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# Crack Evaluation Of Automotive Composite Mono Leaf Spring

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**ABSTRACT**

**In the present scenario, the automobile industry is looking for replacement of conventional materials with composite materials. Composite mono leaf spring is one of the potential items for weight reduction in automobile vehicles. Especially composite leaf spring made of glass fibre reinforced plastics material. These materials are very sensitive to damages such as crack, inter-laminar delamination, de-bonding etc., occurred during service condition. Structural Health Monitoring (SHM) is essential for checking the health status of such components. These damages grow in progression during service and result in catastrophic failure once they grow beyond a critical limit. It is required to investigate the damage occurred in the structure at the early stage to protect the structure from failures. This paper aims to study and analyse by Finite element software (Healthy & Artificial crack) on mono composite leaf spring. It focusses mainly to know the presence, location and severity of the crack which is generated artificially on the leaf spring by vibration parameters. Further, these results are compared with the vibration characteristics of healthy leaf spring.**

**Keywords-** **Composite mono leaf spring, Glass fibre reinforced plastic, Healthy and artificial crack, Structural health monitoring, Vibration parameters.**

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## I. INTRODUCTION

In the present scenario, the low cost and flexibility of the structures manufacturing process with composite materials has motivated significant growth of automotive industries. Composites are being considered to make less weight, secure and more fuel-efficient vehicles. They do not rust or corrode like conventional materials like steel or aluminium, and they could significantly increase vehicle fuel economy by reducing vehicle weight. Ultimately automotive industries are looking for any implementation to reduce the overall weight of the vehicle. This will happen by weight reduction of every component. Suspension leaf spring is also one of the potential items for weight reduction in automobile vehicles. Therefore, the automobile industry is looking for replacement of conventional materials with composite materials [1].

Damage is defined as the changes in geometric properties of a structural system, including changes to the boundary conditions and system connectivity, which harmfully affect the system performance. Composite materials are very sensitive to damages such as crack, inter-laminar delamination, de-bonding etc., occurred during service condition. The crack is the kind of invisible damage which is more severe and common in composite structural components [2]. The composite structures are prone to crack due to over-stress in operation, environmental conditions, any accidental event.

Presently, automotive industries are highly focused in structural health monitoring process is looking for the early damage detection [14].The risk of human lives loss is always associated with structural parts as its failure is unpredictable. It is desirable to investigate the damage occurred in the structure at the early stage to protect the structure from possible catastrophic failures [3]. Structural Health Monitoring is the process of implementing a damage detection strategy for engineering infrastructure. The following levels are described for detecting crack in the composite materials through SHM process. Level 1: Structural integrity (Detect presence of damage). Level 2: Damage localization (Detect presence and location of damage).Level 3: Damage quantification (Detect presence, location and severity of damage) [4].

Non-Destructive Testing (NDT) is the process of inspect, evaluating materials, components or assemblies for discontinuities, or differences in characteristics without destroying the serviceability of the part or system. The common disadvantages in all NDT is piece wise inspection is not proper and in order to inspect the localized damages or measurements, nature of the damage, locate and quantify the damage will not be clearly understood[6]. They are efficient but time consuming, costly and difficult [5].

In this paper composite mono leaf spring of Mahindra Bolero vehicle is taken consideration. With the same geometry of the spring is modelled as a healthy using finite element analysis and artificial created on another replica of the same model. Vibration analysis is carried out in both (healthy and crack) springs to determine the crack parameters (presence, location and severity).

## II.LITERATURE SURVEY

A. Rytter [4] categorized the damage identifications into four performance levels Level 1: Structural integrity; Level 2: Damage localization; Level 3: Damage quantification and Level 4: Prognosis of remaining service life. According to the study, the first three levels of damage detection are related to methodologies directly supported in experimental measurements. Otherwise, a more complete characterization of damage requires the use of analytical and numerical time to estimate the remaining useful life, fourth level of damage characterization.

R. D. Adams et al. [7] investigated the structural damage by the decrease in natural frequencies with the introduction of a single damage, by removing the equivalent to one percent of its cross-section. However, this methodology was insufficient to locate and quantify the damage severity, and also, shown the need for a more complete structural characterization.

