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Static and Modal Analysis of Leaf Spring Using FEA

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Abstract *– The objective of this present work is to estimate the deflection, stress and mode frequency induced in the leaf spring of an army jeep design by the ordinance factory. The emphasis in this project is on the application of computer aided analysis using finite element concept.*

The leaf spring, which we are analyzing, is a specially designed leaf spring used in military jeeps. This spring is intended to bare heavy jerks and vibrations reduced during military operations. A model of such jeep has been shown in this project report.

In analysis part the finite element of leaf spring is created using solid tetrahedron elements, appropriate boundary conditions are applied, material properties are given and loads are applied as per its design, the resultant deformation, mode frequencies and stresses obtained are reported and discussed.

I. Introduction

A spring is defined as an elastic body, whose function is to distort when loaded and to recovers its original shape when the load is removed.

Semi- elliptic leaf springs are almost universally used for suspension in light and heavy commercial vehicles. For cars also, these are widely used in rear suspension. The spring consists of a number of leaves called blades. The blades are varying in length. The blades are us usually given an initial curvature or cambered so that they will tend to straighten under the load. The leaf spring is based upon the theory of a beam of uniform strength. The lengthiest blade has eyes on its ends. This blade is called main or master leaf, the remaining blades are called graduated leaves. All the blades are bound together by means of steel straps.

The spring is mounted on the axle of the vehicle. The entire vehicle rests on the leaf spring. The front end of the spring is connected to the frame with a simple pin joint, while the rear end of the spring is connected with a shackle. Shackle is the flexible link which connects between leaf spring rear eye and frame. When the vehicle comes across a projection on the road surface, the wheel moves up, leading to deflection of the spring. This changes the length between the spring eyes. If both the ends are fixed, the spring will not be able to accommodate this change of length. So, to
Accommodate this change in length shackle is provided as one end, which gives a flexible connection.

The front eye of the leaf spring is constrained in all the directions, where as rear eye is not constrained in X-direction. This rare eye is connected to the shackle. During loading the spring deflects and moves in the direction perpendicular to the load applied.

The springs are initially cambered. More cambered leaf springs are having high stiffness, so that provides hard suspension. Use of longer springs gives a soft suspension, because when length increases the softness increases. Generally rear springs are kept longer than the front springs.

Spring eyes for heavy vehicles are usually bushed with phosphor bronze bushes. However, for cars and light transport vehicles like vans, the use of rubber has also become a common practice. This obviates the necessity of lubrication as in the case of bronze bushes. The rubber bushes are quiet in operation and also the wear on pin or the bush is negligible. Moreover, they allow for slight assembly misalignment, “Silentbloc’ is an example of this type of bushes.

Fatigue strength and hence the life of spring can be increased by shot – peening the top surface of each leaf, which introduces a compressive residual stress, rounding the edges of the leaves also avoids stress concentration, thereby improving the fatigue strength.

When the leaf spring deflects, the upper side of each leaf tips 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, Further if moisture is also present, such inter-leaf friction will cause fretting corrosion which decreases the fatigue strength of the spring, and phosphate paint may reduce this problem fairly.

Occasionally, thin liners of zinc or any other soft metal are also help to keep the value of the friction coefficient constant.

In some springs special insets are provided at the end of each leaf, excepting however the master leaf. The material for the inserts may be rubber or waxed cloth, or even some soft bearing metal impregnated with oil. This gives efficient spring operation.

Sometimes the leaf springs are provided with metallic or fabric covers to exclude dirt. The covers also serve to contain the lubricant used in between the spring leaves.

In case of metal covers, the design has to be of telescopic type to accommodate the length of cover after the change of spring length.

The leaves of the leaf spring require lubricant at periodic intervals. If not, the vehicle is jacked up so that the weight of the axle opens up the leaves. The spring is then cleaned thoroughly and sprayed with graphite penetrating oil. However, it is important to remember that in some vehicles, (e.g. Ambassador) it is specified that the lubricant of spring leaves should not be done. In such cases the instruction must be followed.

The lubrication of shackle pins at regular intervals, say 1000km, should also be done with S.A.E 140 oil. However, no lubrication is required when rubber bushed are used, as in case of the Hindustan Ambassador car.

I.1 Objective

The automobile industry is showing increased interest in the replacement of steel spring with fiberglass composite leaf spring due to high strength to weight ratio. Therefore; this project aims at comparative study of design parameters of a traditional steel leaf spring assembly and mono composite leaf spring with bonded end joints.

By performing static analysis using ANSYS software and mathematical calculations, the maximum bending stress and corresponding payload have to be determined by considering the factor of safety.

Determining and assessing the behavior of the different parametric combinations of the leaf spring, their natural frequencies are compared with the excitation frequencies at different speeds of the vehicle with the various widths of the road irregularity. These excitation frequencies are calculated mathematically.

