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FOR APPLICATIONS IN BUILDING STRUCTURES, CRACK DETECTION IN A COMPOSITE BEAM USING THE FINITE ELEMENT METHOD

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Abstract

A finite element study has been performed for analysis and fault diagnosis in the composite beam named ALUCOBOND with different boundary conditions. The considered beam has an open transverse crack with varying thickness and location with respect to the beam dimension. The Eigen frequency of the cracked beam has been considered as a fault feature in the analysis. the finite element analysis has been accomplished through COMSOL Multiphysics 4.4. The relation of Eigen frequency with crack depth and crack location has been approved with the presentation of the figures for different mode shapes. The number of modes required the figures depend upon the number of output variable needed to find. The diagnosis of the crack in the structure has been performed with contour plotting techniques. The intersection point in the contour diagram has been used as an indication of crack location and depth. The results and their comparison with steel beam crack prediction have been presented at the end.

Keywords- Crack Detection, Contour Plotting, Eigen Frequency

1. INTRODUCTION

The regular assessments of the critical components of any structure or machine are very much important for its safety from failures. This requires a continuous assessment of variation in their static or dynamic behaviour. The changes have generally their origin in local abetment of structural stiffness due to cracks or crack-like error. There are various techniques even in the non-destructive testing field is available for fault diagnosis in the mechanical structure but vibration-based techniques are much used nowadays due to its ability and effectiveness. The presence of a crack steeply affects the dynamic behaviour of materials. The crack position and size directly affect the structure the stiffness, to get the stiffness reduction, natural frequencies of crack-free and cracked components have been compared. The vibration signal analysis is one of the most momentous methods used for condition watching and error diagnostics because they always hold the dynamic facts of the system. In the crack detection area, various authors have done a lot of work for single material structures such as steel or aluminium. Owolabi and Swamidas et al. 2003 [1] in this research paper Mr Owolabi have made efforts to find crack details by applying Frequency response function’s frequency variation and change in amplitude of frequencies. Deokar and Wakchaure 2011 [2] have done the empirical investigation for crack detection in a cantilever beam with natural frequency as basic constraints. Aysakalnad and B N Rao 2012[3] proposed a finite element method for doubled dimensional crack detection. A finite element study has been performed for analysis and fault diagnosis in the composite beam named ALUCOBOND with different boundary conditions. The considered beam has an open transverse crack with varying thickness and location with respect to the beam dimension. The Eigen frequency of the cracked beam has been considered as a fault feature in the analysis. the finite element analysis has been accomplished through COMSOL Multiphysics 4.4. The relation of Eigen frequency with crack depth and crack location has been approved with the presentation of the figures for different mode shapes. The number of modes required the figures depend upon the number of output variable needed to find. The diagnosis of the crack in the structure has been performed with contour plotting techniques. The intersection point in the contour diagram has been used as an indication of crack location and depth. The results and their comparison with steel beam crack prediction have been presented at the end. This paper is also an improved version of Potirniche et al. [4] by increasing the crack depth ratio up to 0.9 and getting more accuracy in the response. In the paper, the author has applied the software Abacus for analysis and modelling of a mechanical component. A technique to find the cracks [5-10].

2. MODELLING OF COMPOSITE BEAM

The proposed model of the composite beam has been modelled on COMSOL software with the given composition: Cladding: 0.5mm: Aluminium Core: 5.0 mm: Solid Polythene and the empirical dimensions are given as height: 6mm, length: 50mm, width: 5mm. The beam model has shown in Figure 1. The following

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assumptions have been made during the Finite element formation of the beam-

i. The presence of crack is introduced by changing the stiffness matrix of the element.

ii. The mass matrix is not affected by the presence of a crack.

iii. Castiglione's first theorem has been applied to avoid the issue of compliance matrix singularity.

iv. The type of crack is edge open transverse crack.

The mass matrix modelling has been done by shape function. Since the mass matrix has been taken constant, there will not be any variation with change in crack location and depth. The stiffness matrix will contain dynamic stiffness term which varies according to crack location and depth. So, the stiffness matrix needed to calculate at each variation. And this will be accomplished in the COMSOL software automatically. The eigenvalue problem has been solved by the equation-1, 2, 3 & 4 using the Newtons Law of motion [8].

$$[\overline{M}]^{s}\{\ddot{q}\} + [\overline{K}]^{s}\{q\} = \{\overline{Q}\}^{s} \qquad 1$$

$$\{q\} = \{q_0\}e^{j\lambda t} \qquad 2$$

$$[\overline{K}]^{s}\{q_0\} = \lambda^2[\overline{M}]^{s}\{q_0\} \qquad 3$$

$$\lambda^2 = \left([\overline{K}]^{s}\right)^{-1}[\overline{M}]^{s} \qquad 4$$

Lambda (λ) is called as Eigen Frequency for free vibration.

