Vibration analysis of a cracked cantilever beam using wavelet technique

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***Abstract*—As we know that in service life structure must have to work safely. But as damage occurs, its breakdown period starts to initiate. In steel construction, aeroplanes, bridges and machinery industries beams are commonly used. Due to static or dynamic loadings cracks become hazardous to the structures, Therefore for structural health monitoring applications crack detection is very important. The aim of the study is to find the effect of crack on the modal parameters like modal frequency and mode shape.A cracked cantilever beam is to be studied under vibration with cracks at different locations. Finite Element Analysis and Experimental analysis with wavelet technique is to be carried for the study of vibrational property of the selected cracked cantilever beam. A comparative analysis of the studies may help us to develop vibrational characteristics with crack location and depth of the crack on the working part.**

Keywords—Crack detection, Cantilever Beam, Wavelet Analysis, Finite Element Analysis

I. INTRODUCTION

As we know that in service life structures must have to safely work safely. But as damage occurs, its breakdown period starts to initiate. In a structure Cracks are commonly occurring damage type. Because of its static and dynamic behavior Cracks become hazardous, so crack detection is very important for structural health monitoring applications. From last few years a more effort has been taken for the development of nondestructive testing techniques for detection of crack in a structure or machine component.

The dynamic response a structural member has been affected by a crack or any local defect, resulting in changes of natural frequencies and mode shapes. This property of changing natural frequency and mode shapes used to detect existence of a crack with its location and depth in the structure. Modal data before damage occurs as a baseline data is used for comparative study by many researchers and all subsequent tests are compared to it. Any variation in the modal properties from the baseline data is used to calculate the crack size and location.

The proposed method is based on the analysis of variations observed in the modal parameters due to crack of dynamic system. Mode shape and natural frequency parameters are selected for analysis. Local flexibility is induced in the structures due to crack at its location as a resulting in reduction of modal frequencies. The modal frequencies reduction is depends on crack parameters like its depth, location and number of cracks.

Here in the present work, a cantilever beam of mild steel with a single open transverse crack at various locations and depth is taken for vibration analysis. The aim of the study is to find the effect of crack on the modal parameters like modal frequency and mode shape.

Free vibration finite element analysis of an uncrackedbeam and a series of cracked beams areperformed. Suitable boundary conditions are used to find out naturalfrequencies and mode shapes. Comparative studies areperformed on natural frequencies and mode shapes of cracked and uncracked beam. Effect of crack location and crack depth will be study using two different methods, namely, FFT analysis andwavelet analysis.

Wavelet analysis is also capable to detect the crack in structure. Wavelet transform is applied on the static and dynamics response of a beam. The result obtained by the wavelet analysis may be useful to detect the location of crack and its depth quite efficiently.

II. LITERATURE REVIEW

During the last few years, considerable work for crack detection in a beam has been carried out using vibration analysis in general and wavelet analysis in particular. Below is a brief literature review of the work being carried out related to the crack detection in a beam.

N. Wu, Q. Wang(2011) proposed the experimental studies on damage detection of beam structures with wavelet transform. The crack detection of a beam structure is experimentally studied using the spatial wavelet transform. [1]

Sivasubramanian.K, Umesha.P.K(2012) used the discrete wavelet transform(DWT) to detect, locate and quantify damage in beam elements. A generalized method had proposed to solve damage identification in beams with a single crack. The proposed methodology used only the measurements made in the damaged state of the beam. They used a Damage Intensity Factor (DIF) to quantify damage in all beams with similar edge conditions.[2]

A Messina(2003) Detects damage in beams through digital differentiator filters and continuous wavelet transforms. In this paper, the continuous wavelet transforms (CWTs) are discussed and compared, from a theoretical and numerical point of view, with those methods known as differentiator operators.[3]