II. Literature Review

Zliahu Zahavi [1] the leaf spring works is very complicated from the point of view of mechanics and numerical computations. The magnitude of loading is high as well as spring deformations. Multi-surfaces 3D contact between subsequent leafs also takes place. The main advantage of leaf springs is that the ends of the spring are guided along a definite path as it deflects to act as a structural member in addition to energy absorbing device. Practically, a leaf spring is subjected to millions of load cycles leading to fatigue failure. Free vibration analysis determines the frequencies and mode shapes of leaf spring.

A. Strzat and T. Paszek [2] performed a three-dimensional contact analysis of the car leaf spring. They considered static three-dimensional contact problem of the leaf car spring. Different types of mathematical models were considered. The static characteristics of the car spring was obtained for different models and later on, it is compared with one obtained from experimental investigations.

Fu-cheng Wang [3] performed a detailed study on leaf spring.. His work mainly discusses the active suspension control of vehicle models. The employing active suspension through the analysis of the mechanical networks is discussed. He derived a parameterization of the set of all stabilizing controllers for a given plant. He considered practical parameters and applications of a leaf spring model through his work, thus supporting both the situations, that is active and passive suspension cases, individually.

I.Rajendran and S. Vijayarangan [4] performed a finite element analysis on a typical leaf spring of a passenger car. Finite element analysis has been carried out to determine natural frequencies and mode shapes of the leaf spring. A simple road surface model was considered.

Gulur Siddaramanna Shiva Shankar [5] performed test on the leaf springs under static loading condition & the stresses and deflection are listed. These results are also compared with FEA. Testing has been done for unidirectional E-Glass/Epoxy mono composite leaf spring only. Since the composite leaf spring is able to withstand the static load, it is concluded that there is no objection from strength point of view also, in the process of replacing the conventional leaf spring by composite leaf spring. Since, the composite spring is designed for same stiffness as that of steel leaf spring, both the springs are considered to be almost equal in vehicle stability. The major disadvantages of composite leaf spring are chipping resistance. The matrix material is likely to chip off when it is subjected to a poor road environments (that is, if some stone hit the composite leaf spring then it may produce chipping) which may break some fibers in the lower portion of the spring. This may result in a loss of capability to share flexural stiffness.

Vinkel Arora, Dr. M.L Aggarwal, Dr. Gian Bhushan [6] perform computer aided design and analysis of a conventional leaf spring, with experimental design considerations and loading conditions. This conventional leaf spring model consists of 37 parts. The material of the leaf spring is 65Si7.The CAD model of the leaf spring is prepared in CATIA and analyzed using ANSYS. The CAE analysis of the leaf spring is performed for the deflection and stresses under defined loading conditions, using ANSYS. The experimental and CAE results are compared for validation. Using CAE tools the ideal type of contact and meshing element is determined in leaf spring model.

M.Venkatesan , D.Helmen Devaraj [7] perform design and experimental analysis of composite leaf spring made of glass fiber reinforced polymer & compare the load carrying capacity, stiffness and weight savings of composite leaf spring with that of steel leaf spring. Compared to steel spring, the composite leaf spring is found to have 67.35% lesser stress, 64.95% higher stiffness and 126.98% higher natural frequency than that of existing steel leaf spring. A weight reduction of 76.4% is achieved by using optimized composite leaf spring.

S. Venkatesh, Dr. S. S. Mohamed Nazirudeen, Dr. A. K. Shaik Dawood, R. Karthikeyan [8] research work describes about the development of porous Aluminium foam for making commercial vehicle leaf spring made of Aluminium. The Aluminium foamed leaf spring has stresses much lower than steel leaf spring and weight of aluminium foamed leaf spring was reduced upto 20%. Using FEA stress and deflection is analysed.

G. Harinath Gowd & E Venugopal Goud [9] perform static analysis on leaf spring by using ANSYS software and it is concluded that for the given specifications of the leaf spring, the maximum safe load is 7700N. It is observed that the maximum stress is developed at the inner side of the eye sections, so care must be taken in eye design and fabrication and material selection. The selected material must have good ductility, resilience and toughness to avoid sudden fracture for providing safety and comfort to the occupants.

Sethilkumar Mouleeswaran [10] performs design and experimental analysis of composite multi leaf spring using glass fibre reinforced polymer are carried out. Compared to steel spring, the composite leaf spring is found to have 67.35% lesser stress, 64.95% higher stiffness and 126.98% higher natural frequency than that of existing steel leaf spring. The conventional multi leaf spring weighs about 13.5 kg whereas the E-glass/Epoxy multi leaf spring weighs only 4.3 kg. Thus the weight reduction of 68.15% is achieved. Besides the reduction of weight, the performance of the leaf spring is also increased. Compared to the steel leaf spring (13.5 kg), the optimised composite leaf spring weighs nearly 76.4% less than the steel spring. Ride comfort and life of CLS are also more when compared to SLS. Therefore, it is concluded that composite multi leaf spring is an effective replacement for the existing steel leaf spring in light passenger vehicles.

