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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.

Keywords: Leaf Spring, Static Analysis, Modal Analysis, Finite Element Analysis.

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.

A. Objective of the Project

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.

DAKSHRAJ KOTHARI, RAJENDRA PRASAD SAHU AND RAJESH SATANKAR [12] perform static and fatigue life analysis of to conventional leaf springs made of respectively SUP 9 & EN 45. These springs are comparing for maximum stress, deflection and stiffness as well as fatigue life. The CAD models are prepared in CATIA and analyzed by using ANSYS 12.1. Computer algorithm using C++ language has been used in calculating maximum stress, deflection and stiffness. SUP 9 springs has lower value of maximum stress, deflection and stiffness in compare to EN45 spring. Predicted fatigue life of SUP 9 spring is higher than EN45 spring. Although, market price is much lower than Sup 9 spring.

Y. N. V. SANTHOSH KUMAR & M. VIMAL TEJA [13] It was observed that the deflection in the composite leaf spring was almost equal so we can say that composite spring had the same stiffness as that of steel spring. It was observed that the composite leaf spring weighed only 39.4% of the steel leaf spring for the analyzed stresses. Hence the weight reduction obtained by using composite leaf spring as compared to steel was 60.48 %.

M. M. Patunkar, D. R. Dolas [14] shows under 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. Indicating reduction in weight by 84.40% same level of performance. Conventional Leaf spring show 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.

M. RAGHAVEDRA, SYED ALTAF HUSSAIN, V. PANDURANGADU, K. PALANIKUMAR [15] Perform design and analysis of laminated composite mono leaf spring. The dimensions of an existing mono steel leaf spring of a Maruti 800 passenger vehicle is taken for modeling and analysis of a laminated composite mono leaf spring with three different composite materials namely, E-glass/Epoxy, S-glass/Epoxy and Carbon/Epoxy subjected to the same load as that of a steel spring. The design constraints were stresses and deflections. The three different composite mono leaf springs have been modeled by considering uniform cross-section, with unidirectional fibre orientation angle for each lamina of a laminate. Static analysis of a 3-D model has been performed using ANSYS 10.0. Compared to mono steel leaf spring the laminated composite mono leaf spring have 47% lesser stresses, 25%~65% higher stiffness, 27%~67% higher frequency and weight reduction of 73%~80%.

K. A. SAIANURAAG & BITRAGUNTA VENKATASIVARAM [16] they compared static, dynamic & shock analysis for two & five layered composite leaf spring. The composite material used is E-Glass Epoxy. In static analysis the maximum displacement is observed in two layered i.e. 101.5mm compared to 83.23mm in five layered. Also during the static analysis Von-mises stress for the five layered is more than two layered i.e. 948Mpa for five layered compared to 795.4Mpa for two layered. For modal analysis various nodes are obtained and a comparative table is drawn for various nodes. The range of frequencies for two layers is 19.2 Hz to 1433 Hz and for five layers is 21.2 Hz to 1612 Hz. In Harmonic analysis amplitude vs. frequency graph for two layered and five layered are considered. For two layered amplitude decreases to a minimum and then increases & remains constant. For five layered amplitude remains constant initially but increases rapidly in the end. For shock analysis as time increases, the displacement initially increases, reaches a maximum and then decreases for a two layer mode, for five layered the deflection v/s time for five layer mode where the displacement initially decreases, reaches a minimum and then increases as the time progresses.

K. K. JADHAO & DR. R.S DALU [17] perform experimental investigation & numerical analysis of composite leaf spring. They used Glass fiber reinforced plastic (GFRP) and the polyester resin (NETPOL 1011). Tested the leaf springs under static loading. These results are also compared with FEA. The weight of the leaf spring is reduced considerably about 85 % by replacing steel leaf spring with composite leaf spring.

Mr. V. Lakshmi Narayana [18] perform Design and Analysis of Mono Composite Leaf Spring for Suspension in Automobiles by using ProE & Ansys. It was observed that the composite leaf spring weighed only 27.96 % of the steel leaf spring for the analyzed stresses. Hence the weight reduction obtained by using mono composite leaf spring as compared to steel was 72.04 %.

Further literatures are available on concepts and design of leaf springs [19]. Some of the springs manufacturing companies publish catalog on leaf spring giving dimension details [22].

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.

A. Modeling of leaf spring

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.
3) Using sweep command draw a section 60 mm X 7 mm thick sweep along the above drawn curves of leaf.
4) According the spring design manual the eye diameter is formed on the first leaf.
5) Thickness of leaves = 7mm.
6) After all the features of all leaves as are modeled, generate family table for each leaf.
7) Generate models for u-clams, axle rod, top support plate etc.
8) Assemble each of the leaf in an assembly model and assemble all other models.
9) Provide a ½ inch dia hole in the leaf spring for bolt.
10) 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

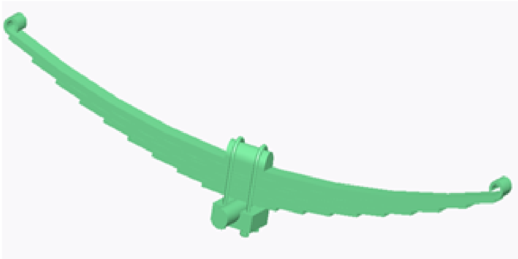


Fig 3.1 Assembly Model of Steel Leaf Spring

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 3.1 DIMENSIONS OF MONO COMPOSITE LEAF SPRING