1Kaustubha V. Bhinge, 2P. G. Karajagi, 3Swapnil S.Kulkarni(2014) established a systematic approach to study and analyze the crack in cantilever beam. They considered this as the inverse problem of assessing the crack location and crack size. The model of beam is generated using finite element method. Initially natural frequencies for uncracked beam was found out by finite element analysis, then Crack was developed of known dimensions at known location. Plots of the spring stiffness verses crack location was obtained for the three lowest transverse mode using the derived relation. There common intersection point will give the crack location & corresponding stiffness.[5]
Yogesh D. Shinde, Prof. S. D. Katekar(2014) done the vibration analysis of a cantilever beam with single open transverse crack for different crack location and depth using experimental method.for this analysis two cases are considered one with transverse load and other without load.[6]
AbhijitNaik, PawanSonawane(2014) has presented the various vibration based Crack/damage diagnosis techniquesfor a cracked structures. These methods use "finite element analysis techniques, together with experimental results, to detect damage in a fibre reinforced composites, laminated composites and non-composite structures for its vibration analysis. [7]
Yong-Ying Jiang, Bing Li, Zhou-Suo Zhang and Xue-Feng Chen, (2015) presented a hybrid method to detect crack locations using wavelet transform and fractal dimension (FD) for beam structures. Wavelet transform is applied to decompose the mode shapes of beam structures. To improve the sensitivity of location detection, FD estimation method is employed to analyze detailed signal of the mode shape. For comparison purpose, curvature mode shape based method is also used to identify the crack locations.[10]

III METHODOLOGY

Many researchers has been investigated the fluctuation in the dynamic characteristics like natural frequencies, modes of vibration of a cantilever beam due to crack.
The present work deals with the vibration analysis of a cantilever beam made from mild steel with a crack using the wavelet technique. Here we have done the modal analysis of a cracked beam on finite element software ANSYS14.5. The FEM results will validated with experiment using FFT Analyzer. Here experimentation is not done. This will be done soon.Wavelet analysis will use the time-amplitude data obtained from FFT analysis to obtain the time frequency data.

Experimental analysis:

The aim of experimental analysis is to verify the natural frequency changes using FEA results ofuncracked and cracked beam.
Experimentation will performed to measure the natural frequencies of a uniform cantilever beam by modal analysis technique for various combinations of crack parameters.

Specimen specification:

Experimental investigation will use mild steel beam. This will consisting of 10 mild steel beam models with the fixed-free ends. Each beam model will be of cross-sectional area 32mm X 20mm with a length of 500 mm from fixed end. It has the following properties:

Table 1. Geometric and Material Properties

Material	Mild steel
Length	500mm
Width	32mm
Height	20mm
Modulus of elasticity	200GPa
Density	7850kg/m^3
Poisson's ratio	0.3

Experimental setup

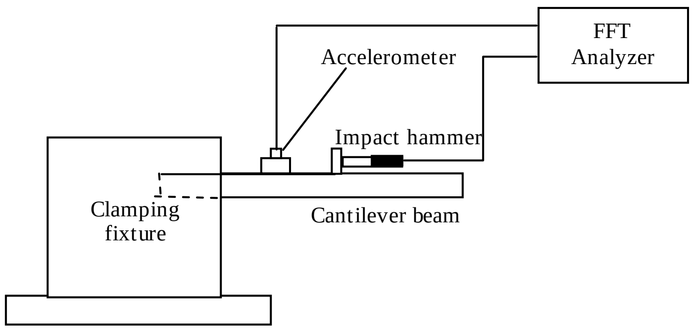
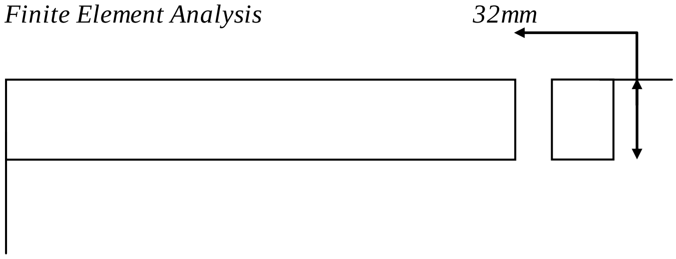


Fig 1. Experimental set up Block diagram

The experimental set up will consisting of the accelerometer, impact hammer, C-clamp, FFT analyzer and a beam as a test specimen etc. as shown in the above block diagram. The whole experimentation is based on the rectangular cross sectional beam at cantilever condition by one end of the beam is fixed and other end is to free. For cantilever condition it is required that the deflection and slope should be zero at the fixed end.

