steel spring.

Patunkar M, Dolas D [5] analysed for the composite leaf spring is done by using ANSYS 10.0 for composite leaf spring the same parameters are used that of conventional leaf spring. The constraint is given at the two eye rolled ends. One of the ends is provided with translational movement so as to adjust with the deflection. This eye end is free to travel in longitudinal direction. This particular motion will help leaf spring to get flattened when the load is applied. Modelling is done without Roll Eye End because their DOF are constrained in specific directions. It is very much clear from the results produced by the ANSYS In static load conditions deflection and stresses of steel leaf spring and composite leaf spring are found with the great difference. Deflection of Composite leaf spring is less as compared to steel leaf spring with the same loading condition. At maximum load condition also Composite Leaf Spring shows the minimum deflection as compared to Steel Leaf Spring. Composite leaf spring can be used on smooth roads with very high performance expectations. However on rough road conditions due to lower chipping resistance failure from chipping of composite leaf spring is highly probable.

Harinath Gowd G [4] evaluated and analyzed by using ANSYS software and it is concluded that for the given specifications of the leaf spring, the maximum safe load. The selected material must have good ductility, resilience and toughness to avoid sudden fracture for providing safety and comfort to the occupations. The same static load conditions deflection and stresses of steel leaf spring and composite leaf spring are found with the great difference. Deflection of Composite leaf spring is less as compared to steel leaf spring with the same loading condition. Conventional Leaf spring shows failure at eye end only. At maximum load condition also Composite Leaf Spring shows the minimum deflection as compared to Steel Leaf Spring. Composite leaf spring can be used on smooth roads with very high performance expectations. However on rough road conditions due to lower chipping resistance failure from chipping of composite leaf spring is highly probable.

Dr. Kirpal Singh [6] evaluates the leaf spring deflections, the upper side of each leaf tip slides or rubs against the lower side of the leaf above it. This produces some damping which reduces spring vibrations, but since this available damping may change with time, it is preferred not to avail of the same. Moreover, it produces squeaking sound. The leaves of the leaf spring require lubrication at periodic intervals. So the spring must to clean thoroughly and sprayed with oil.

Figure 1.1 Types of Leaf Spring [7]

1.1 Types of Leaf Springs

Semi-elliptic type spring

This is the common form of the leaf spring in which the spring is attached to the frame and at its middle to the axle. For front side of the vehicle this type of spring is used with any one of the ends shackled with the frame, while the other end is attached with the simple pin. This spring is fitted longitudinally to the chassis.

1.2 Manufacturing process of leaf spring

The manufacturing process carried out at the works is detailed below. Spring leaves are sized to the required length; they are subjected to various processes like punching, eye rolling, cover/wrapper rolling, end cropping, taper rolling, and so on Leaf Spring also has a state of the art fully computerized Taper Rolling machine for the manufacture of parabolic springs. Leaves are heated in a Furnace and passed on the taper rolling mill, where the parabolic curve is created on the leaves. This operation is fully controlled by the Computer, in which the parabolic co-ordinates are stored. The spring leaves are then fed into a walking beam furnace with automatic temperature controls where they are heated to the critical temperature depending upon the grade of the material used [6].

On attaining the correct temperature, the spring leaves are placed on a combined leaf spring cambering and hardening machine where the spring leaves are cambered to a predetermined curvature and simultaneously oil hardened by the rotation of the drum type cambering machine into the quenching oil bath. By this operation of rapid oil quenching at the critical temperature, the grain structure of the spring leaf is transformed to martensite, which imparts the required hardness to the leaf. The spring leaves are then fed into a conveyorised tempering furnace, passing through various temperature zones with automatic temperature controls, to relieve the stresses developed due to oil hardening. After tempering, the spring leaves are checked to ensure that they have attained the required hardness and tempered martensite structure.

Next, the spring leaves are passed through a shot penning machine, which induces a residual compressive stress on the surface, thereby increasing the fatigue life of the spring.

The spring leaves are then processed, after application of Zinc rich primer / Graphite Primer undercoating. The spring leaves thus processed are assembled into a leaf spring assembly on a Hydraulic Assembling Machine to the required camber. The spring assembly is subjected to a scragging operation by deflecting it by an amount which will develop a maximum, stress equal to 90% of the yield stress of the material after heat treatment. The spring assemblies are finally degreased, de-rusted and spray painted with anti-corrosive paint and baked in an oven to achieve the necessary anticorrosive properties. ILS is also equipped with a full in-house Tool and Die Room where our engineers can design and produce any tool/dies and jigs necessary to facilitate the manufacture of springs [7].

