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Experimental and FEA Analysis of Dynamic Characteristics of Cantilever Beam Influenced by Crack

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Abstract—*A crack can be defined as the discontinuity in a solid structure which is identified by possessing an origination point and by growing from this point to a finite size with time which will either lead, or not, to the separation of the origin structure in two or more pieces. The analysis of damage in the form of crack in structures like beam is important for leading safe operation without obstructing systems optimum performance. The primary objective of the presented study is basically to evaluate the variation in dynamic characteristics of a cantilever beam with respect to crack depth and its location. Five mild steel specimens of beam having rectangular cross-section (40 mm × 5 mm) are fabricated with no crack, and crack at 250 and 500 mm from fixed end with 1.5 and 3 mm crack depth. First 3 natural frequencies and their respective modes are calculated and results are compared with Finite Element Modal Analysis. It has been found that cracks affect the stiffness flexibility along with the static and the dynamic performance of the beam. This study will provide a better insight towards the dynamic characteristics of the cantilever beam with the respect to these parameters and will help in predicting the location and nature of crack by using reverse engineering.*

Keywords*: vibration analysis; cantilever beam; FEA; crack depth and location*

1. INTRODUCTION

Fascination for persuading the ability to monitor a structure and detect damage at the earliest possible stage is noticeable in civil, mechanical, and aerospace engineering communities. In context to this study damage can be defined as "an alteration introduced into a system, either deliberately or accidentally, which unfavorably affect the present or upcoming accomplishment of that system". Some of the methods predefined for damage detection are manual or experimental methods like acoustics or ultrasonic methods, vibration-based damage detection techniques for monitoring of structural health, magnetic fields, radiography, eddy-currents or thermal fields. This study emphasis on the damage detection based on vibration techniques where variation in dynamic properties such as natural frequency and mode shape of the system is analyzed with respect to nature as well as position of the crack.

The important part in the research of vibration analysis for real engineering applications, is a cantilever beam. The cantilevers in machineries and construction should be flexible enough to withstand high levels of stress and strain. An essential factor in the estimation of the safety of the structure is to detect faults and defects in a structure at the early stages. FEA is widely used in SHM in order to obtain the analytical solutions of natural frequencies and dynamical responses. It has been found that changes in dynamic properties of the structure could lead to change in mode shapes, increase in damping, frequency reduction and hence crack detection.

In this current research natural frequencies of a rectangular cross section (40 mm × 5 mm) cantilever beam (mild steel) is calculated in respect to the crack position and depth predefined. Dynamic characteristics are estimated experimentally for first three natural frequencies and the results are compared with the Finite element modal analysis.

2. BACKGROUND

In reference to literature it has been noted that numerous studies are developed for structural safety of beams, especially, crack detection by structural health monitoring.[1–3] This present research explains the monitoring of structural health for detection of crack with respect to the change in natural frequencies and modal shapes of the beam element as well as dynamical response of the beam due to application of harmonic forces. When a structure is affected by damages, its dynamical properties is changed, especially, the crack damage causing a stiffness reduction, along with an inherent decrement in the natural frequencies with an intended enhancement in modal damping, and a change of the mode shapes Consequently, there would be a change in the dynamical response of the structural element. From these, the changes in the position of the crack and its magnitude can be identified. Additionally various analytical[4–6] and experimental[7–9] investigations are presented which describes the dynamic behavior of beam in terms of natural frequencies and modal shapes for various materials, cross-section, depth of crack and crack position of the cantilever beam. In view of the fact that the decrease in natural frequencies can easily be observed, most of the authors use this parameter. In addition to that, some studies focuses on the dynamic response of the beam for the applied harmonic forces and variation in response is analyzed.

3. MATERIALS AND METHODS

3.1 Experimental setup:

A mild steel beam is taken for analysis in experiment. The experimental process revolves round to find the modal parameters such as frequency and modal shape. The experiment set up contains cantilever beam, accelerometer, impact hammer, and data acquisition and computer system. Accelerometer is a kind of transducer used to calculate the vibrational response, that is, acceleration, velocity and displacement. The data acquisition system acquires the vibrational signal given by the accelerometer, and converts it into digital form. The oscilloscope acts as a buffer storage device and as a system analyzer. It takes encrypted data from the data acquisition system and after processing (e.g., FFT), it is then displayed on the oscilloscope screen. Fig.1. shows an experimental setup of the cantilever beam. It consists of a beam specimen of particular dimensions with one end fixed and clamped and the other free. Then an accelerometer is clamped to measure the free vibrational response produced.