Finite Element Analysis



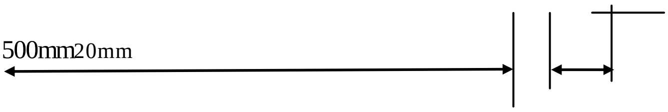


Fig 2. Cantilever beam with dimension

As a numerical analysis technique the finite element method is used for obtaining nearly exact solutions to various engineering problems.
To initiate the analysis, rectangular structure with the dimensions as mentioned in experimental method is modelled without crack & with crack of crack depths 4mm, 8mm, 12mm at 100mm, 200mm, 300mm and 400mm from the fixed end using the "Modelling" module of ANSYS. The material properties like Young's modulus, Poisson's ratio and density of mild steel are as 200GPa, 0.3 and 7850kg/m^3respectively. Using the "Modal Analysis" module of ANSYS the first three natural frequencies of vibration of cracked and without cracked beam are obtained. The distorted shapes corresponding to each mode of vibration are also showed.

Wavelet Analysis

A wavelet is a small wave havingeffectively limited duration having average value of zero and nonzero norm and its energy is concentrated in time. While sine waves as a basis of Fourier analysisdo not have limited duration –they extend from minus to plus infinity. It has characteristics similar to oscillating wavesand it perform simultaneous time and frequency analysis. Wavelet transform is suitable tool for transient, non-stationary or time-varying phenomena.
Wavelets methods combine the structural dynamic parameters such as modal frequencies, modal shape and modal damp, etc. with the determined exponent to detect the damage location and depth.

Wavelet and Gabor analyses are two sorts of JTFA. The continuous wavelet andGabor transforms of a time signal $x(t)$ are defined as

$$CWT(a,b) = <x, \psi_{a,b}> = \frac{1}{\sqrt{|a|}} \int_{-\infty}^{+\infty} x(t) \psi^* \left(\frac{t-b}{a}\right) dt \ldots.. \ (1)$$

$$CGT(b,\omega) = <x, g_{b,\omega}> = \int_{-\infty}^{+\infty} x(t)\, g^*(t-b) e^{-j\omega t} dt \ldots.(2)$$

where the elementary functions are

$$\psi_{a,b} = \frac{1}{\sqrt{a}} \psi\left(\frac{t-b}{a}\right) \qquad \ldots\ldots.(3)$$

$$g_{b,w} = g(t-b) e^{j\omega t} \qquad \ldots\ldots.(4)$$

and * denotes the complex conjugate.

A comparison of Eqs. (1) and (2) shows that the wavelet transform and the Gabor transform are similar except that the elementary functions are different. The wavelet transform uses the dilated and translated version of the mother wavelet $\psi(t)$ to decompose the signal, while the Gabor transform uses the modulated and shifted copy of$g(t)$.

In the CWT, the analyzing function is a wavelet, ψ. The CWT compares the signal to shifted andcompressed or stretched versions of a wavelet.By comparing thesignal to the wavelet at various scales and positions, we obtain a function of two variables. As the wavelet is complex, the CWT is a complex-valued function with scale and position. Also as the signal is real-valued function, the CWT is a real-valued function of scale and position. For a scale parameter, a>0, and position, b, theCWT is
The results of the transform are wavelet coefficient that show how well a wavelet function correlates with the signal analyzed. Hence, sharp transitions in $f(x)$ create wavelet coefficient with large amplitude and this precisely is the basis of the proposed identification method.
The calculation of the WT applying equation (1) and (2) permits the function W(a,b) to be obtained. Normally the function is represented graphically in the scale position plane (with position parameter b as abscissa and scale parameter a as ordinate). W(a,b) is a function with complex values which can be represented by modulus and phase.

IV. RESULTS AND DISCUSSION

The mode shapes and the values of natural frequencies obtained by Finite element analysis i.e. by ANSYS software are discussed as follows for cracked and uncracked beam.