3. METHODOLOGY FOR COMSOL MODELING

The Eigen frequency of the cracked beam has been considered as a fault feature in the analysis. the finite element analysis has been accomplished through COMSOL Multiphysics 4.4. The relation of Eigen frequency with crack depth and crack location has been approved with the presentation of the figures for different mode shapes. The number of modes required the figures depend upon the number of output variable needed to find. The diagnosis of the crack in the structure has been performed with contour plotting techniques

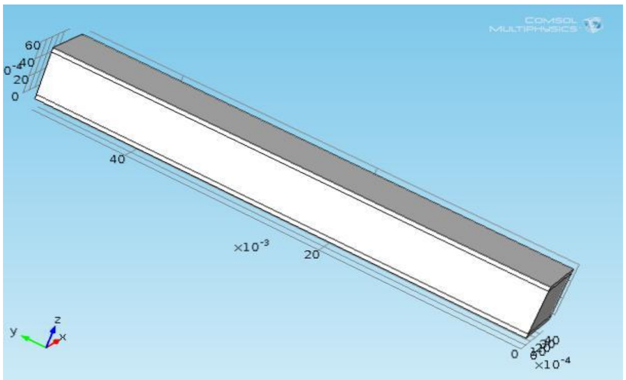

Figure 1 Composite Beam with Dimension

The Eigen frequency analysis has been carried out through COMSOL Multi-Physics 4.4 using the following steps:

i. Setting up of the parameters (L, b, h and k) in global definitions.

ii. Construct geometry and set up the width, depth, height of the block also set the position and finally build all objects.

iii. Introduce the crack with difference operation from geometry column

iv. Define material properties (young's modulus, mass density and Poisson's ratio).

v. Define solid mechanics, set the physics setting and also set the boundary conditions.

vi. Set the mesh size, and also set the user-controlled mesh setting then finally build the mesh.

vii. Set the parameter sweep and desired Eigen frequency understudy tab.

viii. The final step is to compute.

ix. We get the different Eigen frequencies and mode shapes for different parameter

x. Set the mesh size, and also set the user-controlled mesh setting then finally build the mesh.

xi. Set the parameter sweep and desired Eigen frequency understudy tab.

xii. The final step is to compute.

xiii. Get the different Eigen frequencies and mode shapes for different parameter

4. RESULTS AND DISCUSSIONS

With the fixing of the boundary as fixed beam and varying the crack thickness and crack position with respect to the length of the beam section, various Eigen frequencies have been found which were distinctive to each other. After having all the Eigen frequency, we have normalized them as according to uncracked beam natural Eigen frequency. The normalized eigenfrequencies for different mode shapes are given in Table 1, Table 2 and Table 3. Figure 2 is the representation of the variation of normalized Eigen frequency with respect to crack depth ratio (a/H) for mode I. Here it can be observed that the reduction in the normalized Eigen frequency for the Blackline (c/L = 0.5) is the most as compared to the other two. The reason behind is that in the first mode there is a maximum dynamic bending moment (and maximum bending amplitude) which result in maximum bending stiffness reduction. And at other places, there is less reduction in distance from maximum bending amplitude.

Here in the Figure 3 which is made for Mode II, the variation of the normalized Eigen frequency with respect to crack depth at the constant crack position is shown. The black line (c/L = 0.5) is having at least one reduction as compared to another one. Since it is a second mode Diagram so in this figure node pint formation occurs at the middle point. The maximum dynamic bending deflection occurs at one-fourth position. So, for the crack position c/ L = 0.25, there is maximum reduction in the natural frequency as compared to the other two. And the black line (c/L = 0.5) having a maximum crack is less deflected as comparable to other because of node point formation at the middle section of beam. It can be concluded that for II mode the Eigen frequency value depends upon the crack depth (a/H) as taken crack position constant.

The Figure 4 has been made for variation of the normalized Eigen frequency with respect to crack depth ratio (a/H) for the third mode. In the third mode of vibration since one half sine waveforms so at two-point node formation occurs in between the edge of the beam. And that occurs usually near about 1/8th of the length. So, if the crack is made at position of c/L = 0.125 then there will be very less reduction in the normalized Eigen frequency. And that is why the blue line (c/L) is above all in the diagram. And the crack position c/L falls near about maximum dynamic bending moment so there is maximum reduction of the normalized Eigen frequency. And the black line is the lowest in the diagram.