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

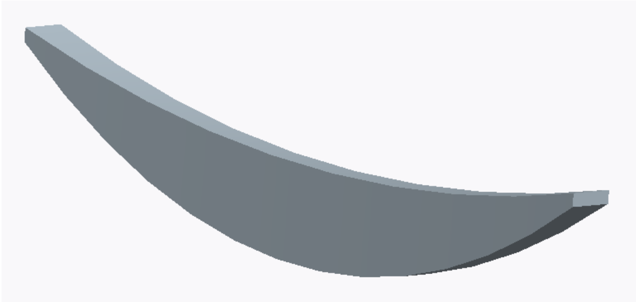


Fig 3.2 Model of mono composite leaf spring

B. Finite Element Modeling and Boundary conditions

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.

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.

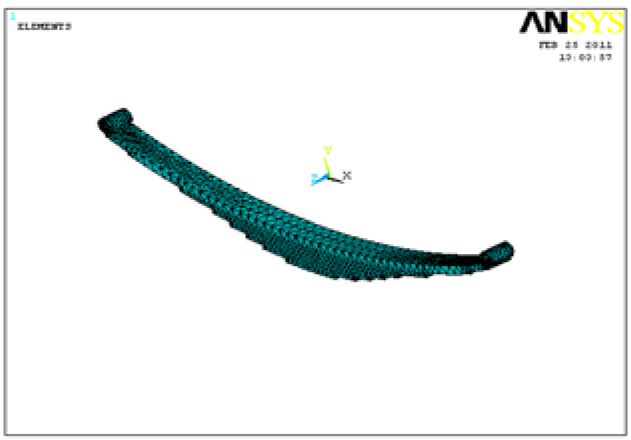


Fig 3.3 Meshed model brick 40 node 95 for steel leaf spring. Assembly

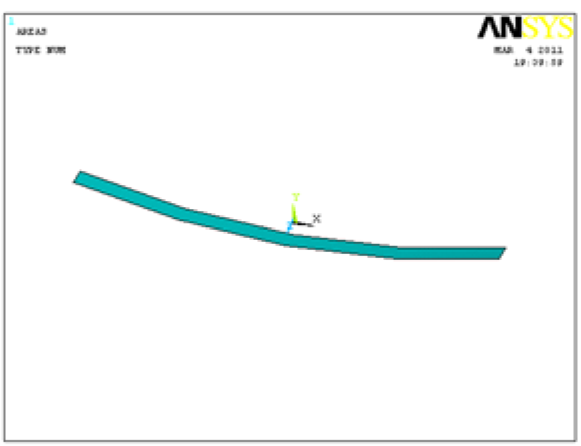


Fig 3.4 Area model of layer in mono composite carbom leaf spring

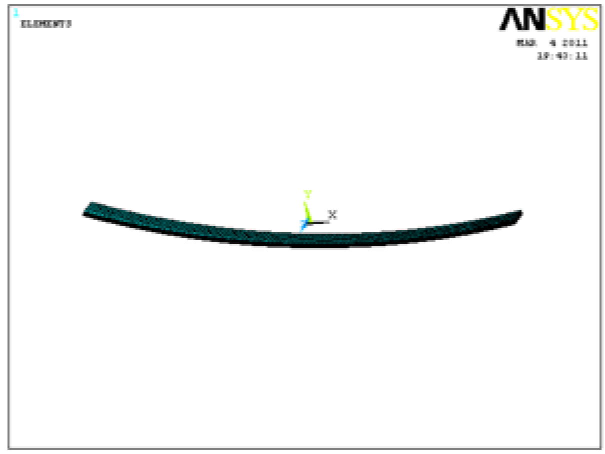


Fig 3.5 Meshed model shell 99 linear layer 99 for composite leaf spring

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/mm2
Density þ= 7. 86 E – 6 kg/mm3
Poisson's ration = 0.3
Yield Stress = 1680 N/ mm2.

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

Material = Carbon epoxy
Young's modulus E = 1.34E11 N/mm2
Density þ= 1600 Kg/mm3
Poisson's ration = 0.2
Shear modulus = 5.8e9

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.

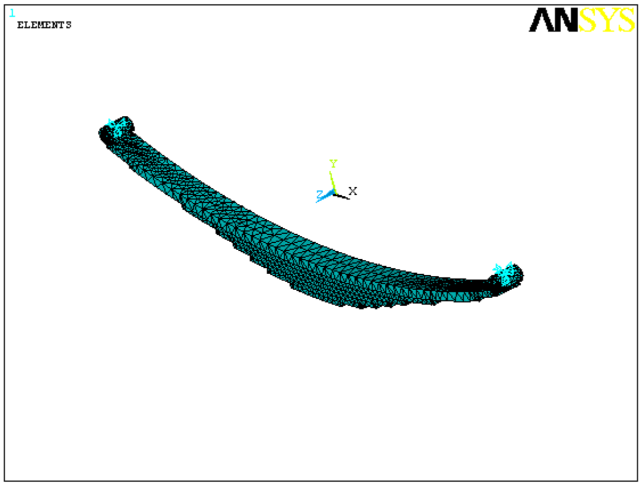


Fig 3.6 Boundary conditions of steel leaf spring assembly

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.