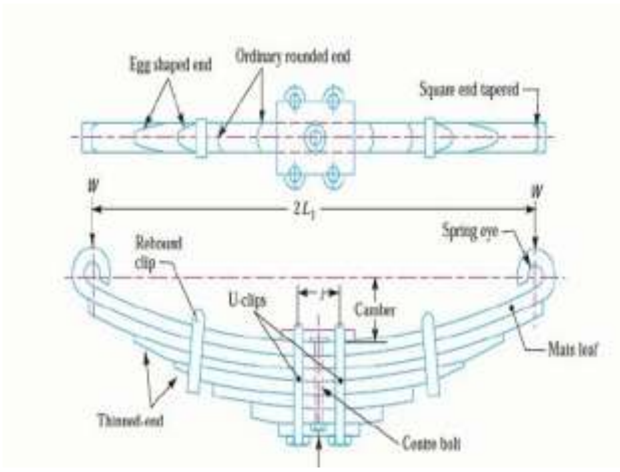


Figure 1.2 Layout of Semi-elliptic leaf spring [7].

2.OBJECTIVE AND METHODOLOGY

2.1 OBJECTIVES

The main objective of this project is,

- To optimize the designed leaf.
- To design the proposed leaf spring
- To analysis the spring.
- To carry out creep and fatigue test.

2.2 METHODOLOGY

The above objectives can be achieved by the following methods as follows,

- Optimization can be achieved by the parameters (length, width, thickness) available.
- Designing can be achieved by using CATIA software in accordance with the specifications available.
- Analysis can be achieved through by using simulating software ANSYS.
- It can also be achieved through the simulating software ANSYS.

3. CALCULATION AND MODELLING OF LEAF SPRING

Table 3.1 Calculated values of the Leaf Springs

Parameters	Values
Length of the leaf spring (l)	1300mm
Width (w)	90mm
Thickness (t)	14 mm
Sustain load (l)	70*103 N
Full length leaves (n_f)	3
Graduated leaves (n_g)	11
Total no. of leaves (n)	14
Band width	100mm
Stress	400 N/mm^2
Ratio of total spring depth/width	2*105 N/mm^2
Young's modulus (E)	2*105 N/mm^2
Initial gap (C)	6.34 mm.
Load exerted on the band (W_b)	318.3 N.
Deflection of spring	9.61 mm.
Maximum bending moment (M_B)	70000Nmm.
Inner diameter of eye (d_i)	10mm.
Shear stress (f_s)	22.29N/mm^2

The above specifications are obtained from appendix. By using these parameters designing and analyzing of leaf spring were engaged.

The length of the leaf springs used in this work is shown in Table 3.2.

Table 3.2 Length of the Leaf Springs

Sl. No	**Length of the leaf (l)**
1	192.30
2	284.61
3	376.92
4	469.32
5	561.53
6	653.84
7	746.15
8	838.46
9	930.76
10	1023.07
11	1115.38
12	1207.69
13	1300.00
14	1470.00

The above specifications are obtained from appendix. By using these parameters designing and analyzing of leaf spring were engaged.

3.1 MATERIAL SELECTION

There are many situations in engineering where no single material will be suitable to meet a particular design requirement. For example aerospace application need materials that should have low densities ,high strength and stiffness ,good abrasive, impact and corrosion resistance. Such a combination of characteristics is not met by conventional metals, alloys, ceramics and polymeric metals. Frequently strong materials are relatively dense; also, increasing the strength or stiffness generally results in a decrease in impact strength.

3.1.1 E-glass/epoxy

Glass Fiber Reinforced Plastics (GFRP) is considered a potential material system offering non-conductive, non-magnetic, good chemical resistance and good mechanical strength.

The loading rate sensitivity of the polymer composites appeared to be inconsistent and contradictory at some points of conditioning time and as well as at a temperature of conditioning. This Phenomenon may be attributed to low-temperature hardening, matrix cracking, misfit strain due to differential thermal coefficient of the constituent phases, and also to enhanced mechanical keying factor by compressive residual stresses at low temperatures.

The main emphasis of the investigation was to evaluate the roles of percentage matrix phase and interfacial areas on the inner laminar shear failure mechanism of glass/epoxy composites at ultra-low temperatures for different loading speeds. The mechanical performances of the laminated specimens at low temperatures were compared with room temperature property. Phenomena may be attributed by low-temperature hardening, matrix cracking, and misfit strain due to differential thermal coefficient of the constituent phases and also by enhanced mechanical keying factor by compressive residual stresses at low temperatures [4].