The Figure 5 has been drawn between the normalized Eigen frequency and variation crack position with respect to length (c/L). It can be observed that the dependency of normalized Eigen frequency upon both crack depth and crack position as well. This is a first mode figure in which their maximum dynamic bending moment occurs at the middle section of the beam and when we introduce a crack at c/L = 0.5 then this effect creates an extra reduction in the normalized Eigen frequency. ince the black is having a crack at middle and also the depth of crack is maximum so both contribute to the reduction of Eigen frequency. And other is having a crack depth less than black one so there is less Eigen frequency in them.

The Figure 6 has been drawn between the normalized Eigen frequency and variation crack position with respect to length (c/L). It can be observed that the dependency of normalized Eigen frequency upon both crack depth and crack position as well. This is a second mode figure in which their maximum dynamic bending moment occurs at one-fourth of the section of the beam and when we introduce a crack at c/L = 0.25 then this effect creates an extra reduction in the normalized Eigen frequency. Since the black is having a crack at middle and also the depth of crack is maximum so both contribute to the reduction of Eigen frequency. And other is having a crack depth less than black one so there is less Eigen frequency in them. Form the above diagram we can observe the Eigen frequency depends upon the crack position (c/L).

The Figure 7 has been drawn between the normalized Eigen frequency and variation crack position with respect to length (c/L). The dependency was shown normalized Eigen frequency upon both crack depth and crack position as well in Fig-6. Third mode- maximum dynamic bending moment occurs at one eight of the section of the beam and when we introduce a crack at c/L = 0.125 then this effect creates an extra reduction in the normalized Eigen frequency. Since, the black is having a crack at middle and also the depth of crack is maximum so both contribute to the reduction of Eigen frequency. And other is having a crack depth less than black one so there is less Eigen frequency in them. Form the above diagram we can observe the Eigen frequency depends upon the crack position (c/L).

4.1 CONTOUR PLOTTING:

4.1.1 Intended Crack for fixed-fixed beam:

Eigen Frequency for First Mode: 5434.27 Hz.

Eigen Frequency for Second Mode: 5762.88 Hz.

Eigen Frequency for Third Mode: 9259.07 Hz.

4.1.2 Uncracked fixed-fixed Beam:

Eigen Frequency for First Mode: 5479.72 Hz.

Eigen Frequency for Second Mode: 6168.81 Hz.

Eigen Frequency for Third Mode: 9835.94 Hz

The contour plotting method is a graphical method in which a graph is plotted between the crack depth (a/H) and crack position (c/L). In this technique the contours of Normalized Eigen frequency contours drawn on a coordinate system consisting of ordinate as crack depth (a/H) and abscissa as crack position (c/L).

The values for plotting of normalized Eigen frequency can be fetched from the table of normalized Eigen frequency chart. Here are three vibration modes of normalized Eigen frequency. So, three contour plots for the specimen normalized Eigen frequency will be drawn. Now the intersection point of the three contour plots will be matched from the ordinate and abscissa. And the achieved crack depth and crack position will be the final output of the system. If all three contours do not meet at a point then we have to apply a mass centroid methodology for finding the crack depth and crack position.

For specimen, Normalized Eigen Frequency lets we introduced an intended crack at any intended place such as at length of 17 mm from the origin point and the ratio of the depth of intended introduced crack is a/H= 0.27. Now with the help of COMSOL software, the Eigen frequency for these cracks at all three modes can be calculated. Further, it will be normalized for making it to comparative with others. All the three contours have been plotted on the same coordinate and they intersect at a point. By observing the figure, we can have the final output vale of the crack depth and crack position.