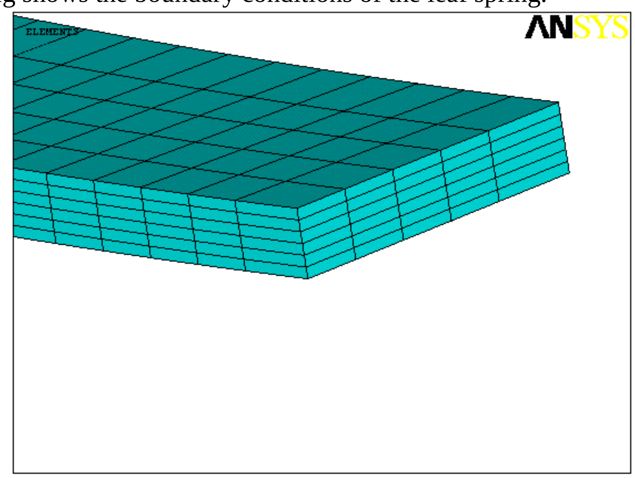


Fig 3.7 Layer arrangement in composite shell linear layer 99

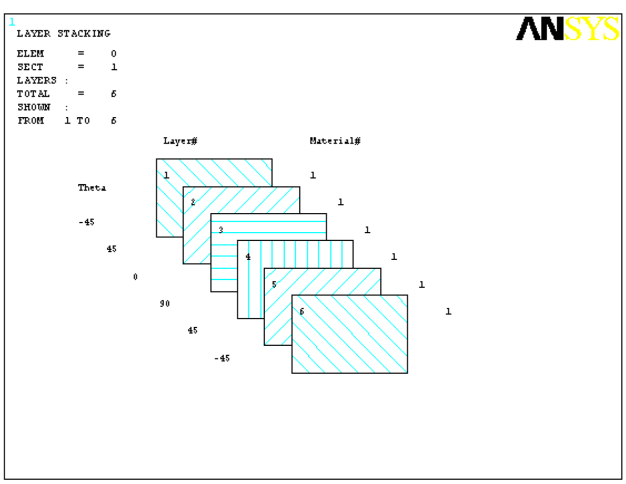


Fig 3.8 Orientation of layer fibers

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 delamination 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

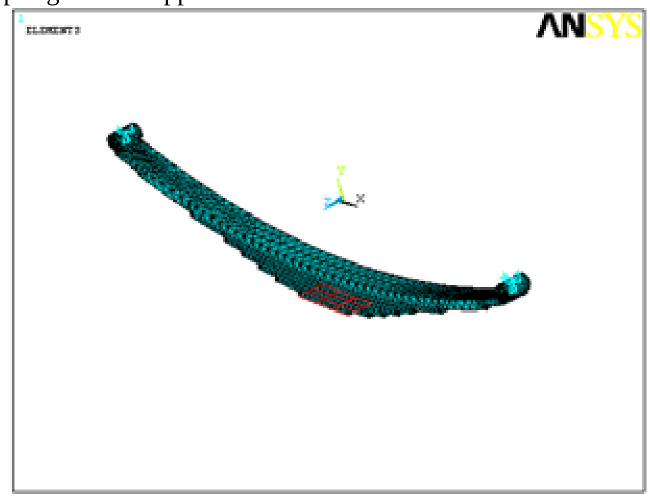


Fig 3.9 Loading and boundary conditions of steel leaf sring

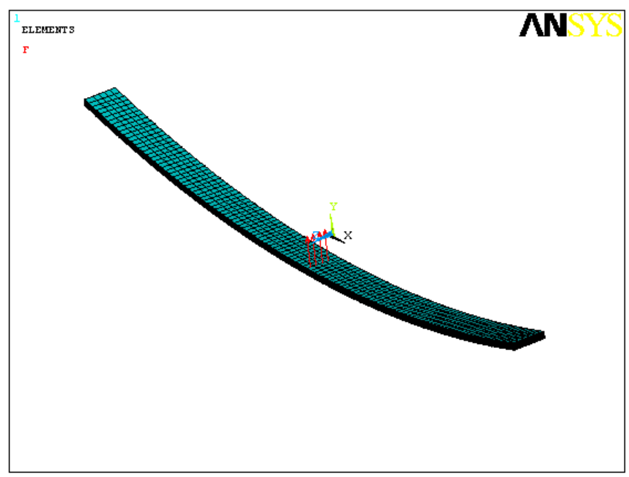


Fig 3.10 Loading and boundary conditions of composite leaf spring

C. 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.

D. Modal Analysis

Modal analysis is carried out to determine the natural frequencies and mode shapes of the leaf spring. Modal analysis is performed for various parametric combinations of the leaf spirit. The parameters are camber, span, thickness, number of leaves. Here, camber varies from 80 to 110 mm, span varies from 1220 to 1420 mm, thickness varies from 7 to 10mm and number of leaves varies from 9 to 12 keeping width is constant.