Kumar Krishan And Aggarwal M. L. [11] perform 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 including that the design is safe from failure.

III. Analysis Of Leaf Spring

Introduction

In computer – aided design, geometric modeling is concerned with the computer compatible mathematical description of the geometry of an object. A cad model of a typical LCV leaf spring is modeled on based on mathematical calculations on Pro/Engineer software

After geometric modeling of the leaf spring with given specifications it has to be subjected to analysis. ANSYS software is used to analyze the stresses by performing static analysis for the given leaf spring specification to assess the behavior of the leaf spring with various parametric combinations. Analysis involves discrimination called meshing, boundary conditions, and loading conditions.

III. 1. Modeling of leaf spring

III.1.1 Steel leaf spring assembly

Pro Engineer software was used for this particular model and the steps are as follows:

1. Start a new part model with Metric units set.
2. Draw the sketches of the trajectories of each leaf of spring with the radius obtained from calculations with span1220mm camber 80.
1. Using sweep command draw a section 60 mm X 7 mm thick sweep along the above drawn curves of leaf.
2. According the spring design manual the eye diameter is formed on the first leaf.
3. Thickness of leaves = 7mm.
4. After all the features of all leaves as are modeled, generate family table for each leaf.
5. Generate models for u-clams, axle rod, top support plate etc.
6. Assemble each of the leaf in an assembly model and assemble all other models.

7. Provide a ½ inch dia hole in the leaf spring for bolt.
8. Export the model to iges – solid – assembly – flat level.

The following are the model dimensions.

1. Camber = 80mm
2. Span = 1220mm
3. Thickness of leaves = 7mm
4. Number of leaves = 10
5. Number of full length leaves nF = 2
6. Number of graduated length leaves nG = 8
7. Width = 60
8. Ineffective length = 60mm
9. Eye Diameter = 20mm
10. Bolt Diameter = 10mm

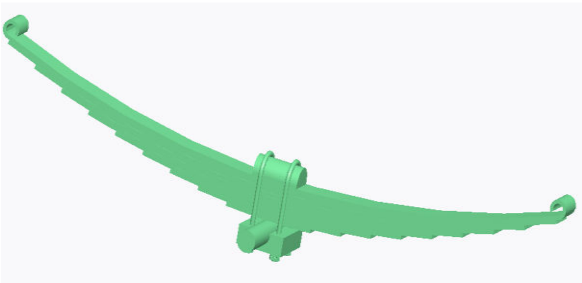

Fig 3.1 Assembly Model of Steel Leaf Spring

III.1.2 Composite mono leaf spring

The steps for modeling are as follows:

1. Start a new part model with Metric units set.
2. Draw the sketch of the trajectory with dimensions of first leaf of spring of steel spring assembly without eyes, span is same as 1220mm and camber 80.
3. The geometrical dimensions are carried forward from the steel leaf spring except for the number of plates and thickness in order to maintain the required cross section area. Generate sketches cross section dimensions at center and ends as mentioned in table follows:
4. Using swept blend
5. Select trajectory
6. Pivot direction
7. Select plane for pivot direction
8. Select origin trajectory
9. Select cross section sketches. The model is ready.
10. Export the model to iges – solid – part – flat level.

TABLE VI.1 DIMENSIONS OF MONO COMPOSITE LEAF SPRING

Parameters	At center	At end
Breadth in mm	70	70
Thickness in mm	150	21

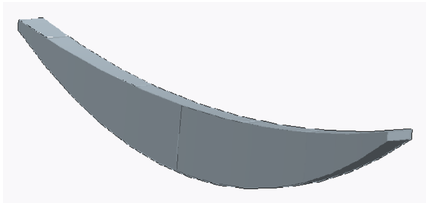

Fig 3.2 Model of mono composite leaf spring

VI. 2 Finite Element Modeling and Boundary conditions.

VI.2.1 Element Type:

For steel leaf spring brick 20 node95 is well suited to modal irregular meshes (such as produced from various CAD/CAM Systems.) the element is defined by four nodes having six degrees of freedom at each node: translation in the nodal x, y, and z directions and rotations about the nodal x, y, and z directions. The element also has stress stiffening capability. A 10 – node tetrahedral element without rotational degrees of freedom is also available called solid 92.

For mono composite leaf spring Shell 99 linear layer 99 with 6 degrees of freedom is a typically used standard element type.

Assumptions and Restrictions

Brick 20 node 95 uses a mixed (or hybrid) scheme with constant shear strains resulting in a non – frame invariance of the element stiffness matrix. The element must not have a zero volume. Elements may be numbered either as shown in above figure or may have node L below the IJK plane. Care should be taken when applying force loads and displacement contra tints to this solid element with rotational degrees of freedom. For uniform results, applied moments should accompany applied forces, and rotational displacement constrains should be where appropriate. The rotational stiffness of an isolated node or line of nodes is quite small and is typical inappropriate as the sole rotational constraint of the model or an adjacent bean or shell element. Applied pressure loads on an element face are automatically converted to the equivalent force and moment loads. When the Brick 20 node 95 elements are used with other element types, the constraints to prevent rigid body motion should be specified on the nodes. It is also recommended that at least one of the nodes have specified constraints in each of the three rotational directions.