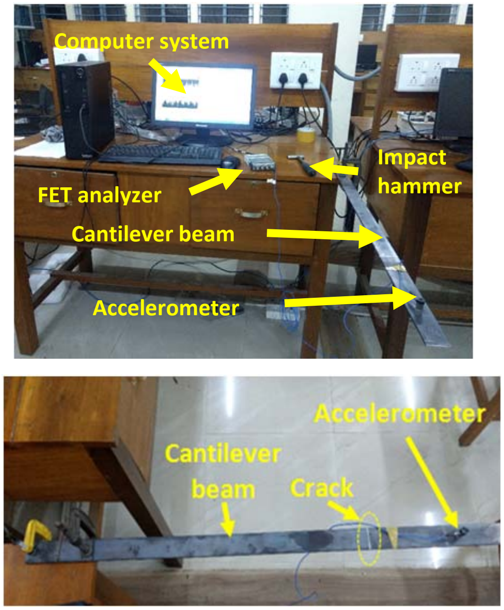

Fig. 1 Experimental Setup

3.1.2. Experimental results:

The cantilever beam was struck with an impact hammer in order to give initial excitation to beam. This sets the beam into a phase of natural vibration. All the data was recorded obtained from the vibrating beam with the help of accelerometer attached to it. Fig. 2and Fig. 3 shows the responses obtained from the FFT analyzer. From these responses, the first few natural frequencies are noted as shown in Table 1.

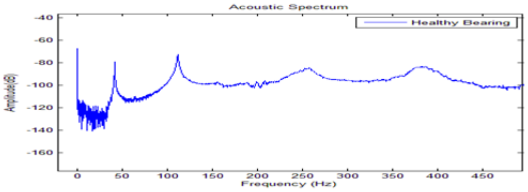

Figure.2

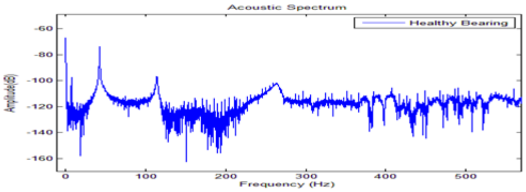

Figure.3

Table 1. Natural frequencies obtained experimentally

S.NO	Location of crack	crack depth	Natural Frequency
1	Uncrack	0	6.83 42.63 53.72
2	250 mm	1.5 mm	6.89 42.31 53.51
3	250 mm	3 mm	6.82 42.52 53.79
4	500 mm	1.5 mm	6.23 42.53 53.42
5	500 mm	3 mm	6.22 42.49 53.51

3.2. Finite Element Modeling:

The FE analysis is brought out for the cracked beams (Cantilever, Fixed-Free) to determine the modal shape of transverse vibration at different crack depth location. The cracked beams used in the current research have the dimensions as, length of the cantilever beam (l) = 750 mm, Width of the cantilever beam (b) = 40 mm, height of the cantilever beam (h) = 5 mm. Relative crack depth varies in the range of 1.5 mm to 3mm, Relative crack location = at 250 mm and 500mm from fixed end.

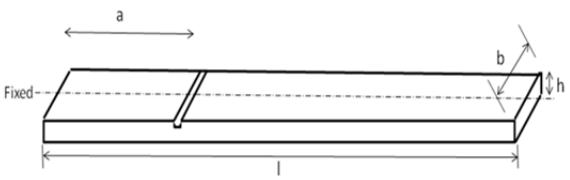

Fig. 4. Geometry of beam

Material used for the analysis is mild steel having the following material properties.

1. Young's modulus = 205 GPA
2. Density =7850 kg/m3
3. Poisson's ratio =0.28

Convergence study has been carried out for cracked beam model for first natural frequency in order to get the optimum number of elements for meshing. Meshing is done by SOLID 187 type element (Fig.5) having 10 nodes with 3 degrees of freedom for each node 3D space. It has been found that the optimum meshing can be done with 923 numbers of elements as further refinement doesn't lead to much variation in the results as shown in Fig.6.

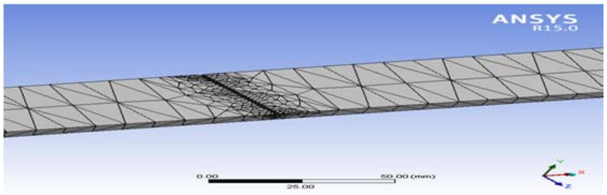

Fig. 5. Meshed model

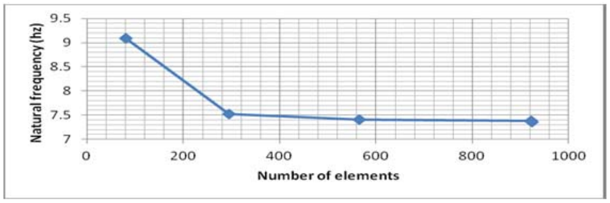

Fig. 6. Convergence study for cracked beam at first natural frequency

Finite element analysis is carried out in modal analysis domain in ASYS 15.0 by considering the one end of the beam is fixed and other is free. Results are calculated for three natural frequencies and its mode shape. Crack location is at a distance of 250 mm and 500 mm from the fixed end and crack depth is 1.5 and 3 mm.