Modal analysis need only boundary conditions, it is not associated with the loads apply, because natural frequencies are resulted from the free vibrations. The boundary conditions are same as in the case of static analysis.

After post – processing, from solution options, new analysis is to be selected as modal. The solution options are takes as below.

S O L U T I O N O P T I O N S

PROBLEM DIMENSIONALITY ………….3 – D
DEGREES OF FREEDOM ………………...UX UY UZ ROTX ROTY ROTZ
ANALYSIS TYPE…………….…………MODAL
EXTRACTION METHOD………………...SUBSPACE
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).

IV. RESULTS AND DISCUSSION

Introduction

For the material specification of the steel and composite leaf springs the static analysis is performed to find the maximum safe stress and the corresponding pay load. And also modal analysis is performed for various parametric combinations to find the natural frequencies and mode shapes to find the behavior of the leaf spring. And these natural frequencies are compared with the excitation frequencies at different speeds of the vehicle at various widths of the road irregularities.

A. Static Analysis

Static analysis is performed to find the Von – Mises stress by using Ansys software and these results are compared with bending stresses calculated in mathematical analysis at various loads.

The following table gives bending stresses at various loads.

Load (N)	Theoretical Stress (N/mm^2)	Von – Mises Stress (N/mm^2): Steel	Carbon epoxy: 6 layers	Carbon epoxy: 12 layer
2000	266	339	228.4	182.7
3000	400	504.1	319.8	274.1
4000	533	679	411.2	365.4

Fig 4.1 Stress Comparison Chart

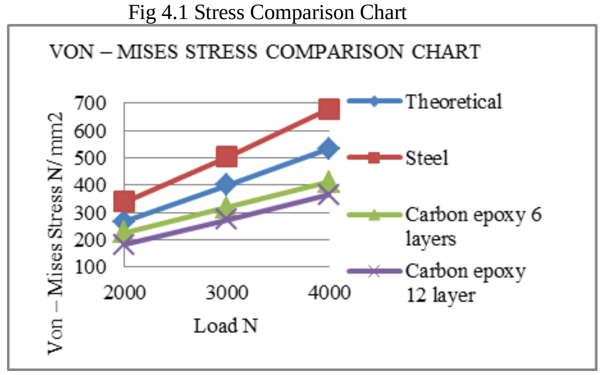


TABLE 4.1 COMPARISON OF THEORETICAL STRESS AND ANSYS VON–MISES STRESS

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/mm2) 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