III.2.2 Meshing

Meshing involves division of the entire of model into small pieces called elements. This is done by meshing. It is convenient to select the free mesh because the leaf spring has sharp curves, so that shape of the object will not alter. To mesh the leaf spring the element type must be decided first. Here, the element type is Brick 20 node 95, shell 99 linear layer 99 for composite leaf spring Fig3.3, 3.4, 3.5 shows the meshed models of leaf spring.

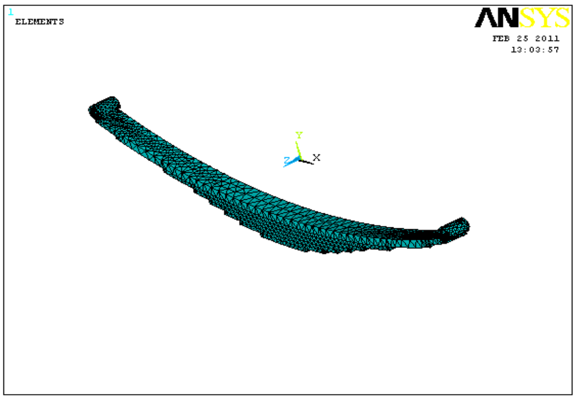

Fig 3.3 Meshed model brick 40 node 95 for steel leaf spring. Assembly

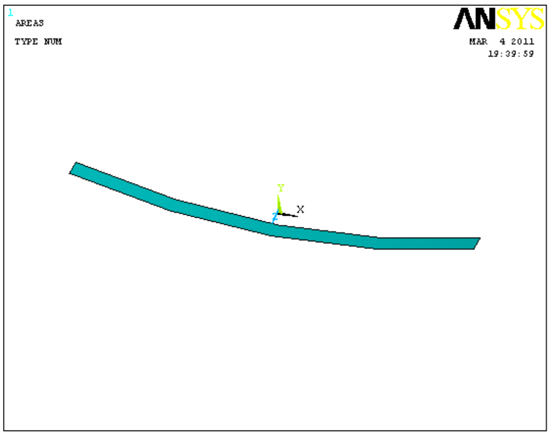

Fig 3.4 Area model of layer in mono composite carbom leaf spring

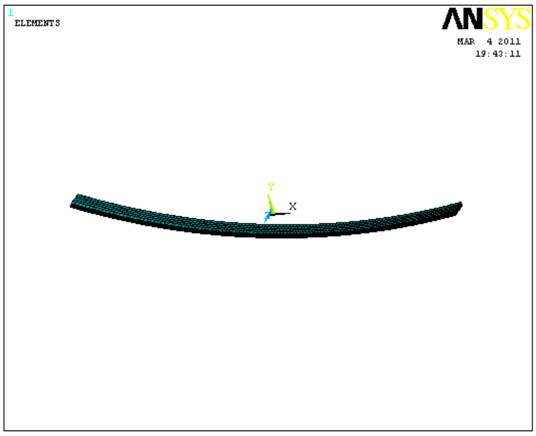

Fig 3.5 Meshed model shell 99 linear layer 99 for composite leaf spring

The material properties of the leaf spring have to decided, it is necessary to give young's modules of the material, density, poison's ratio to carryout modal analysis and density is not necessary in the case of static analysis.

The following are the material properties considered for steel spring.

Material = Manganese Silicon Steel
Young's modulus E = 2.1 E5 N/mm^2
Density þ= 7. 86 E – 6 kg/mm^3
Poisson's ration = 0.3
Yield Stress = 1680 N/ mm^2.

The following are the material properties considered for composite leaf spring.

Material = Carbon epoxy
Young's modulus E = 1.34E11 N/mm^2
Density þ= 1600 Kg/mm^3
Poisson's ration = 0.2
Shear modulus = 5.8e9

III.2.3 Boundary Conditions

The leaf spring is mounted on the axle of the automobile; the frame of the vehicle is connected to the ends of the leaf spring. The ends of the leaf spring are formed in the shape of an eye. The front eye of the leaf spring is coupled directly with a pin to the frame so that the eye can rotate freely about the pin but no translation is occurred. The rear eye of the leaf spring is connected to the shackle, which is a flexible link; the other end of the shackle is connected to the frame of the vehicle. The rear eye of the leaf spring has the flexibility to slide along the X – direction when load applied on the spring and also it can rotate about the pin. The link oscillates during load applied on the spring and also it can rotate about the pin. The link oscillates during load applied and removed.