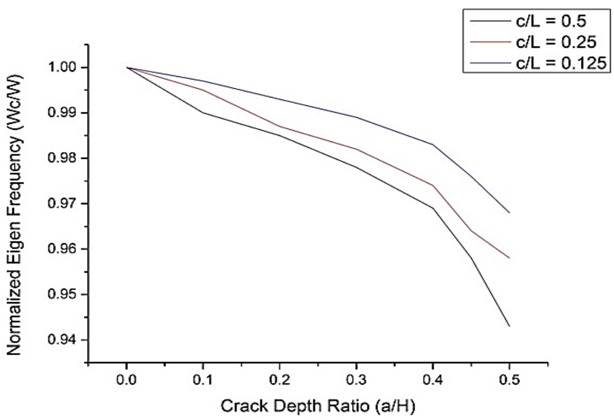

Figure 2 Wc/W Vs. a/H for mode I

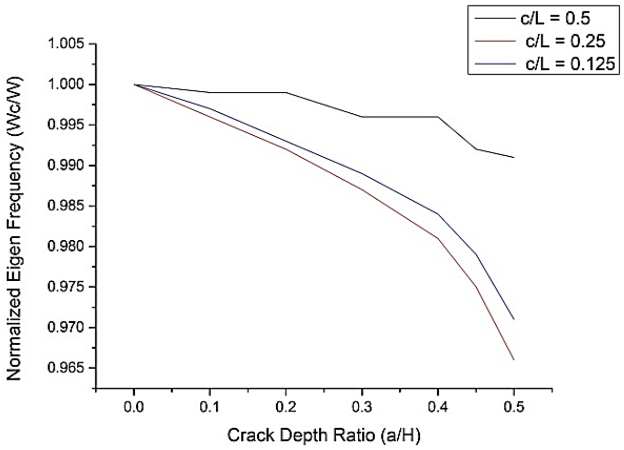

Figure 3 Wc/W Vs. a/H for Mode II

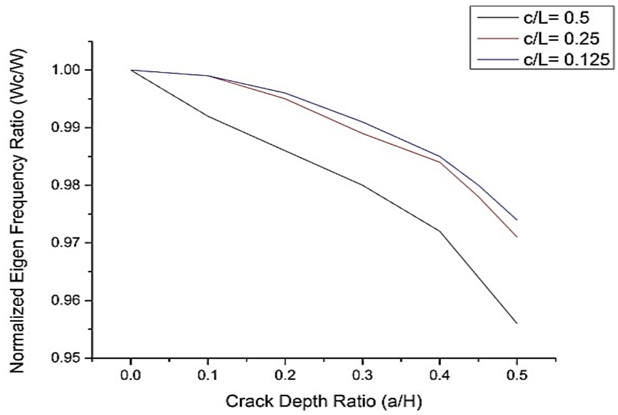

Figure 4 Wc/W Vs. a/H for Mode III

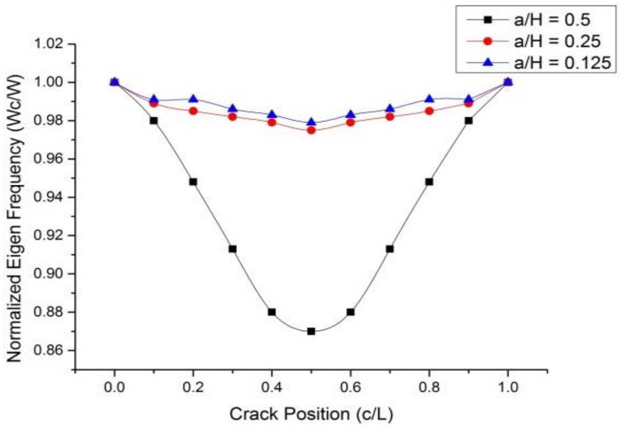

Figure 5 Wc/W Vs. c/L for Mode I

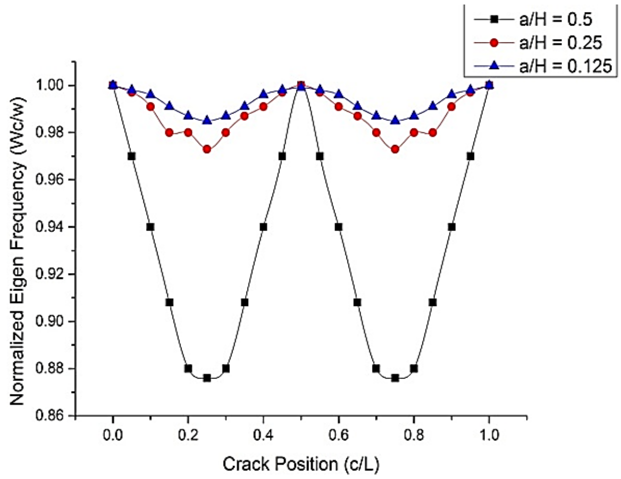

Figure 6 Wc/W Vs. c/L For Mode II

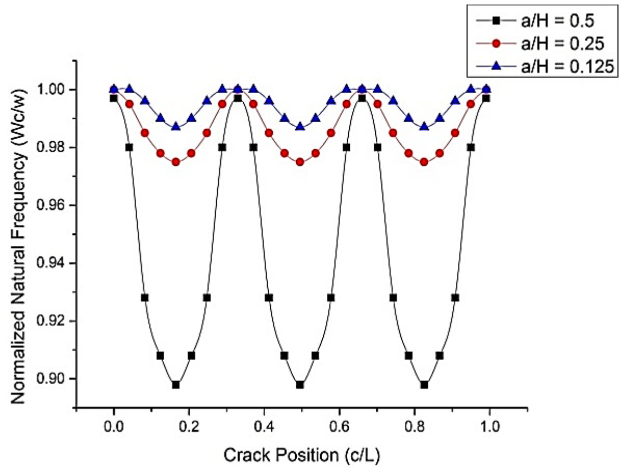

Figure 7 Wc/W Vs. c/L for Mode III

Table 1 Normalized Eigen Frequency Table for 1st mode

Crack Location(c/L) Crack Depth (a/H)	Uncracked	0.1	0.3	0.5	0.7	0.9
0.1	1	0.9992	0.9963	0.9951	0.9970	0.9986
0.2	1	0.9982	0.9890	0.9787	0.9894	0.9984
0.3	1	0.9978	0.9754	0.9521	0.9755	0.9981
0.4	1	0.9970	0.9410	0.9113	0.9437	0.9979
0.5	1	0.9950	0.8864	0.8307	0.8914	0.9968

Table 2 Normalized Eigen Frequency Table for 2nd Mode

Crack length (c/L) Crack depth(a/H)	Uncracked	0.1	0.3	0.5	0.7	0.9
0.05	1	0.9909	0.9976	0.9897	0.9980	0.9896
0.1	1	0.9218	0.9598	0.9065	0.9628	0.9158
0.2	1	0.8956	0.9417	0.8920	0.9443	0.8896
0.3	1	0.8709	0.9244	0.8837	0.9262	0.8648
0.4	1	0.8459	0.9063	0.8776	0.9070	0.8417
0.5	1	0.8359	0.8861	0.8727	0.8853	0.8318

Table 3 Normalized Eigen Frequency Table for 3rd mode

Crack length (c/L) Crack depth(a/H)	Uncracked	0.1	0.3	0.5	0.7	**0**.9
0.05	1	0.9975	0.9995	0.9968	0.9997	0.9970
0.1	1	0.9758	0.9916	0.9629	0.9934	0.9718
0.2	1	0.9684	0.9884	0.9538	0.9905	0.9637
0.3	1	0.9610	0.9848	0.9493	0.9870	0.9563
0.4	1	0.9489	0.9804	0.9467	0.9823	0.9430
0.5	1	0.9140	0.9744	0.9453	0.9758	0.9087

Table 4 Prediction of crack for Fixed Composite Beam