Table 3.3 Properties of E-glass/epoxy [4]

1	Fiber volume fraction v_f (%)	52
2	Tensile strength (MPa)	767
3	Tensile modulus (GPa)	36.9
4	Tensile strain to failure (%)	2.2
5	Flexure strength (GPa)	1023
6	Flexure modulus (GPa)	43.3
7	Shear modulus (GPa)	3.3
8	Poisson ratio	0.3

3.2 MODELLING

The modeling of Leaf Spring is done by using CATIA software. The spring was modeled with element SOLID 95/SOLID 186. This is used for 3-D modeling of solid structures having 20 nodes. It can tolerate irregular shapes without as much loss of accuracy. SOLID 186 elements have compatible displacement shapes and are well suited to model curved boundaries. It is defined by eight nodes having three degrees of freedom at each node translations in the nodal x, y and z directions. This element is used for Hex-meshing as shown in figure 3.1 [4]

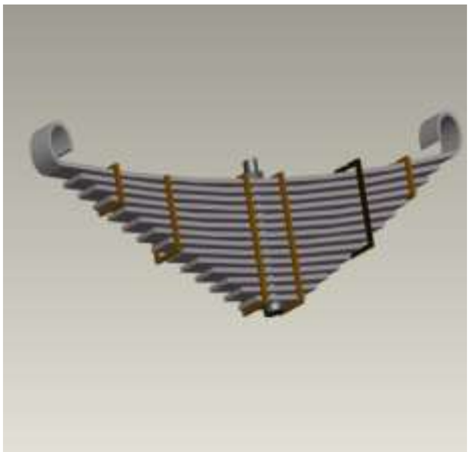


Figure 3.1 Model of Leaf Spring [5]

3.2.1 PROCEDURE

In the process, the stress is the specified field variable is selected and its convergence is monitored and evaluated. Selecting the right techniques of meshing are based on the geometry, model topology, analysis objectives. Tetrahedral meshing produces high quality meshing for boundary representation solids model imported from the most CAD system.

3.3 MESHING

ANSYS 13.0 is the software used for the pre and post processing. This leaf spring is meshed with different elements and different meshing types. At first the spring was meshed with element SOLID 187. This element is a higher order 3-dimentional, 10- node element. SOLID 187 is a quadratic displacement behavior. Meshing is performed on the FE model to ensure sufficiently fine sizes are employed for accuracy of calculated results but at competitive cost. After testing the spring model for different element sizes with above elements SOLID 186 and SOLID 187 one by one it was seen that smaller mesh size captures the higher stress value. The element SOLID 187 is the test Mesh. But smaller element size is less than 2 mm for both the types of elements was it implemented [5]

3.4 PARAMETRIC SELECTION

Table 3.4 Selection of Parameters

Symbol	**Parameters**	**Levels**		
		1	**2**	**3**
A	Number of leafs (N)	13	14	15
B	Effective Length of leaf (L)	590	600	610
C	Width of the leaf (w)	88	90	92

The selection of parameters having 3×3 matrix. Each parameter having 3 variables.

3.5 ORTHOGONAL ARRAYS

Two basic kinds of OAs are available. When all factors involved have 2- levels the available arrays are L4, L8, L12, L16, and L32. Similarly for 3-level the available arrays are L9, L18, L27. The table 3.5 is given will be helpful in selecting orthogonal arrays for the particular situation. In this project is recommended to select L9 array.

Table 3.5 Orthogonal Array for L9

Sl. No.	**No of leaf (n)**	**Length (l) mm**	**Width (w) mm**
1	13	590	88
2	13	600	90
3	13	610	92
4	14	600	88
5	14	610	90
6	14	590	92
7	15	610	88
8	15	590	90
9	15	600	92

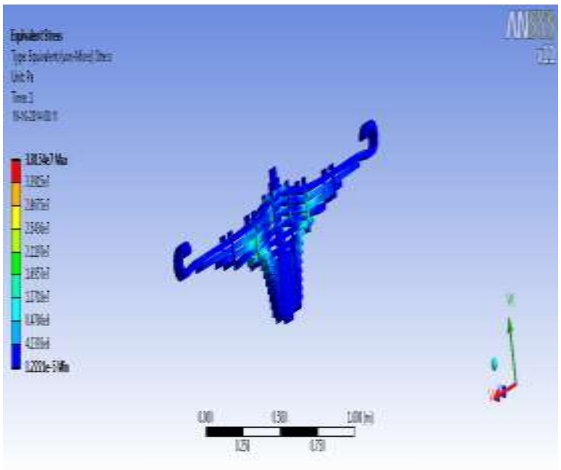
4 RESULTS AND DISCUSSION

Among the combinations of eighteen, the parameters were taken and designed and analyses using software CATIA and ANSYS. Through analysis maximum permissible stress and the deformation results can be achieved for all the eighteen combinations. The deformed and un-deformed shape of the leaf spring is shown in Figure 5.1to 5.9 and the Table 5.1 gives the stress values for given loading conditions. From the graph, it is known that the best three combinations were selected with the help of the analysis result. Generally leaf springs used in the automotive trucks leads to cracks when they are subjected to loads more than 12 tons, so in order to recover from these demerit, a combinations of nine set were selected and engaged with the analysis to determine stress variations and deformations occur.