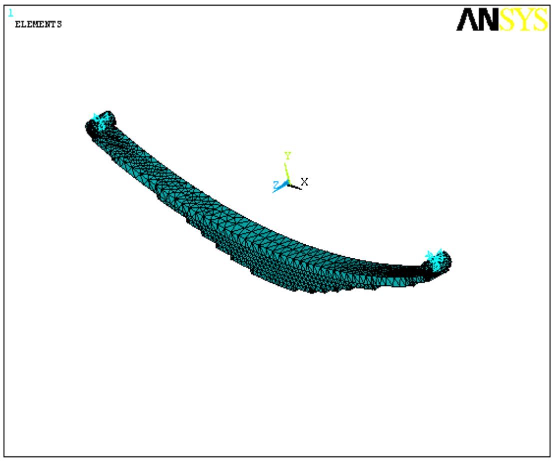

Fig 3.6 Boundary conditions of steel leaf spring assembly

Therefore the node of rear eye of the leaf spring is constrained in all translational degree of freedom, and constrained the two rotational degrees of freedom. So the front eye is constrained as UX, UY, UZ, ROTX, ROTY and the nodes of rear eye is constrained as UY, UZ, ROTX, ROTY, fig shows the boundary conditions of the leaf spring.

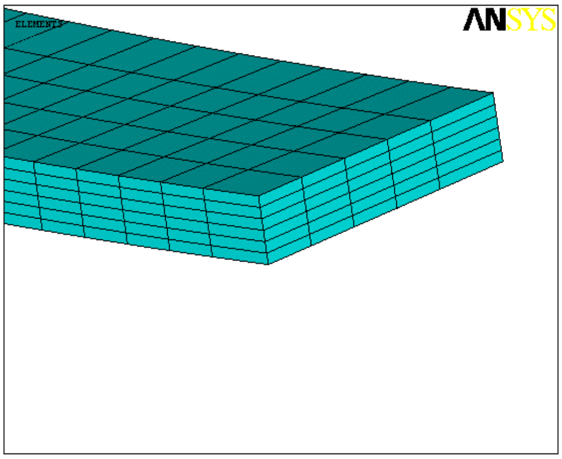

Fig 3.7 Layer arrangement in composite shell linear layer 99

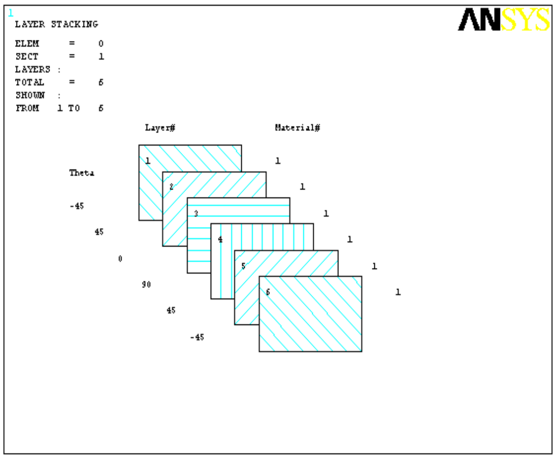

Fig 3.8 Orientation of layer fibers

The models is constrained in all six degrees of freedom UX, UY, UZ, ROTX, ROTY ROTZ at the ends they are considered to be adhesively bonded end joints to enhance performance of composite leaf spring for delimitation and stress concentration

The load is distributed equally by all the nodes associated on the bottom surfaces of bottom most leaf. The load is applied along Fy direction as shown in Fig 7.2 to apply load. For this problem the load is 4000 N, and the numbers of associated nodes are bottom surface of bottom plate. For steel leaf spring pressure is applied and for composite leaf spring force is applied

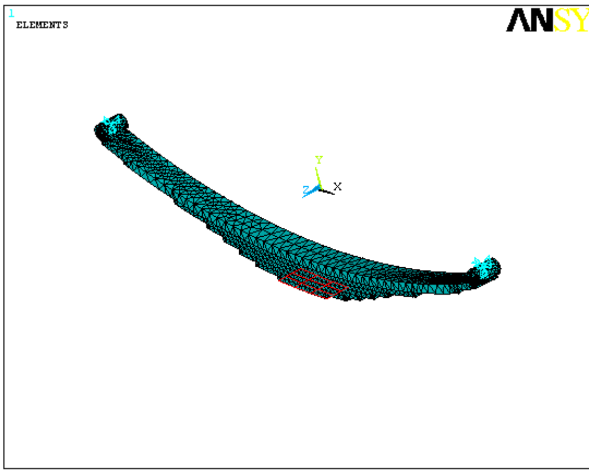

Fig 3.9 Loading and boundary conditions of steel leaf sring

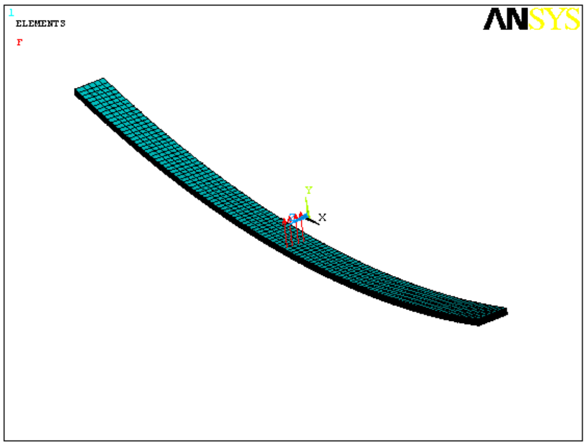

Fig 3.10 Loading and boundary conditions of composite leaf sring

III.3 Static Analysis

After the preprocessing, the solution has to be done. From solution phase, choose the new analysis as static. Then solve the current load step option.

