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Design and Fabrication of Fatigue Test Rig for Composite Leaf Spring

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Abstract: Fatigue test rig is a mechanical instrument helps to find out the fatigue strength of a material. Fatigue is considered as the single largest factor which causes failure of metals. An approximate of 90% metallic failures is caused by fatigue. Due to the non-homogeneity and an-isotropic properties of composite materials, it is very complex to predict the behavior of these materials subjected to fatigue load. So it is very essential to get a clear idea about the fatigue behavior of a composite material. Designing and modelling an apparatus of low cost fatigue test rig aided with an electric motor and load was applied gradually to determine fatigue strength of the material. Each time a test rig must be designed and fabricated to meet the specific requirements. In this work design, analysis and fabrication of a test rig was conducted to perform a fatigue test for a leaf spring made of composite material having specific requirements.
Index Terms: Fatigue, Fatigue test rig, composite leaf spring

I. INTRODUCTION

Due to the repetitive or cyclic loading, strength of the material will be reduced and leads to the failure of a material. This process is called fatigue failure. It generally occurs in load bearing components in auto mobiles, biomedical implants, industrial and other machines that are subjected to constant and continuous stresses in the form of different loads such as bending, thermal expansion and contraction, compression, tension, vibration or other stresses. The yield strength of the material is often greater than these stresses. However when stress acting at sufficient number of times, it leads to fatigue failure. There are chances of fatigue in aircraft components and that is the possible reason for the finite life of them.

In general, fatigue is a process by which a material cracks or fails due to the continuous and constant stresses applied below the ultimate strength of the material. A fatigue failure usually consists of three stages:

A. Crack Initiation
B. Crack Propagation
C. Fast Fracture

Majority of machineries and most of the structures do not operate under a constant load and stress. In practical scenario these loads and stresses are changing constantly The initiation and growth of cracks in the material leads to fatigue failure. Fracture happens when crack grows large so that the remaining material without crack might become unable to support the applied loads. The most importance functional requirements of the test rig are, fixing the specimen and applying alternating and fluctuating load on the composite specimen to achieve the fluctuating condition of the beam. The load can be applied by using an electric motor and using eccentric crank mechanism of motor having rotary motion, reciprocating motion can be achieved. The total displacement (D) produced will be two times of the value of the eccentricity (e).

II. COMPOSITE LEAF SPRING

Leaf spring is a type of spring, mainly used as the sus- pension system in wheeled vehicles. It is being used for this purpose for a very long time. For heavy vehicle applications, a leaf spring can be fabricated by a number of leaves bonded on top of each other in many layers, often with gradually shorter leaves.The application of composite materials was helped to de- crease the overall weight of leaf spring without compromising on stiffness and load carrying capacity of the previous ones. Composite materials are quite capable of storing more strain energy and high strength to weight ratio as compared with steel. Therefore mono leaf composite spring is the better replacements for multi-leaf steel. Composite material helps to reduce a substantial weight but may increase the production cost when comparing with their steel counter parts.

Composite leaf springs are more flexible so that it can occupy vibrations in the vertical direction and shocks due to irregularities of road and so that the amount of potential energy stored in the spring and will be released slowly as strain energy. So we can offer an effective suspension system by increasing the energy storage capability of a leaf spring.

The fatigue properties of a glass fiber reinforced plastic (GFRP) epoxy composite materials have been studied earlier. Using fatigue modulus and degrading rate of the material theoretical equations are formulated to predict the fatigue life. This can be used in practical application by simplifying the strain failure criteria.

III. LITERATURE SURVEY

By considering different types of vehicles having leaf springs and different loading conditions, verities of composite leaf spring have been introduced. Fatigue is one of the main causes of failure of a leaf spring. So these two have very importance in the design and fabrication of the automobiles. It is also very important to find out the fatigue life in any structures because main reason for failure in metals. The test rigs used for fatigue testing are always having a customized design. The test rig should meet the requirements of the structure to be checked. There is no standard or generally accepted test rig for fatigue experiments.