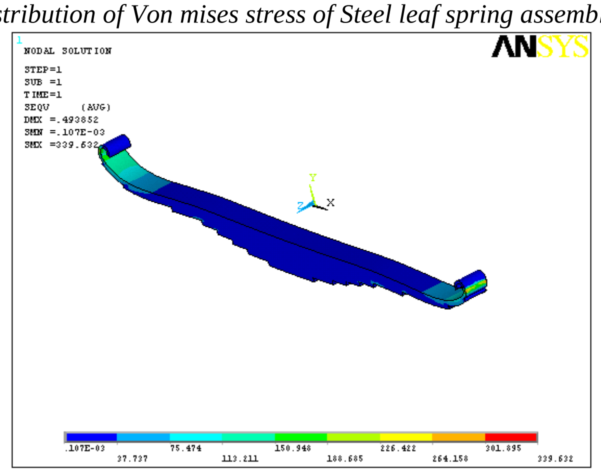


Fig 4.2 Distribution of Von mises stresses at a load 2000 N

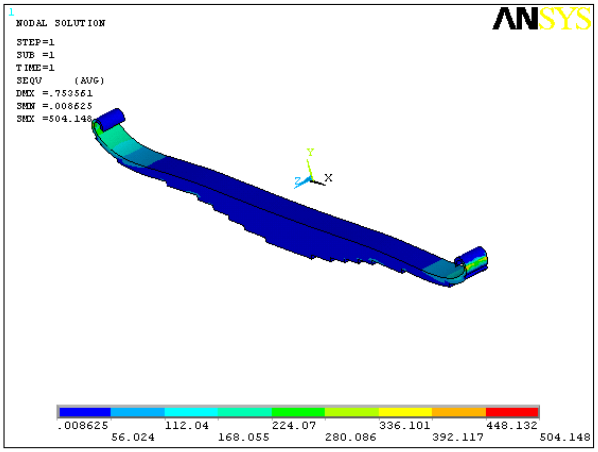


Fig 4.3 Distribution of Von mises stresses at a load 3000 N

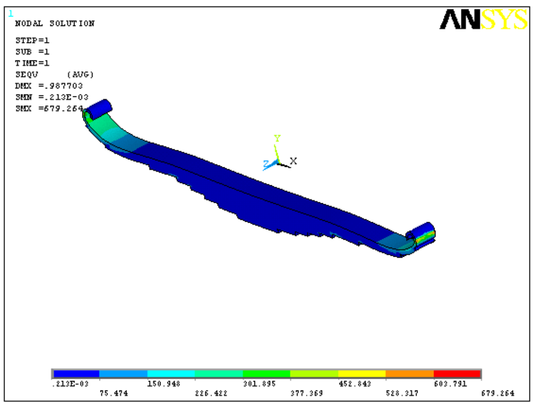


Fig 4.4 Distribution of Von mises stresses at a load 4000 N

Distribution of Von mises stresses of Mono composite leaf spring

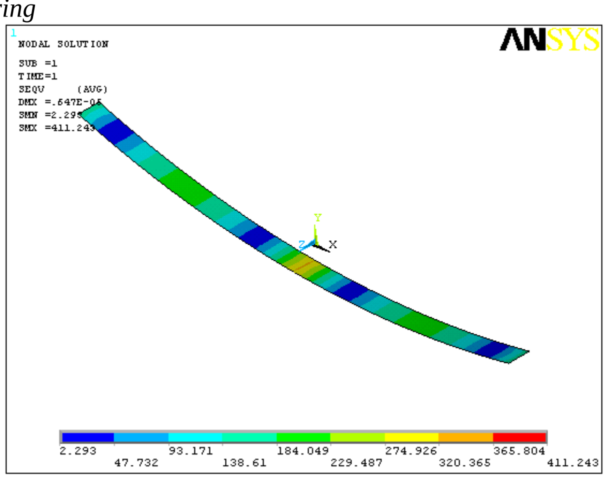


Fig 4.5 Distribution of Von mises stresses at a load 4000 N on Carbon epoxy 6 layers

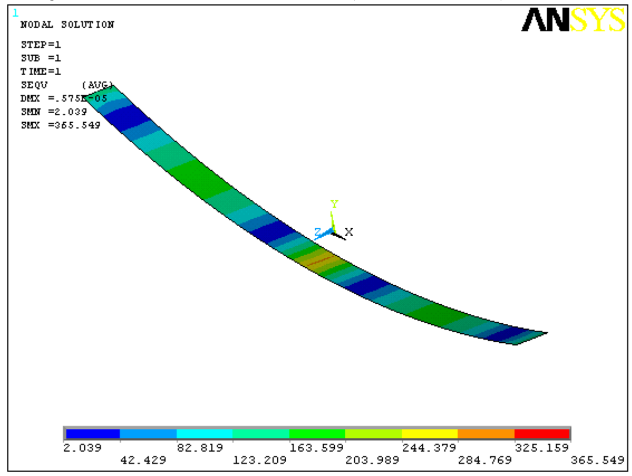


Fig 4.6 Distribution of Von mises stresses at a load 4000 N on Carbon epoxy 12 layers

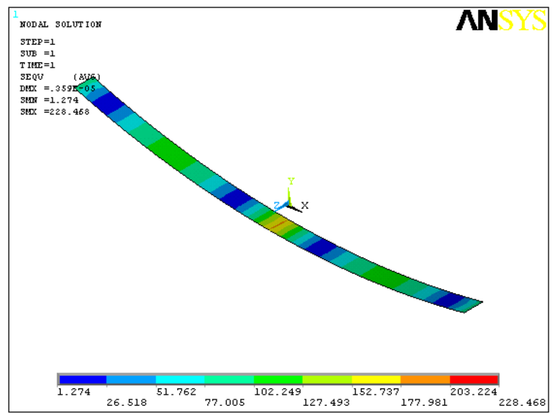


Fig 4.7 Distribution of Von mises stresses at a load 2000 N on Carbon epoxy 6 layers

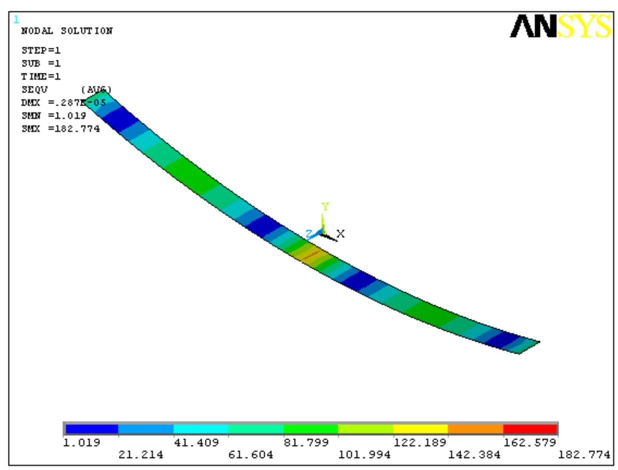


Fig 4.8 Distribution of Von mises stresses at a load 2000 N on Carbon epoxy 12 layers