S. No.	Actual Crack		Predicted Crack		Prediction Error	
	Location (c/L)	Size (a/H)	Location (c/L)	Size (a/H)	Location (c/L)	Size (a/H)
1.	0.34	0.27	0.36	0.28	5.88%	3.70%
2.	0.50	0.10	0.505	0.09	1.2%	10.0%
3.	0.50	0.20	0.51	0.21	2%	5.00%
4.	0.50	0.30	0.48	0.32	4%	6.67%
5.	0.50	0.40	0.51	0.39	2%	2.50%
6.	0.50	0.50	0.52	0.494	4%	1.20%

Table 5 Comparison of the result with Steel Beam Crack Prediction Error

S. No.	Prediction Error for Steel Fixed-Fixed Beam [14]		Prediction Error for Composite Fixed-Fixed Beam	
	Location (c/L)	Size (a/H)	Location (c/L)	Size (a/H)
2.	7.29	0.79	1.2%	10.0%
3.	0.75	8.60	2%	5.00%
4.	2.17	2.02	4%	6.67%
5.	3.23	3.2	2%	2.50%
6.	3.98	0.66	4.0%	1.20%

5. CONCLUSION

Due to crack in the beam the stiffness of the beam reduces especially at that particular section.

The Eigen frequency which depends upon stiffness of beam also reduces in the same manner.

There is an inverse relationship between crack depth and Eigen frequency.

The Contour Plotting Techniques suits in same manner to both composite and steel beam.

Accuracy of the implemented technique depends upon material selected during the procedure.

The crack position with respect to the length matter most in calculation of Eigen frequency.

The contours of input Eigen frequency may not always intersect at a single point so we have approached a mass centroid method for detecting an intersection point for all modes contour line.

The no. of modes of contour lines depends upon the output variable such as crack depth etc. of the system.

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