Researchers usually follows an existing idea or develop a new test rig which meets the specific requirements. Since the test rigs using for the fatigue test are always having a customized design majority papers follows a standard set of steps for designing the test rig. There are various researchers for the study and comparison of different types of composite leaf spring. S. Rajesh and N. Saravanan et.al[1] illustrates the designing procedures of test rig used for the fatigue testing. The major steps involved in the design of a fatigue testing rig are designing of spring, design of motor, design of bearing. Rest of the designing procedures involves the fabrication and the material selection process. N. Nagabhooshanam, S. Baskarb, P. K. Nagarajanc, K.Sathish kumar et.al[2] in their work describes the designing procedure of all functional and non-functional parts. Suitable standards for sub-assemblies such as coupling, bearing and motor are selected, design calculations are carried out to ensure their strength and based on that preliminary assembly drawing are prepared. Since the test rigs using for the fatigue test are always having a customized design majority papers follows a standard set of steps for designing the test rig. There are various researchers for the study and comparison of different types of composite leaf spring.Mahmood M. Shokrieh and Davood Rezaei et.al[3] deals with the properties and optimization characteristics of composite leaf spring. In some previous designs the width and of the spring are fixed along the longitudinal axis. In some of their designs, width is kept constant and thickness is variable along the spring. Another design is presented so that the thickness and width are fixed from eyes to the middle of the spring and towards axle seat the width reduces hyperbolically and a linear increment in thickness. In this study design of a spring with more realistic situation was done by removing the simplified assumptions. Vivek Rai and Gaurav Saxena[4] deals with the selection and properties of the composite material, fibers and resin selection. Materials of the leaf spring probably consist of 60-70 % of the vehicle cost and influence the performance and quality of the vehicle. A small amount of weight reduction in vehicle may result a wider economic impact. Composite materials are more light weight and shows high flexibility compared with steel. Hence, composite materials can be used for the design and manufac- turing of leaf spring. Most commonly used fibers are glass,

carbon etc. Glass fibers are usually exhibits high strength and also cost effective. Therefore glass fiber is selected. The types of glass fibers are C- glass, S-glass and E-glass. The C-glass fiber provides improved surface finish. S-glass fiber exhibits very high modular, highly used in aeronautical industries. The Epoxy glass fiber is a standard reinforcement fiber with high quality glass used for all the present systems which meets the required mechanical properties. Thus, Epoxy glass fiber is well suited for this application. The properties of the Epoxy glass fiber are given in the table I.

Properties	Values
Tensile modulus along X direction(Ex) MPa	34000
Tensile modulus along Y direction (Ey) MPa	6530
Tensile modulus along Z direction (Ez) MPa	6530
Tensile strength, MPa	900
Compressive strength, MPa	450
Shear modulus along XY direction (Gxy), MPa	2433
Shear modulus along YZ direction (Gyz), MPa	1698
Shear modulus along ZX direction (Gxz), MPa	2433
Poisson ratio along XY direction (NUxy)	0.217
Poisson ratio along YZ direction (NUyz)	0.366
Poisson ratio along ZX direction (NUzx)	0.217
Mass density, kg/mm3	2.6106
Flexural modulus, MPa	40000
Flexural strength, MPa	1200

Table I. Mechanical properties of e-glass epoxy.

Span	825mm
Camber	70mm
Width	50mm
Thickness	6mm

Table II
Standard Dimensions Of A Leaf Spring Available In Market.

IV. DESIGN PROCEDURES

With the extensive use of laminated composite materials in all engineering fields, composite laminates with optimized design has been an extensive subject of research in recent years. Since the composite leaf spring is a mono leaf, the shape of the spring must be optimized. For this an optimized geometry must be selected. This is achieved with the finite element method using ansys software.

A. Design Of Leaf Spring

Before starting the design and optimization of a leaf spring we have to consider any standard dimension of a leaf spring which is available in the market. Then only we are able to compare the experimental test values with the standard test values and predict the strength of the E-glass epoxy material. The standard dimension of a leaf spring used in Maruthi 800 is given in the following table II. First we have to find out the deflection of the beam when subjected to a particular load through analytically and analysis and compare the values with the deflection of leaf spring having same span and cross sectional area and load of the analyzed beam obtained from the analysis. The expression for the deflection of a simply supported beam is given by

$$Deflection,\ w = \frac{-P * X(4X^2 - 3l^2)}{48 * E * I} \qquad (1)$$

X = distance between the load and fixed end
L = total length of the beam.
E = Young's Modulus of the material.
I = Moment of inertia.