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

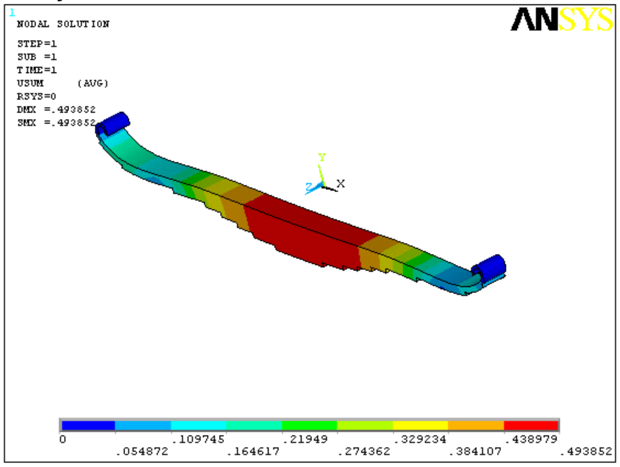


Fig 4.9 Distribution of Displacements plots at a load of 2000 N on steel leaf spring

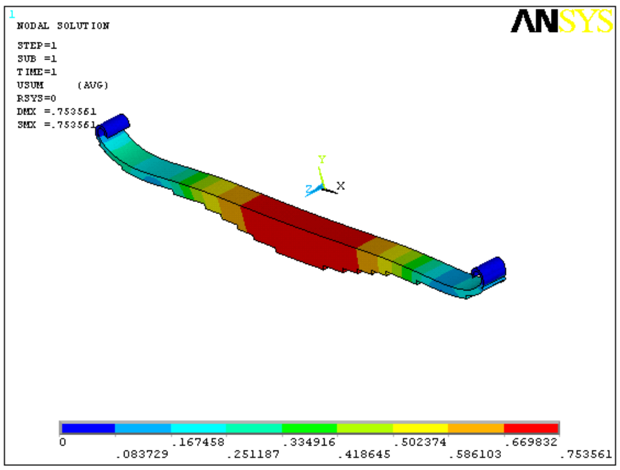


Fig 4.10 Distribution of Displacements plots at a load of 3000 N on steel leaf spring

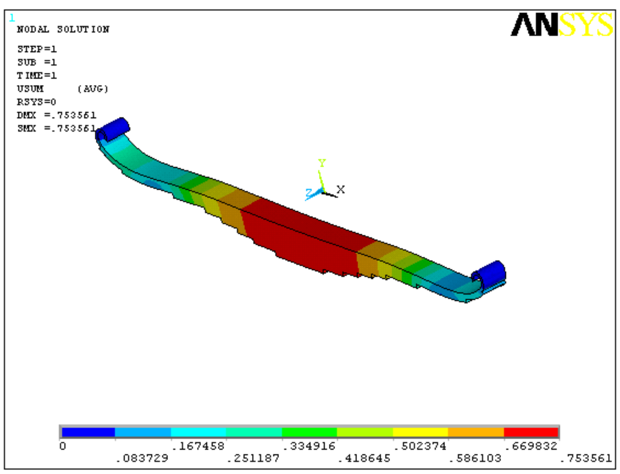


Fig 4.11 Distribution of Displacements plots at a load of 4000 N on steel leaf spring

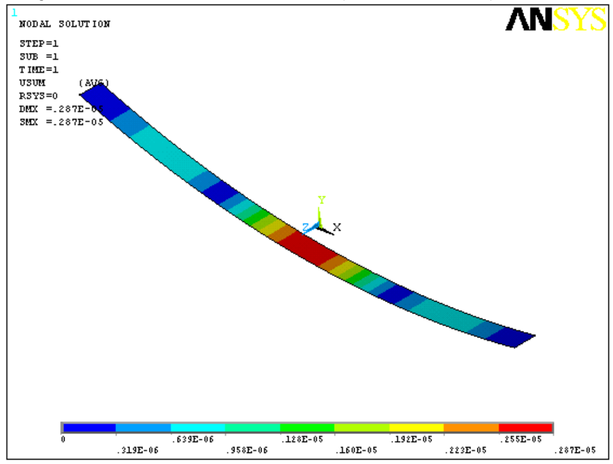


Fig 4.12 Distribution of Displacements plots at a load of 2000 N on Mono composite carbon epoxy leaf spring

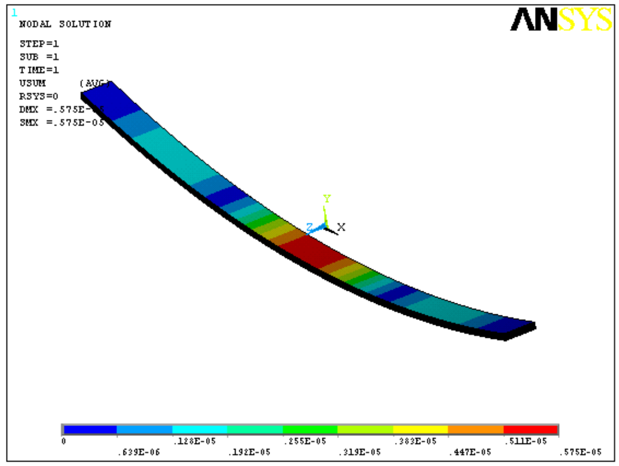
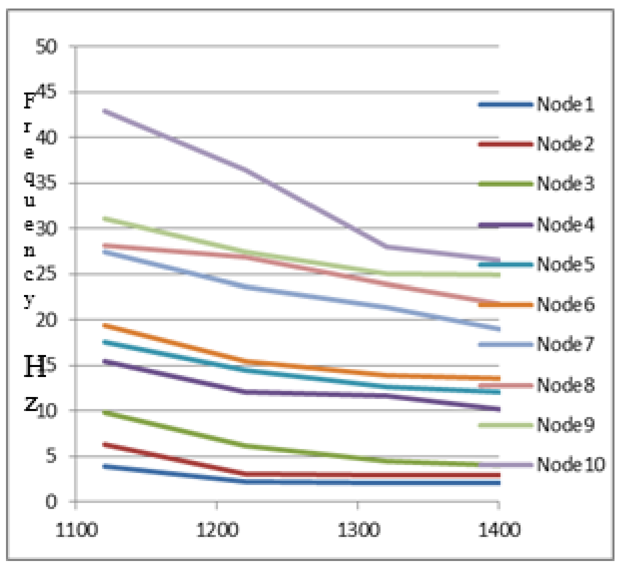