L. Rubio et al. [8] Investigated an effective crack identification procedure based on the dynamic behaviour of a Euler–Bernoulli cracked beam. An inverse problem has been solved by the use of the classical optimization technique .It's minimizing the least square criterion applied to the closed-form expression for the frequencies obtained through the perturbation method. The author applied this method successfully to a simply supported Euler–Bernoulli beam.

W. H. Tsai et al. [9] considered the use of frequency response functions (FRF) as a solution for the detection of the structural integrity. The experimental measurement of FRFs in a laboratory bridge model, allowed the identification of a 3 mm cut in one of the tested bars. The analysis of the risk failure in trusses structures was investigated by using poles changes in the FRFs.

Kaushar H. Barada et al. [3] studied the first two natural frequencies of the cracked beam. These frequencies are determined experimentally and used for detection of crack location and size. Researcher concluded that the crack present near to fixed end imparts greater reductions in natural frequency than that away from the fixed end. The detected crack locations and size are compared with the experimental results and found to be in good agreement.

Zhigang Yu et al. [10] investigated diagnosis of cracked composite beams of practical significance and able to be used in structural health monitoring. A model-based approach is developed in this literature to determine the location and size of an open edge crack in composite beam. Numerical experiments have demonstrated the excellent computational efficiency and satisfactory identification performance. The influences of crack size, crack location and material gradient on the natural frequencies of a cracked cantilever beam are studied.

Jeslin Thalapil et al. [11] analyzed the natural frequency of monolithic beams with longitudinal cracks for developing a method for its detection. An analytical method had been developed to address both forward problem of determination of natural frequencies knowing the beam and crack geometry details as well as inverse problem of detection of crack with the knowledge of changes in the beam natural frequencies.

## III.DETAILS OF ACTUAL COMPONENT

The work is carried out on Mahindra Bolero vehicle suspension mono leaf spring. This mono leaf spring manufactured by ARC industries. It is made by glass fibre reinforced plastic (GFRP) material. The actual spring as shown in Fig1.

Fig1: Actual Mono Leaf Spring

### A. Geometry of leaf spring:

The cad model design of leaf spring done by CATIAV5R19 software. The cad model as shown in the fig2.The following dimensions was listed table1.

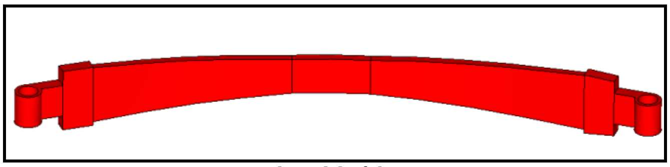

Fig2. Cad Model of the spring

Table1:

| S.NO | Parameter | Length(mm) |
|---|---|---|
| 1 | Length of leaf spring from Eye to Eye(L) | 1200 |
| 2 | Width at both end | 116 |
| 3 | Width at centre | 72 |
| 4 | Thickness at both end | 13 |
| 5 | Thickness at centre | 18 |
| 6 | Eye inner Diameter | 38 |
| 7 | Eye outer Diameter | 52 |

### B. Material and properties of GFRP

All GFRP material properties collected from ANSYS software library. The material and properties tabulated on the table2.

 

Table2: GFRP Material and properties

| Sr. No | Properties | Value |
|---|---|---|
| 1 | Tensile modulus along X-direction(E1) | 45000 MPa |
| 2 | Tensile modulus along Y-direction(E2) | 10000 MPa |
| 3 | Tensile modulus along Z-direction(E3) | 10000 MPa |
| 4 | Poisson ratio along XY-direction($NU_{XY}$) | 0.300 |
| 5 | Poisson ratio along YZ-direction(($NU_{YZ}$) | 0.400 |
| 6 | Poisson ratio along ZX-direction($NU_{ZX}$) | 0.300 |
| 7 | Mass density of the material(ρ) | $2.0x10^{09}$Tonne/$m^3$ |
| 8 | Shear modulus along XY-direction($G_{XY}$) | 5000 MPa |
| 9 | Shear modulus along YZ-direction($G_{YZ}$) | 3846.2 MPa |
| 10 | Shear modulus along ZX-direction($G_{ZX}$) | 5000 MPa |

## IV.VIBRATION APPROACH

Vibration parameters are best approach for finding crack evaluation in composite materials.