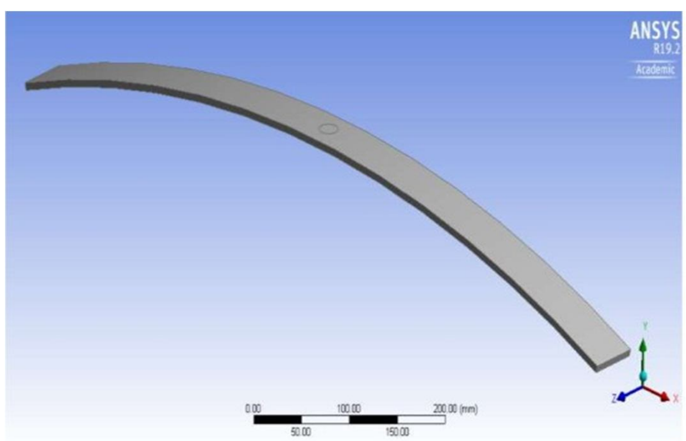

Fig. 1. Leaf spring model

Young's modulus	210000 MPa
Density	7800 Kg/m^3
Ultimate yield strength	841 MPa
Yield strength	248 MPa

Table III. Properties of Mild Steel

P = Load acting on the beam.
Here
P = 700N
X = 0.4125m
L = 0.825m
E = 2*10 11 N/m 2

$$I = \frac{b * d^3}{12} \quad (2)$$

Moment of Inertia I will be obtained as $9e^{-11}$ Substituting the values in equation (1), we will get the deflection of the beam as 0.04549 N. Now analyzing the beam using ansys with the boundary conditions given below.

1) One end fixed.
2) One end having displacement in the X – direction only.
3) Force 700N in the Y – direction acting downwards.

Mild steel is used as the material. The properties of the mild steel is given below in the table–3. By analyzing the beam under specified conditions the deflection is obtained as 0.045208 m. Both the analytical value and analysis values are nearly same which shows that the procedures of analysis are correct. Now analyzing the leaf spring using the same boundary conditions mentioned above. The deflection of the leaf spring obtained is 0.045246m. By comparing the analysis values of deflection of both leaf spring and beam having same span, camber length and cross sectional area which is subjected to a same load shows same deflection. So we can use the design procedures of a beam for designing a leaf spring which is easier.

Span	412.5mm
Camber	35mm
Width	25mm
Thickness	3mm

Table IV. New Dimensions of Scaled Down Model of The Leaf Spring.

B. Scale Down Calculations

While designing the leaf spring it is very important to keep the value of factor of safety as 1. If factor of safety is less than 1, then the initiation of crack will occur very fast and if the factor of safety value is greater than 1, then the number of cycles at which fatigue failure will occurs may tends to infinity. Then it will become very difficult to calculate the fatigue failure during the experiment. By considering the above mentioned conditions we are setting the factor of safety as 1.

In order to keep the factor of safety value 1, we have to maintain the maximum stress value acting on the material equal to the maximum yield strength of the material which is equal to 2.5*10 8 N/m 2 . So we need to select a particular load which satisfies the condition. The required load can be calculated by using the following expression

$$\frac{E}{R} = \frac{M}{I} = \frac{\sigma}{Y} \quad (3)$$

By substituting the values in equation 3, the obtained load equal to 181.59 N and corresponding torque will be 74.9 Nm. Here maximum stress is considered as $2.5e^8 N/m^2$. Practically it is very difficult to accommodate a motor having such high torque. For the experimental purpose, scaling down all design parameters, thereby scale down the torque. Consider the equation

$$\sigma = \frac{P * X * Y * 12}{b * d^3} \quad (4)$$

By reducing and substituting values in equation 4 P/d^2 ratio is obtained as $5e^6$ and the value of load depends on the thickness only. To obtain a particular load value we have to choose a thickness based on this ratio. Here d is considered as 3mm which is 50% of the standard value of base design. Therefore all other design parameters are reduced 50% of the standard values. The load corresponding to 3mm thickness is 45N. The new dimension of the scale down model are given in the table 4.
Now analyzing the leaf spring in ansys with new dimensions but of same boundary conditions as mentioned in the above analysis. The deflection obtained in the beam when subjected to a load of 45N is 0.011541m.