Fig 4.13 Distribution of Displacements plots at a load of 4000 N on Mono composite carbon epoxy leaf spring



Span in mm

Fig 4.14 Comparative chart of variation of natural frequency with span

B. Modal Analysis

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.

1. *Variation of natural frequency with span*

Table 4.2 gives the natural frequencies when the span increases from 1120mm to 1420mm By keeping remaining parameters constant.
Camber = 80mm, Thickness = 7mm
Number of leaves = 1
When span increases the spring becomes soft and hence the natural frequency decreases. Every three modes are in one set of range. There is a considerable gap between mode 3 to mode 4, mode 6 to mode 7 and mode 9 to mode 10.

It is observed from the Fig that the decrease of frequent value with the increase of span is very high for mode 10 compared to remaining modes.

TABLE 4.3 VARIATION OF ARC RADIUS WITH SPAN

Span in mm	Arc radius in mm
1120	2000.000
1220	2365.600
1320	2762.500
1420	3190.625

Table 4.3 shows the variation of arc radius with span of fixed camber. When span increases the arc radius also increases.

2. *Variation of natural frequency with camber*

Table 7.4 gives the natural frequencies when the camber increases from 80mm to 110mm
By keeping remaining parameters constant
Thickness = 7mm
Span = 1220mm
Number of leaves = 10
Table 4.4 shows the variation of natural frequency with camber. When camber increases the spring becomes stiff and hence the natural frequency increases.
Every three modes are almost in one set of range. There is a considerable gap between mode 3 to mode 4, mode6 to mode 7, and mode9 to mode 10. It is observed from the Table 4.4 that the increase of frequency value with the increase of camber is very high for mode 10 compared to remaining modes.

TABLE 4.5 VARIATION OF ARC RADIUS WITH CAMBER

Camber in mm	Arc radius in mm
80	2165.60
90	2112.20
100	1910.50
110	1746.36

Table 4.5 shows the variation of arc radius with camber of fixed span. When camber increases the arc radius decreases.

3. *Variation of natural frequency with thickness*

The following table gives the natural frequencies when the thickness increases from 7mm to 10mm
By keeping remaining parameters constant
Camber = 80mm
Span = 1220mm
Number of leaves = 10
Table 4.6 shows the variation of natural frequency with thickness of the spring. When thickness increases the natural frequency also increases. Its natural frequency increases like variation of natural frequency with camber, but with thickness the natural frequency increasing rate is lesser than that of variation of natural frequency with camber. Every three modes are almost in one set of range. There is a considerable gap between Mode 3 to mode4, mode6 to mode 7 and mode 9 to mode 10. It is observed from Fig. 4.6 that the increase of frequency value with the increase of thickness is very high for mode 9 and mode 10 compared to remaining modes.

4. *Variation of natural frequency with number of leaves*

The following table gives the natural frequencies when the number of leaves increases from 9 to 12
By keeping remaining parameters constant
Camber = 100mm, Span = 1220mm, Thickness = 7mm

Table 4.7 shows the variation of natural frequency with number of leaves of the spring. Even though the number of leaves increases there is no considerable increase in natural frequency, it is almost constant. It is observed that every three modes are in gradual increment, there is considerable increase in natural frequency from mode 3 to mode 4, there is much increase in natural frequency from mode6 to mode7 and there is very much in increase in natural frequency from mode 9 to mode 10.

The mode shapes for modes 1, 3 & 10 and for different parameters like Camber, Span, thickness of leaves and number of leaves are presented in the following Tables 4.8. To 4.16

The variation of exciting frequency with vehicle speed for assumed width of road irregularity. At low speeds the wheel of the vehicle passes over road irregularities and moves up and down to the same extent as the dimensions of the road irregularity.

So, the frequency induced is less. If the speed increases and the change in the profile of the road irregularity are sudden, then the movement of the body and the rise of the axles which are attached to the leaf spring are opposed by the value of their own inertia. Hence, the frequency induced also increases. The exciting frequency to very high for the lower value of road irregularity width, because of sudden width.