The solution will be done, the following table given the Von – Mises stress at various loads

Static analysis is to be performed to find the allowable stresses. The leaf spring is mounted on the axle of the leaf spring. So load applied from bottom surface of both the leaf springs. All the steel leaves are bounded together with the centre bolt, so the entire load is concentrated on the bottom surface of the leaf spring. NUMBER OF MODES TO EXTRACT ………………… 10
NUMBER OF MODES TO EXPAND
……………..………10

The natural frequencies and mode shapes of different combinations of leaf spring are presented in the next chapter (Results and Discussion).
It is seen that from the above graph, when load is increased the bending stress increases, linearly, so load-stress graph gives the straight – line relationship. The theoretical results and ANSYS results are varying in parallel as load increases. But in the case of mono composite leaf spring the 6 layer spring had marginal increase in stress while the 12 layer has comparatively higher increase in stress values.

For the steel leaf spring it is observed that at load 4000 N, the stress crosses the yield stress (1479 N/mm^2) by considering the factor of safety 2. It is also observed that the stresses development in 12 layer configuration is much lesser than stresses observed in theoretical and steel leaf spring. Therefore it is concluded that the maximum safe payloads considered for analysis of leaf spring are safe for all the iterations.

Distribution of Von mises stress of Steel leaf spring assembly

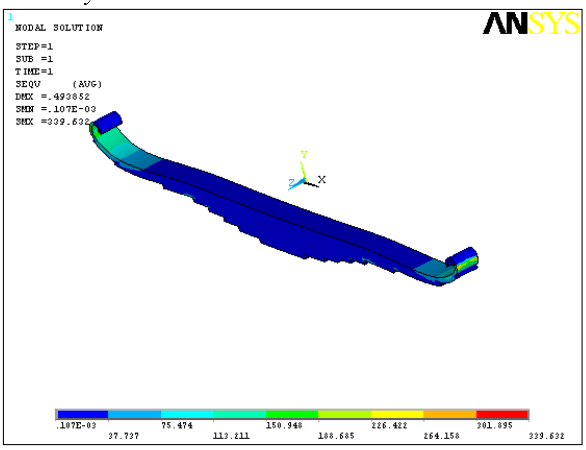

Fig 4.2 Distribution of Von mises stresses at a load 2000 N

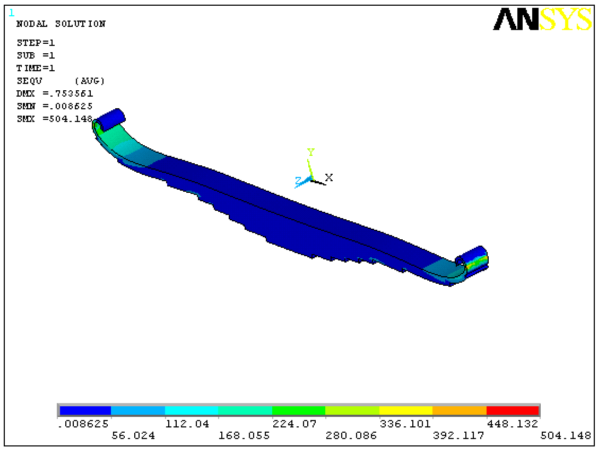

Fig 4.3 Distribution of Von mises stresses at a load 3000 N

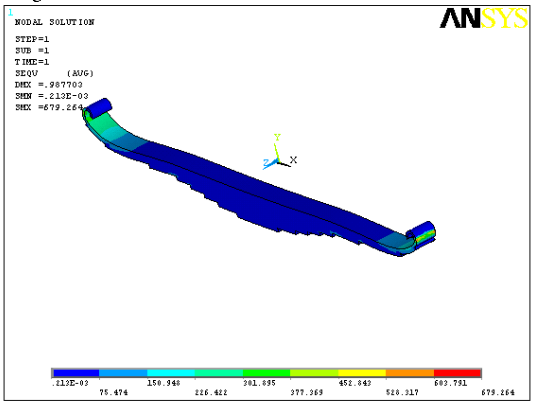

Fig 4.4 Distribution of Von mises stresses at a load 4000 N

Distribution of Von mises stresses of Mono composite leaf spring

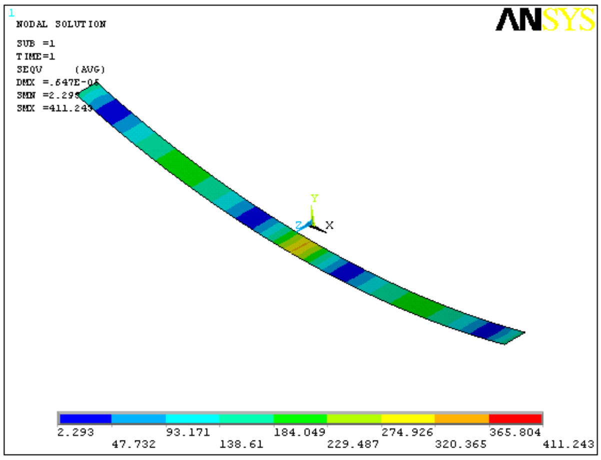

Fig 4.5 Distribution of Von mises stresses at a load 4000 N on Carbon epoxy 6 layers.

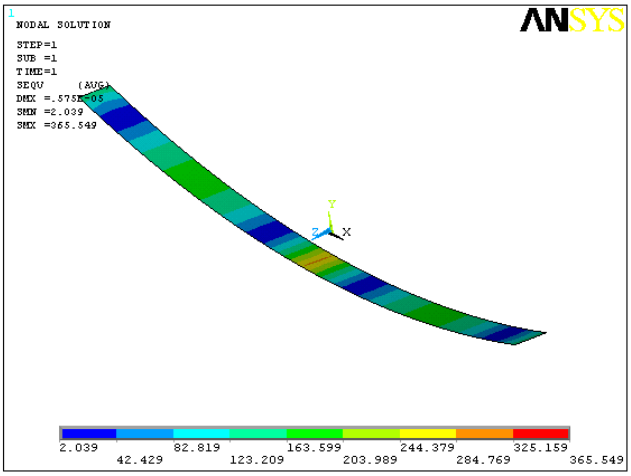

Fig 7.6 Distribution of Von mises stresses at a load 4000 N on Carbon epoxy 12 layers.

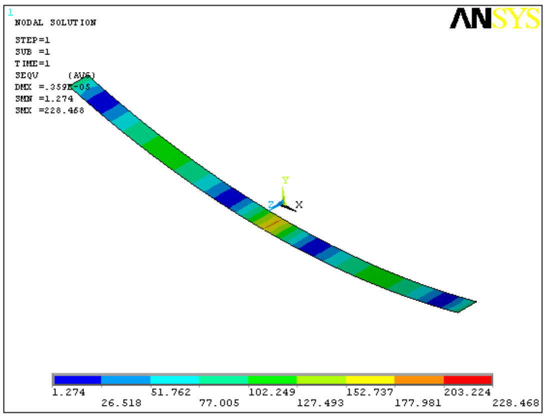

Fig 4.7 Distribution of Von mises stresses at a load 2000 N on Carbon epoxy 6 layers

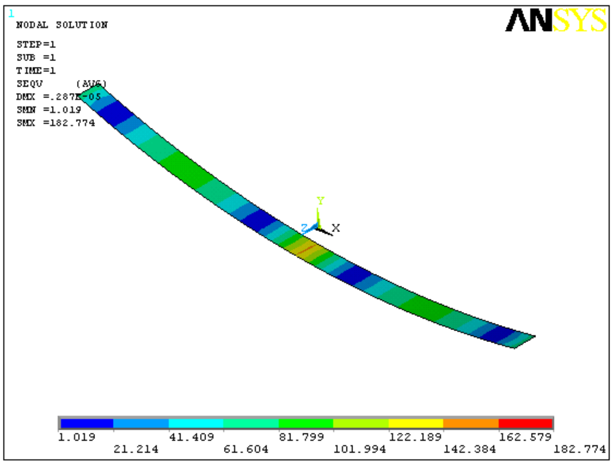

Fig 4.8 Distribution of Von mises stresses at a load 2000 N on Carbon epoxy 12 layers

From the above figures, the maximum stress developed is at inner side of the eye sections of steel leaf springs i.e. the red color indicates maximum stress, because constraints applied at interior of the eyes. The maximum stress developed is at the mid region in the middle of the mono composite leaf springs i.e. the red color indicates maximum stress, because constraints applied at the adhesively bonded joints at interior of the eyes.