C. Design Of Composite Leaf Springs

In this work Epoxy Glass Fiber Reinforced Plastic is the composite material used for the fabrication of the leaf spring. The properties of a uni-axial Epoxy Glass Fiber Reinforced Plastic is given in table 5. While designing the composite leaf spring, we have to keep the load and deflection obtained in the mild steel as constant. Then only we can compare the stress acting on the composite leaf spring and leaf spring made of mild steel and the strength of the composite leaf spring. In order to keep the load and deflection constant, we need to change the moment of inertia accordingly. For Epoxy Glass Fiber Reinforced Plastic,

Span	412.5mm
Camber	35mm
Width	25mm
Thickness	3mm

Table V. Design Parameters Of The Composite Leaf Spring

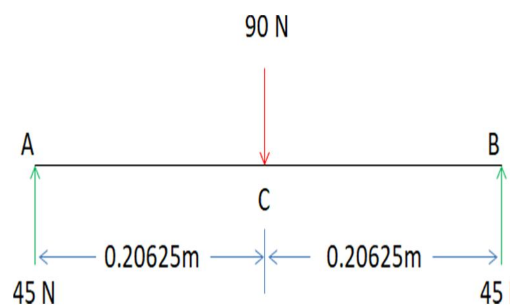

Fig. 2. Force diagram of leaf spring

w = 0.01169 m P = 90 N
x = 0.020625m
l = 0.4125m Ex = $0.17e^{11}$
Substitute the above values in equation (1), we will get the value of 'I' as $60.62e^{-10}$ m^4. In the moment of inertia the 'b' value is kept constant by considering the geometrical limitations, so the changes made only in the value of d. Then the value of d is obtained as 6.8 mm. Design values of the composite leaf spring are given in table 5.

D. Selection Of Motor

The most importance functional requirements of the test rig are, fixing the specimen and applying alternating fluctuating load on the composite specimen to achieve the following fluctuating conditions. The load can be applied by using an electric motor and using eccentric crank mechanism of motor having rotary motion, reciprocating motion can be achieved. The motor should produce enough to torque and power as per the fluctuating conditions. Before selecting a motor with specified power all loads acting on the system must be considered. According to the fig-2 the torque acting on the point c is 9.28125Nm. Then the required power of the motor will be 170.064 watts.

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V. DESIGN AND FABRICATION OF TEST RIG

Fatigue test rigs are generally having a customized design because it should satisfy all the requirements of the structure to be tested. Here the fatigue test rig should satisfy the design conditions of the composite leaf spring. We should design and fabricate a leaf spring according to the design parameters of the leaf spring mentioned in table 5. The minimum span length of the test rig should be 412.5 mm. If the length can be adjusted then it will be more convenient. The design of the test rig should be done in such a way that it can hold a leaf spring with desired dimensions mentioned in table 5. In addition to the dimensions the test rig must be capable of withstanding all kind of loads and vibration acting on the leaf spring. The test rig design should be in such a way that it should be capable of accommodating all the deformations acting on the spring while subjected to load.

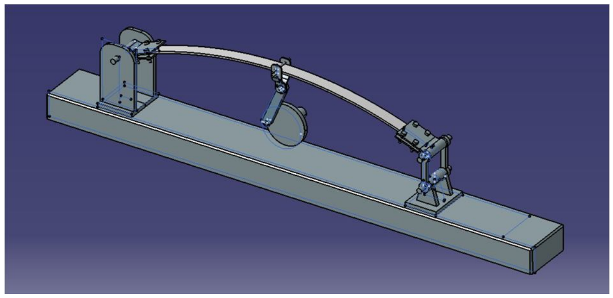

Fig. 3. Assembly model of the test rig.

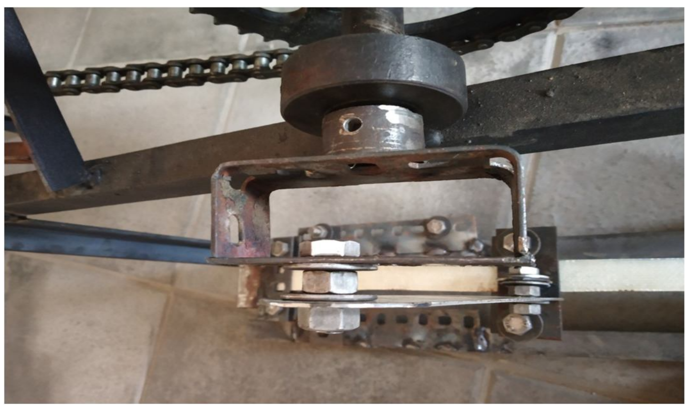

Fig. 4. Crank.