It is noted that the some of the excitation frequencies are very close to natural frequencies of the leaf spring. But they are not exactly matched; hence no resonance will takes place. It may be noted that for speeds above 100 kmph the resonance problem may occur

TABLE 4.2 VARIATION OF NATURAL FREQUENCY WITH SPAN

Span	Frequency (Hz at Modes)									
mm	1	2	3	4	5	6	7	8	9	10
1120	3.896	6.281	9.803	15.423	17.617	19.471	27.401	28.192	31.062	42.924
1220	2.180	3.113	6.189	12.134	14.532	15.534	23.581	26.895	27.450	36.484
1320	2.126	3.012	4.509	11.643	12.625	13.925	21.420	23.920	25.102	27.959
1420	2.126	2.891	3.941	9.899	11.962	13.491	18.462	21.270	24.952	26.152

TABLE 4.4 VARIATION OF NATURAL FREQUENCY WITH CAMBER

Camber	Frequency (Hz at Modes)									
In mm	1	2	3	4	5	6	7	8	9	10
80	2.180	3.113	6.189	12.134	14.532	15.534	23.581	26.895	27.450	36.484
90	2.198	3.843	7.523	12.723	14.921	16.843	24.562	27.725	29.432	38.281
100	2.212	4.621	8.624	13.894	16.031	17.946	25.763	28.893	31.251	40.322
110	2.412	4.998	9.752	14.362	16.926	19.288	26.891	30.430	33.421	42.621

TABLE 4.6 VARIATION OF NATURAL FREQUENCY WITH THICKNESS

Thickness	Frequency (Hz at Modes)									
In mm	1	2	3	4	5	6	7	8	9	10
7	2.180	3.113	6.189	12.134	14.532	15.534	23.581	26.895	27.450	36.484
8	2.189	3.813	7.123	12.511	14.789	16.441	24.382	27.428	29.211	37.984
9	2.202	4.621	8.135	13.784	15.981	17.486	25.409	28.663	30.992	40.001
10	2.299	4.819	9.241	14.165	16.464	18.998	26.649	30.012	32.894	42.061

TABLE 4.7 VARIATION OF NATURAL FREQUENCY WITH THICKNESS OF LEAVES

Number of leaves	Frequency (Hz at Modes)									
	1	2	3	4	5	6	7	8	9	10
9	2.211	4.620	8.599	13.901	16.001	17.992	25.761	28.881	31.249	40.123
10	2.212	4.621	8.624	13.894	16.031	17.946	25.763	28.893	31.251	40.322
11	2.213	4.621	8.711	13.798	16.052	17.981	25.769	28.981	31.261	40.351
12	2.2131	4.623	8.709	13.891	16.061	17.909	25.762	28.789	31.263	40.336

TABLE 4.8 VARIATION OF EXCITATION FREQUENCY WITH VEHICLE SPEED

Speed (Kmph)	Frequency Hz (at WRI=1m)	Frequency Hz (at WRI =2m)	Frequency Hz (at WRI =3m)	Frequency Hz (at WRI=4m)	Frequency Hz (at WRI =5m)
20	5.5500	2.77	1.8518	1.3888	1.11111
40	11.1111	5.54	3.7037	2.7777	2.22222
60	16.6666	8.31	5.5555	4.1664	3.33333
80	22.2222	11.08	7.4074	5.5552	4.44444
100	27.7777	13.85	9.2593	6.9440	5.55555

V. CONCLUSIONS AND FUTURE SCOPE OF WORK

The leaf spring has been modeled using solid tetrahedron 4 – node element. By performing static analysis it is concluded that the maximum safe load is 4000 N for the given specification of the leaf spring.

These static analysis results of mono composite Carbon Epoxy leaf springs are compared to steel leaf spring.

The results show:

1) The stresses in the composite leaf spring are much lower than that of the steel spring.
2) The composite spring can designed to strengths and stiffness much closer to steel leaf spring by varying the layer configuration and fiber orientation angles.
3) The strength to weight ratio is higher for composite leaf spring than conventional steel spring with similar design

The major disadvantages of composite leaf spring are the matrix material has low chipping resistance when it is subjected to poor road environments which may break some fibers in the lower portion of the spring. This may result in a loss of capability to share flexural stiffness. But this depends on the condition of the road. In normal road condition, this type of problem will not be there. Composite leaf springs made of polymer matrix composites have high strength retention on ageing at severe environments.

The steel leaf spring width is kept constant and variation of natural frequency with leaf thickness, span, camber and numbers of leaves are studied. It is observed from the present work that the natural frequency increases with increase of camber and almost constant with number of leaves, but natural frequency decreases with increase of span. The natural frequencies of various parametric combinations are compared with the excitation frequency for different road irregularities. The values of natural frequencies and excitation frequencies are the same for both the springs as the geometric parameters of the spring are almost same except for number of leaves.

This study concludes that it is advisable to operate the vehicle such that its excitation frequency does not match the above determined natural frequencies i.e. the excitation frequency should fall between any two natural frequencies of the leaf spring.

An extended study of this nature by varying the layer configuration higher strengths can be achieved. Replacing the conventional leaf spring by composite leaf spring can be considered from strength, stiffness and vehicle stability point of view in vehicle stability. Instead of mono composite material, multi composite materials with multiple layers can be considered for study. An efficient design and manufacturing process of composite material leaf spring can reduce the cost and weight of the vehicle.

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