Distribution of Displacements plots of Steel leaf spring assembly

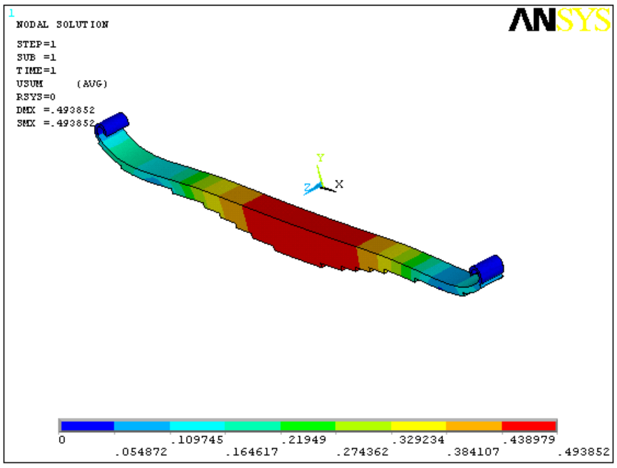

Fig 4.9 Distribution of Displacements plots at a load of 2000 N on steel leaf spring

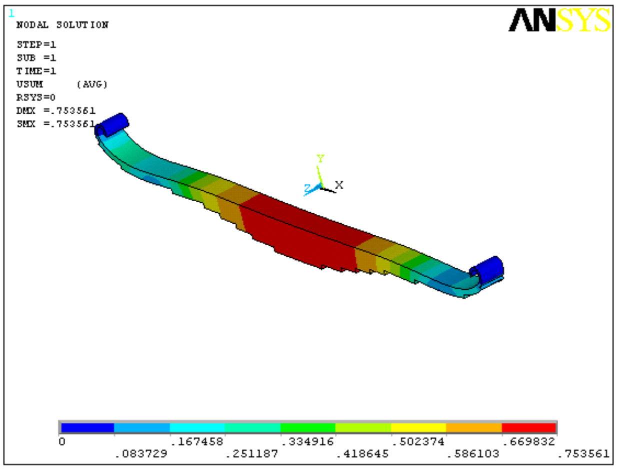

Fig 4.10 Distribution of Displacements plots at a load of 3000 N on steel leaf spring

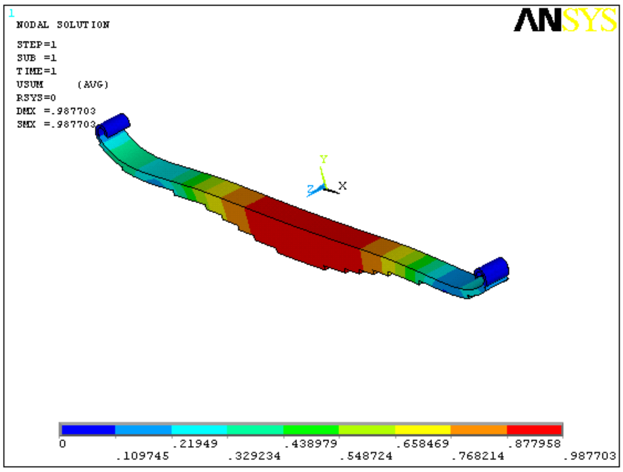

Fig 4.11 Distribution of Displacements plots at a load of 4000 N on steel leaf spring

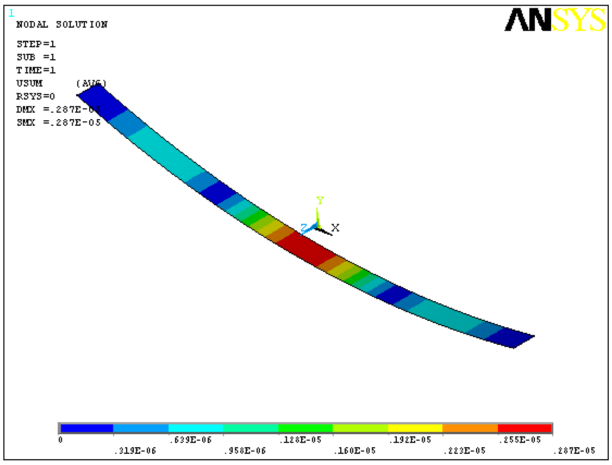

Fig 4.12 Distribution of Displacements plots at a load of 2000 N on Mono composite carbon epoxy leaf spring

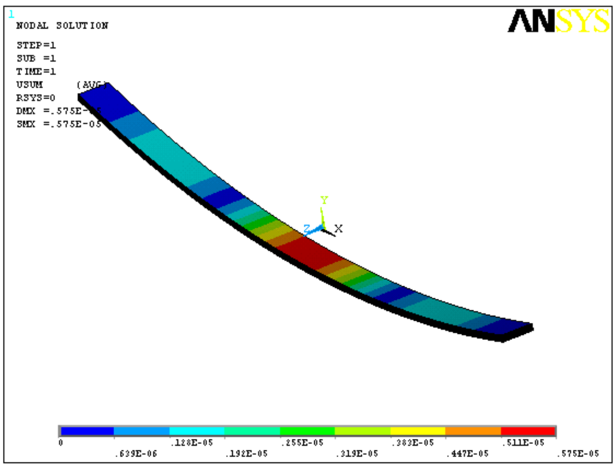

Fig 4.13 Distribution of Displacements plots at a load of 4000 N on Mono composite carbon epoxy leaf spring

From the leaf spring specification width is fixed and other parameters namely thickness, camber, span and number of leaves are taken for parametric variation. First ten modes are considered for analysis. Variations of natural frequencies with spring parameters are studied

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