The test rig mainly consists of a supporting base, clamp, hinged support, shackle, shackle support, connecting rod and a crank. The test rig must be capable of housing a motor with enough torque and power to produce the rotary motion. The connecting rod is used to convert the rotary motion into linear motion. The load is applied on the center of the leaf spring. The leaf spring is attached to the test rig with the help of a hinged support on one side and a shackle on the other. Hinged support allows the leaf spring to move only in one axis that is in X- direction while the shackle will allow the leaf spring to move in both X and Y directions when subjected to a specific load. This type of support will be provided so that the deformations acting on the leaf spring when subjected to the load can be accommodated. This type of assembly will allows a rotational effect too.

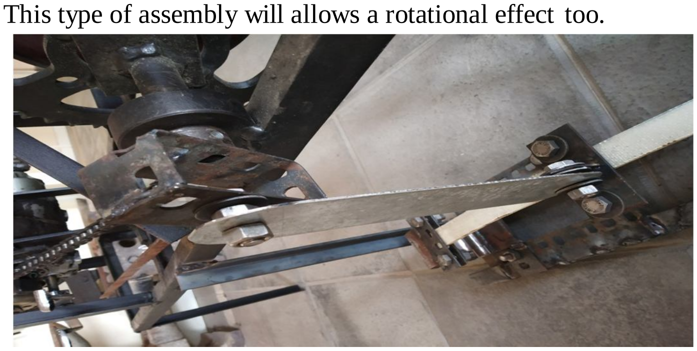

Fig. 5. Connecting rod.

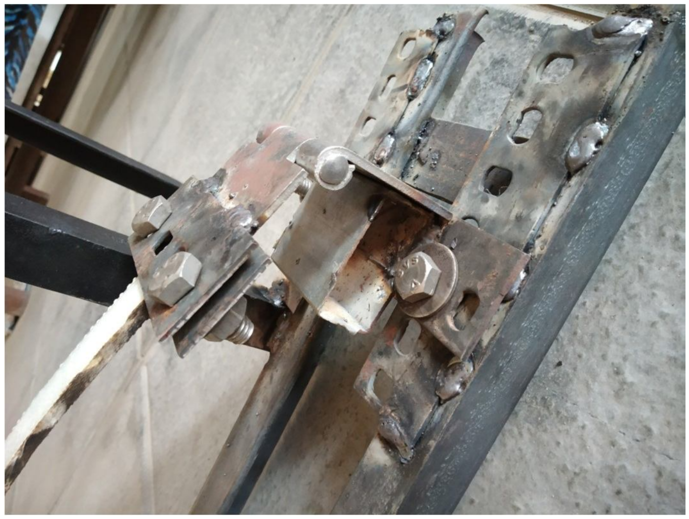

Fig. 6. Hinged support.

The crank is a single part which is connected to the shaft of the motor/engine and the connecting rod. It transmits the rotational effect from the motor/engine shaft to the connecting rod. The speed of the crank depends on the speed of the motor/engine.

Connecting rod is fixed between the crank and leaf spring. Both of the ends of the connecting rod is bolted with the crank and center of the leaf spring. Connecting rod is used to convert the rotary motion produced by the crank into linear motion required to apply the load.

Hinged support is provided on one end of the leaf spring in order to provide movement in the Y direction only. It allows one end of the leaf spring to move in Y direction such that the deformations can be accommodated when the leaf spring is subjected to the load. When the leaf spring is subjected to load, it will shows a tendency to move in both X and Y directions. In order to obtain a proper deformation these movements must be accommodated. Shackle is provided on one end of the leaf spring so that that end is fress to move in both X and Y directions

Fig. 7. Shackle.

Fig. 8. Testrig.

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The test rig is fabricated in such a way that the effective span length can be adjusted to a limit as per the requirement of the leaf spring. The frames, supports, hinge and shackle of the leaf test rig is made up of mild steel. The leaf spring can be fixed at the center of the test rig in such a way that the load can be acted on the center of the leaf spring.

VI. RESULT AND DISCUSSIONS

A. Analysis Of Stress

The leaf spring was simulated under and bending and normal stresses are important. Composites usually exhibit an- isotropic properties and because of that other components of the stress tensor must be studied. Here longitudinal ten- sile strength was greater than the longitudinal compression strength of, so failure always occurs at the lower (compression) surface of spring. Therefore, in stress analysis more consider- ation was given to this particular surface.