FEA Results for uncracked beam

The lowest three transverse natural frequencies are required input to the analytical model. Hence, out of six mode, mode no
1, mode no 3 and mode no 5 are the important mode for which change in natural frequencies needs to be estimated for different crack locations and crack sizes.

The results of normal mode analysis of uncracked beam are as follows,

Mode No	Frequency (Hz)	Mode Shape
1	65.373	Vertical Bending
2	104.29	Lateral Bending
3	406.69	Vertical Bending
4	641.51	Lateral Bending
5	1125.8	Vertical Bending
6	1305.8	Torsional @ X- axis

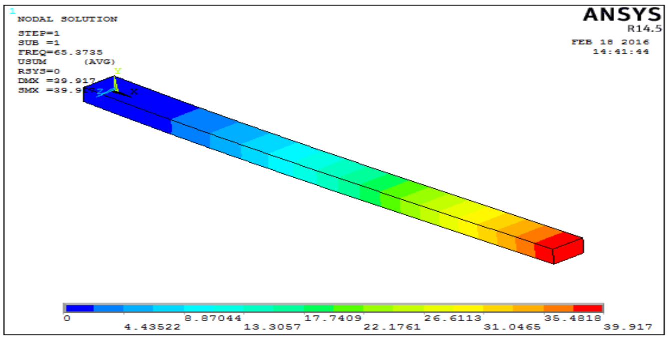


Figure 3: Mode Shape 1- Uncracked Beam

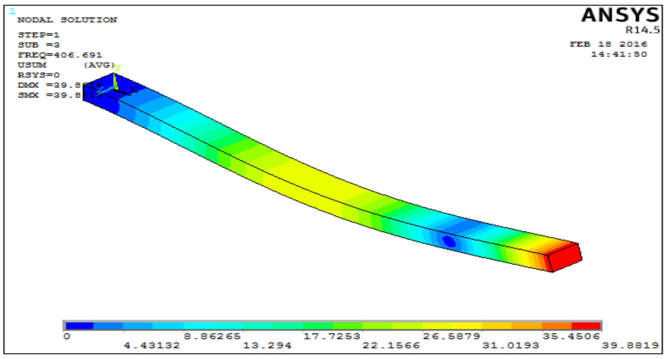


Figure 4: Mode Shape 3- Uncracked Beam

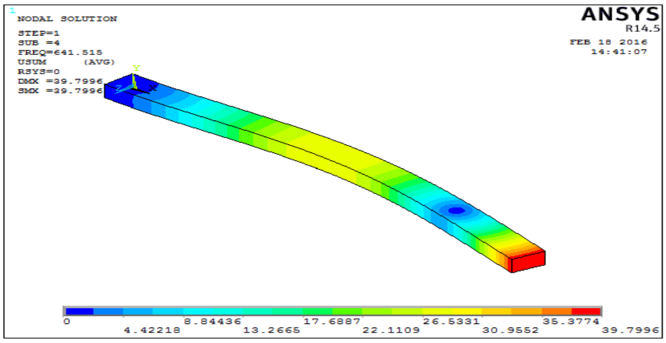


Figure 5: Mode Shape 5- Uncracked Beam

FEA Analysis Result of cracked Beam

Similar sets of analysis are carried out for the cracked beam. Sufficient mesh densities are maintained at crack width and depth to get accurate results.

Below figures indicate the mode shapes of beam with crack at 100mm location from fixed end at the depth of 4mm.