3.2.1. FEA Results:

For each of stated model results are shown below in terms of natural frequency and corresponding modal shapes. And it was observed that in all the cases the modal natural frequencies decrease and mode shape increase with increase in crack depth.

Model 1: Uncrack cantilever beam

S.NO	Location of crack	Depth of crack	Natural frequency
1	Uncrack beam		7.3885 46.295 58.665

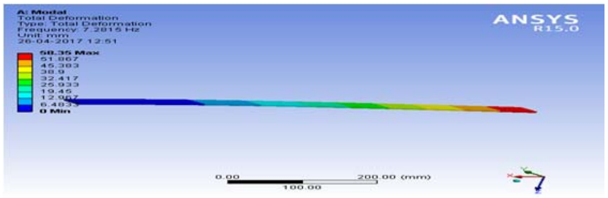

Fig. 7. First mode shape frequency of the uncrack beam

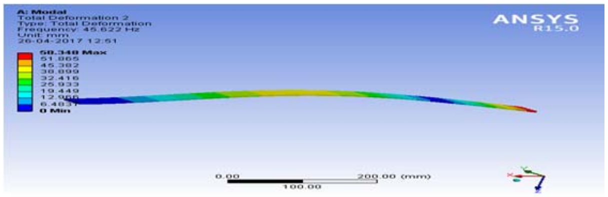

Fig. 8. Second mode shape frequency of the uncrack beam

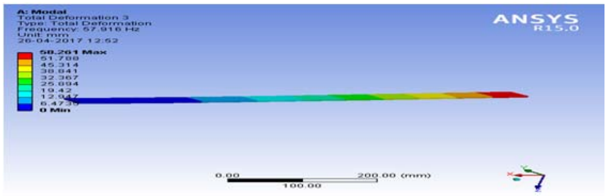

Fig. 9. third mode shape frequency of the uncrack beam

Model 2: Crack location= 250 mm and crack depth =1.5 mm

S.NO	Location of crack	Depth of crack	Natural frequency
1	250mm	1.5mm	7.3793 46.484 58.601

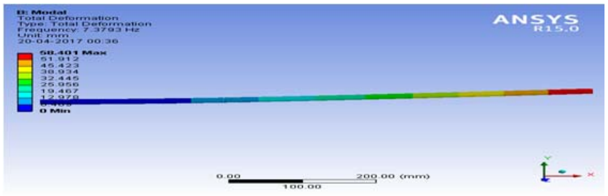

Fig. 10. First mode shape frequency of the beam with 250mm with 1.5mm crack

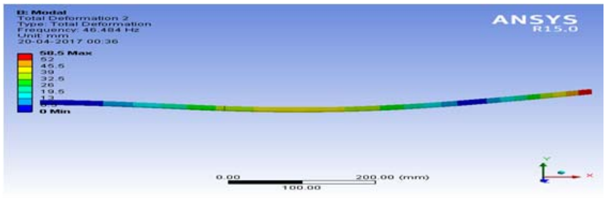

Fig. 11. Second mode shape frequency of the beam with 250mm with 1.5mm crack

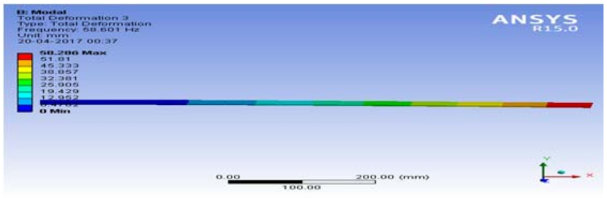

Fig. 12.Third mode shape frequency of the beam with 250mm with 1.5mm crack.

Model 3: Crack location= 250 mm and crack depth =3 mm

S.NO	Location of crack	Depth of crack	Natural frequency
1	250mm	3mm	7.3046 46.255 58.265