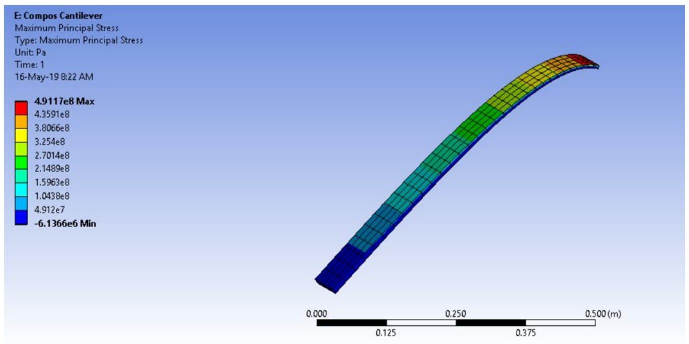

Fig. 9. Maximum principal stress of cantilever composite beam at 350 N.

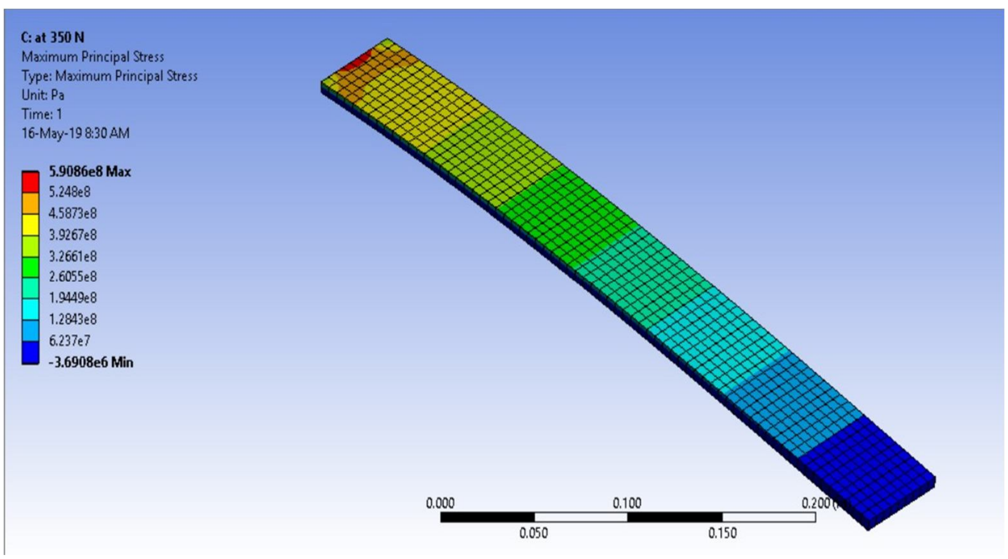

Fig. 10. Maximum principal stress of cantilever beam of mild steel at 350 N.

By comparing figures 8 and 9 it is observed that the maximum principal stress of a composite cantilever beam at 350 N load is 491 MPa and that of a cantilever beam made of mild steel is obtained as 590 MPa.

B. Natural Frequency

The maximum frequency produced by road irregularities is usually considered as 12 Hz. So in order to avoid resonance the natural frequency of leaf spring must be higher. The stiffness of both steel leaf spring and composite leaf spring are same but difference in weight. Composite leaf springs are light weight compared to a leaf spring made of steel. So first natural frequency of composite leaf spring might be greater than that of the steel one. First five natural frequencies of steel and composite leaf springs are simulated using ansys and listed in Table VI. Considering the Table VI, it is understood that first natural frequency of leaf spring is nearly three times greater than the frequency produced by road irregularities and resonance will not occur.

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C. Deformation Analysis

To avoid the high degree of non-linearity in result optimized leaf spring is analyzed assuming large deformations and small strains behavior.

Frequency mode	Steel leaf spring	Composite leaf spring
1	29.6 Hz	33.3 Hz
2	51.8Hz	57.6 Hz
3	94.9Hz	173.1 Hz
4	102.5Hz	248.9 Hz
5	134.3Hz	464.2 Hz

Table VI
First five natural frequencies of composite and steel leaf spring.

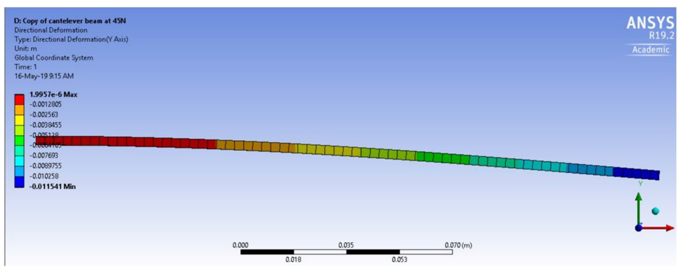

Fig. 11. Deflection of the leaf spring of Mild steel at 45 N.