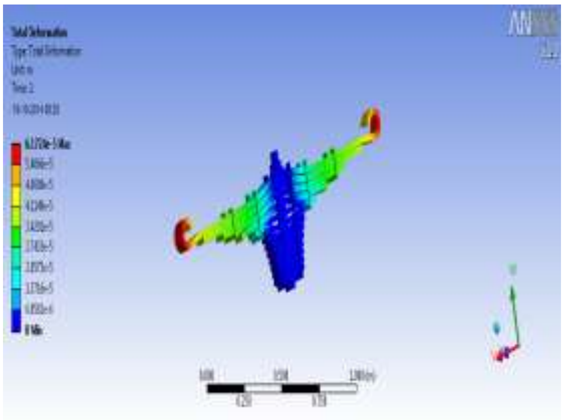
Table 4.1

Results from stress variations

Parameters	**No of leaves**	**Width (mm)**	**Length (mm)**
Leaf spring	13	88	600



Equivalent Stress (Set 1)



Total Deformation (Set 1)

Figure 4.1 Analysis of Leaf Spring (Set 1)

In figure 4.1 shows the stress and deformation of set 1. The maximum and minimum value of Equivalent stress is 3.8154e7and 1.2221e-5.The maximum and minimum value of the deformation is 6.1724e-5 and 0.

From Figure 4.1, it is obvious that maximum stress developed is at inner side of the eye sections i.e. the red color indicates maximum stress, because the constraints applied at the interior of the eyes. Since eyes are subjected to maximum stress, care must be taken in eye design and fabrication and material selection. The material must have good ductility, resilience and toughness to avoid sudden fracture.

Table 4.2 Result from Analysis

Sl. No.	**No. of leaf(n)**	**Effective length (l)**	**Width (w)**	**Deformation**	**Stress (N/mm^2)**
1	13	590	88	6.172E-05	3.815E+07
2	13	600	90	4.854E-05	2.515E+07
3	13	610	92	4.261E-05	3.683E+07
4	14	600	88	3.932E-05	1.753E+07
5	14	610	90	0.134E-04	4.042E+07
6	14	590	92	0.140E-04	2.451E+08
7	15	610	88	5.494E-05	3.581E+07
8	15	590	90	5.515E-05	4.112E+07
9	15	600	92	5.594E-05	3.836E+07

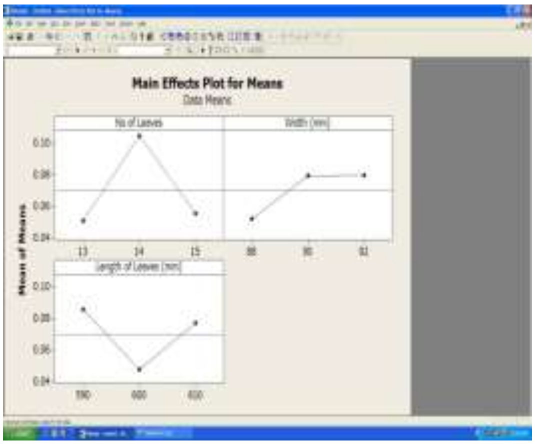


Figure 4.2 Plot for Equivalent Stress

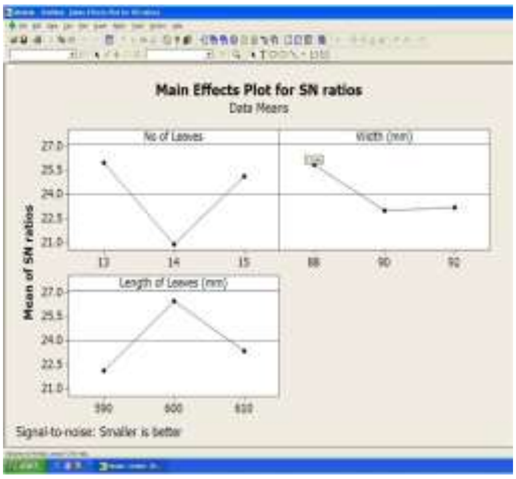


Figure 4.3 Plot for deformation

5. CONCLUSION

The detailed analysis of Design and Parametric Optimization of Heavy Duty Leaf Spring give the following. This project is to analyze the spring behavior in static condition for deflection and stresses. Finite element analysis using ANSYS gives output result. Thus by applying a given load (7 tons) for all the nine combinations of parameters get a withstand able values for stresses and deformation. With the help of the graph, it gives 2 best suited leaf springs out of nine combinations. With observing the graph, (equivalent stresses), out of nine parameters we get three withstanding parameters.

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