### A. Introduction to vibration methods:

Generally vibration methods used for crack detection in composite materials.

i. Method based on Natural Frequency:

Natural frequency is one of the parameter for finding the crack in composites. The crack can be detected by the variation of natural frequencies [12]. Methods based on natural frequency shifts are two types: the forward and the inverse problem. The forward problem consists in determining what the natural frequency changes due to a known damage case (which may include its location, extension and type) will be. Typically, damage is modelled numerically and the natural frequencies are measured experimentally and compared to those related to each of the damage cases initially predicted. The inverse problem consists of determining damage parameters, such as crack length or location, from changes in the natural frequencies [11].

ii.Method based on Frequency Response Function (FRF) Approach:

Frequency response functions are complex functions, with real and imaginary components. A frequency response function expresses the structural response to an applied force as a function of frequency. The response may be given in terms of displacement, velocity, or acceleration. Frequency values were extracted by transformed signals in frequency domain using the Fast Fourier Transform (FFT) technique. The results of FRFs were obtained using software: one axis stands for amplitudes of FRFs in terms of displacements, velocity, acceleration of the logarithmic scale and other axis stands for frequency values [1].

iii. Methods based on the dynamic measurement of stiffness or flexibility

Change in the local stiffness due to create artificial crack, it was recommended the use new methodologies based on measurement of the structure dynamic stiffness. The differences in the structural stiffness matrix between undamaged and damage cases is use to detect and locate cracks in structures. Further, the method of the stiffness matrix error, defined by the difference of the stiffness matrix between the analytical/numerical model and experimental data, it was proposed to detect damage in the case of a large variation of stiffness [10].

B. Crack evaluation using vibration parameters:

i.Presence of the crack:

This level, it is possible to get the information about the presence of crack in the structure. It can be achieved by monitoring certain mechanical properties of the structure over time. Those are strain energy, fundamental natural frequency, phase information, stiffness reduction.

In this paper, variation of natural frequencies method choosing finds the presence of the crack. Created artificial crack in the component so that stiffness will be decrease at the same time natural frequency also decreases.

ii.Location of the crack:

In this level can find exact location of the crack in the component. The methods dedicated to the damage localization are based on physical principle of the reduction in local structural stiffness. Indirectly, they can be identified from the local disturbances or discontinuities. The experimental structural responses, such as displacement, rotation, bending moment or strain fields are the signs for the local disturbances. Another method is based on the analysis of the structural stiffness or flexibility changes, which are identified from experimental modal parameters.

iii.Severity of the crack:

Here, can find the how much severity of the crack in structure, from the any vibration parameter like frequency, stiffness, displacements, velocity, acceleration of the component .The critical level of the crack information is the quantification of stiffness decrease and estimation of the damage real dimensions. The procedure requires a high accuracy in evaluating the structural response. With respect to area affected by the crack, this can be assessed by analysing the contours of local disturbances by creating artificial crack.

In this paper for finding the severity of crack, taken in to account the damage and undamaged spring of natural frequency and calculated the percentage of the severity of the crack in leaf spring.

## V.FINITE ELEMENT ANALYSIS

A. Modelling: Meshing of the mono leaf spring done in hyper mesh software. The type element is tetrahedral mesh. The healthy and artificially created crack mesh models are as shown in fig3 and fig4.

 

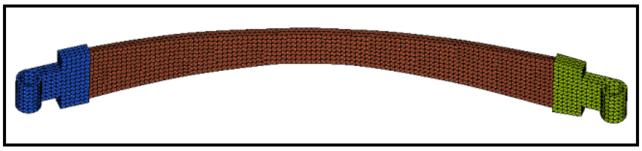

Fig3. Healthy leaf spring

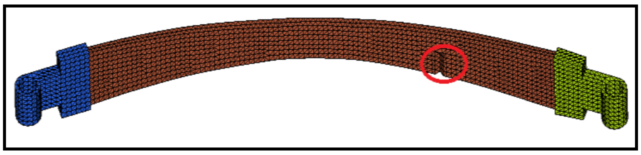

Fig4.Crack leaf spring

B.Boundary Conditions:

The actual boundary conditions in full vehicle level assemble were font eye and rear eye end Y-rotation and rear eye X-translation will be allowed and remaining all constrained.