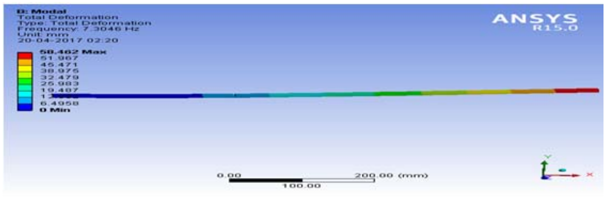

Fig. 13. First mode shape frequency of the beam with 250mm with 3mm crack

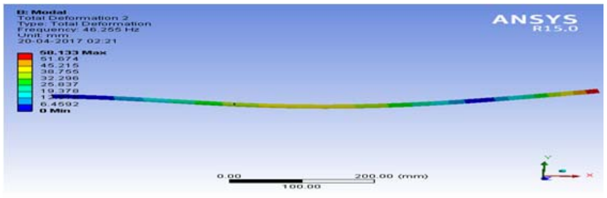

Fig. 14: Second mode shape frequency of the beam with 250mm with 3mm crack

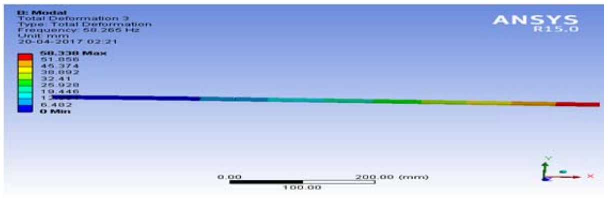

Fig. 15: Third mode shape frequency of the beam with 250mm with 3mm crack.

Model 4: Crack location= 500 mm and crack depth =1.5 mm

S.NO	Location of crack	Depth of crack	Natural frequency
1	500mm	1.5 mm	7.2107 46.577 58.611

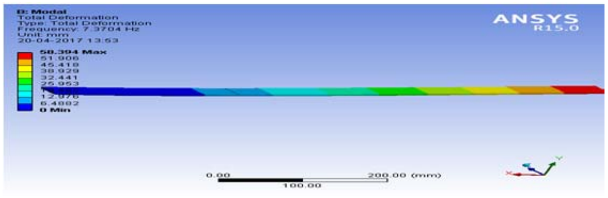

Fig. 16. First mode shape frequency of the beam with 500mm with 1.5mm crack

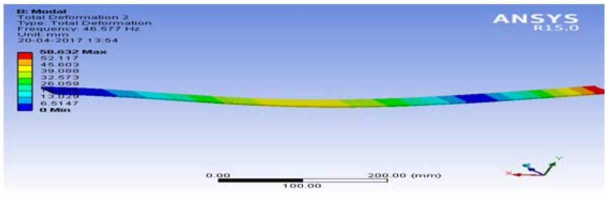

Fig. 17. Second mode shape frequency of the beam with 500mm with 1.5mm crack

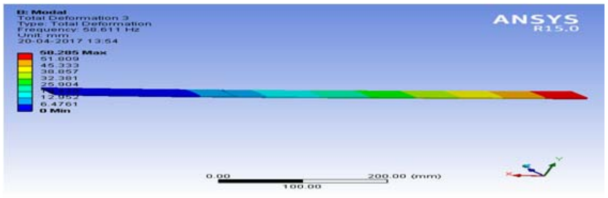

Fig. 18. Third mode shape frequency of the beam with 500mm with 1.5mm crack

Model 5: Crack location= 500 mm and crack depth =3 mm

S.NO	Location of crack	Depth of crack	Natural frequency
1	500mm	3mm	7.2107 45.738 57.54

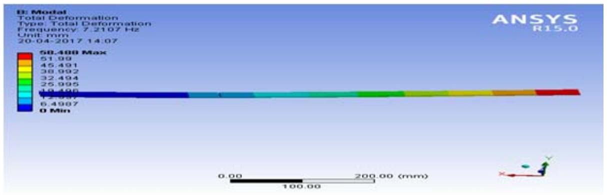

Fig. 19. First mode shape frequency of the beam with 500mm with 3mm crack

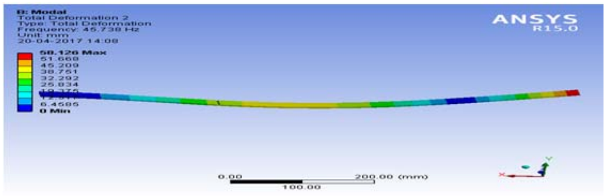

Fig. 20. Second mode shape frequency of the beam with 500mm with 3mm crack

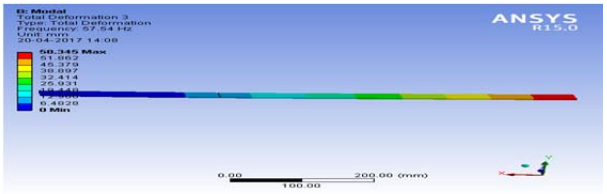

Fig. 21. Third mode shape frequency of the beam with 500mm with 3mm crack

4. CONCLUSIONS

The experimental and finite element modal analysis was performed and studied the variation in natural frequencies. It is found that the result obtained is in close agreement between experimental and finite element results. Vibrational study conducted by varying the crack position starting from the fixed end. It is observed that the variables have a significant influence on the mode frequencies. The cracks are severe threat to the performance of the structures. It decreases the stiffness of the cantilever structures leading to affect the vibration signatures (Natural frequency and Mode Shape). The present paper estimates the crack depth effect on vibration parameters found out.

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