The analytical solution of deflection was obtained as 0.01169 m and the analytical solution is obtained as 0.0115 and 0.01154 for composite leaf spring and leaf spring made of mild steel respectively.

A steel leaf spring used in the rear suspension of light passenger cars was analyzed by two analytical and finite ele- ment methods. The experimental results verified the analytical and finite element solutions. The steel was replaced with an optimized composite Epoxy-glass material for fabricating leaf spring. Main consideration was given to the optimization of the leaf spring geometry. The stress acting in the composite leaf spring considerably lower than that of the steel spring. Com- posite leaf spring with optimized design geometry weights nearly 80% less than the steel spring. Natural frequency of composite leaf spring is also very high than that of the steel leaf spring and is quite capable of avoiding the resonance.

VII. CONCLUSIONS

The modeling and analysis of a leaf spring made up of mild steel and Epoxy-glass composite was done in ansys and on the bases of design values, design and fabrication of the fatigue test rig was done. Through effective analytical and analysis approach, fabrication of a low fatigue test rig can be achieved. The design shows high flexibility and efficiency compared to the previous ones. The values of deflection of the composite leaf spring obtained from the mathematical calculations, analysis and experiment are almost same. So we can say that the test rig is working properly. The test rig is fabricated in such a way that the effective span length, width and thickness of the leaf spring can be varied. So the test rig is capable of testing other leaf spring with desired dimensions and materials.

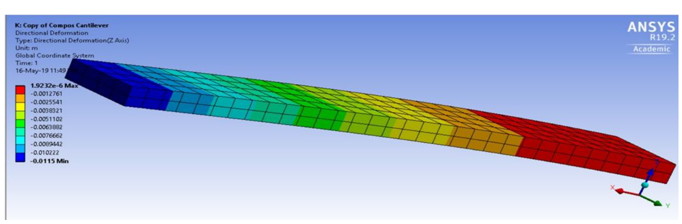

Fig. 12. Deflection of the composite leaf spring at 45 N.

REFERENCES

[1] S. Rajesh N. Saravanan. Design and fabrication of low cost fatigue test rig. Imperial journal of interdisciplinary research, vol-2, issue-10, 2016; 684-688.
[2] N. Nagabhooshanam, S. Baskarb, P. K. Nagarajanc, K.Sathish kumar. Design and fabrication of fatigue test rig and preliminary investiga- tion on flax composite beam. Materials Today: Proceedings 5 (2018) 11771–11779.
[3] I. S. Jacobs and C. P. Bean, "Fine particles, thin films and exchange anisotropy," in Magnetism, vol. III, G. T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271–350.
[4] Vivek Rai, Gaurav Saxena. Development of a composite leaf spring for a light commercial vehicle (Tata magic). Int. Journal of engineering research and applications. Vol-3, Issue-5(2013) 110-114.
[5] Stephens, Ralph I.; Fuchs, Henry O. (2001). Metal Fatigue in Engineer- ing (Second edition Ed.). John Wiley Sons, Inc. p. 69.
[6] Bhandari V.B, "design of machine elements", Second Edition, Tata McGraw-Hill Book Co., 2007.
[7] orvi A. A preliminary approach to composite beam design usingfem analysis. Comp Struct 1990;16:259–75.
[8] Ryan WE. Method of making a molded fiber reinforced plastic leaf spring, US patent 4,560,525 (24/12/1985).
[9] Nickel HW. Bushing construction for a fiber reinforced plasticleaf spring, US patent 4,565,356 (21/1/1986).
[10] Abrate S. Optimal design of laminated plates and shells. Comp Struct 1994;29:269–86.
[11] Pozhilarasu and T. Parameshwaran Pillai, Comparison of Performance f Glass Fiber Reinforced Plastic Leaf Spring with Steel Leaf Spring. International Journal of ChemTech Research, 5(3), 2013, pp 1339-1345.
[12] M. Venkatesan and D. Helmen devaraj, Design and analysis of Com- posite leaf spring in light vehicle .International Journal of Modern Engineering Research,2(1), 2012, 213-218.