In this paper used free-free condition for analysis purpose because here worked on component level.

C.Analysis:

For solving purpose used Radioss software and hyper view for plotting the results from hyper works module.

i.Natural frequency:

In free-free analysis first 6 modes of natural frequencies are coming almost zero values because of those are all rigid body modes. In rigid body modes no translations and no rotational degree of freedom will be available .Rigid body modes are plotted Table3.

Table3: First 6 Rigid Body modes frequency values

| Mode No. | Frequency value (Hz) |
|---|---|
| 1 | 1.505715E-03 |
| 2 | 2.056353E-03 |
| 3 | 2.298166E-03 |
| 4 | 2.392185E-03 |
| 5 | 2.454446E-03 |
| 6 | 2.525834E-03 |

ii.Mode Shapes for Healthy and Damage Model:

In this paper modal shapes of $7^{th}$ mode, $8^{th}$ mode and $9^{th}$ modes were shown for variation of natural frequencies.

Healthy Spring (50.7Hz) Damaged spring (49.44Hz)

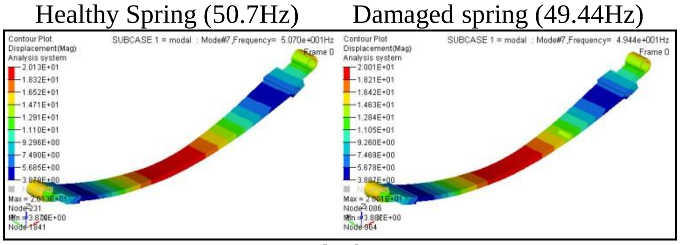

Fig5.Mode Shape 7

Healthy spring(154.3Hz) Damaged Spring(153.6Hz)

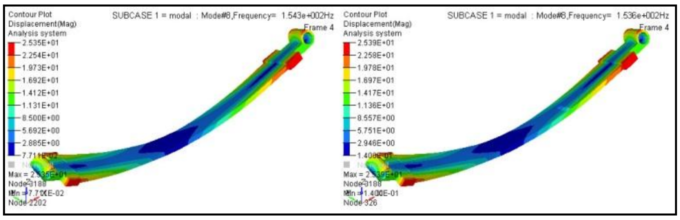

Fig6.Mode Shape 8

Healthy spring (190.7Hz) Damaged spring(183.8Hz)

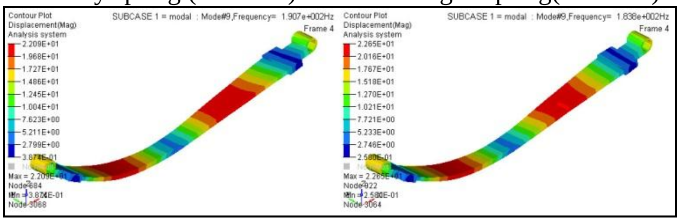

Fig7.Mode Shape 9

iii.Severity of the Leaf spring:

For calculating severity of spring frequency taken into account [13].

Severity= [(Healthy freq.-Damage freq.)/Healthy Freq.]X100

Mode7 Severity: 2.5%
Mode8 Severity: 0.44%
Mode9 Severity: 3.6%

## VI. Results and Discussions

As per FEA results found the crack in the leaf spring through the vibration methods. Comparison Table: As per FEA results the damaged frequency values decreased compare to healthy leaf spring. The comparison values listed in Table4.

Table4: Healthy Leaf Spring Frequency Values

| Mode No. | Healthy Frequency value (Hz) | Damage Frequency value(Hz) |
|---|---|---|
| 7 | 50.70 | 49.43 |
| 8 | 154.30 | 153.62 |
| 9 | 190.67 | 183.81 |

## VII.CONCLUSIONS

In this paper based on results concluded found the crack parameters (presence, severity) through structural health monitoring process.

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