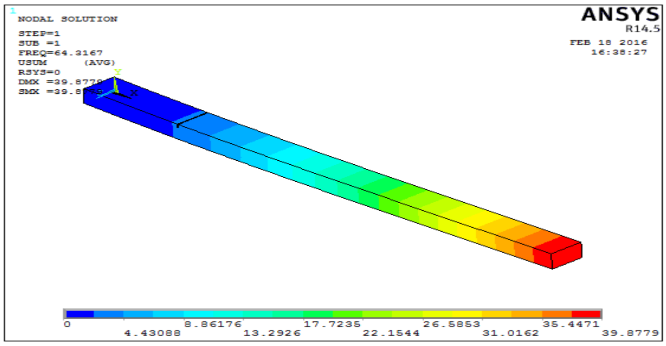


Figure 6: Mode shape-1 for crack at 100mm location from fixed end and at 4mm crack depth

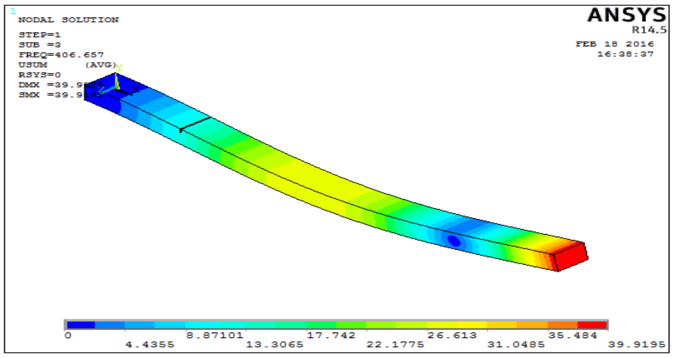


Figure 7: Mode shape-3 for crack at 100mm location from fixed end and at 4mm crack depth

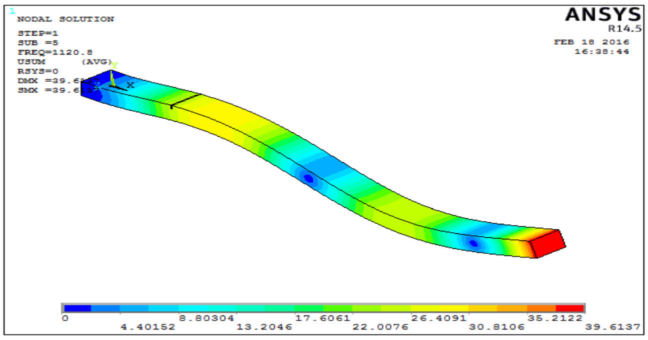


Figure 8: Mode shape-5 for crack at 100mm location from fixed end and at 4mm crack depth

Due to crack natural frequencies are reduced but mode shapes are unaffected. But the phases of mode shapes are changed in some cases. Results of the twelve different cases are tabulated as follows,

Beam No.	Case No.	Crack from fixed end		Natural frequencies from FEA		
		L (mm)	D (mm)	Mode 1	Mode 2	Mode 3

1	Uncracked Beam			65.373	406.69	1125.8
2	1	100	4	64.317	406.66	1120.8
	2	100	8	60.889	406.47	1103.8
	3	100	12	52.976	405.99	1063.8
3	4	200	4	64.943	402.53	1118.8
	5	200	8	63.447	388.88	1096.9
	6	200	12	59.371	358.4	1052.3
4	7	300	4	65.276	401.02	1116.6
	8	300	8	64.899	382.19	1088.3
	9	300	12	63.737	337.97	1033.5
5	10	400	4	65.393	405.55	1113.5
	11	400	8	65.39	401.42	1070.2
	12	400	12	65.324	388.59	957.8

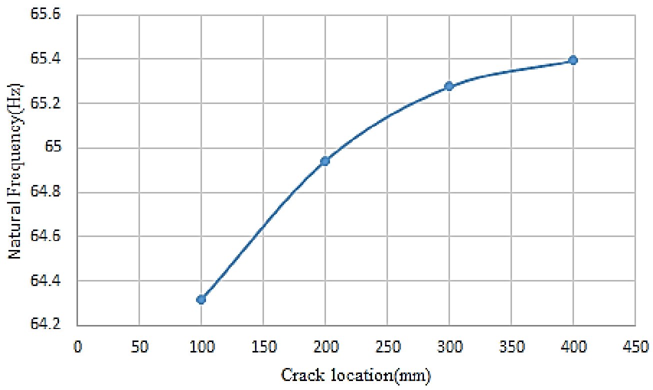


Fig.9 Crack location Vs. first natural frequency for crack at 4mm crack depth

From above Fig., it is observed that, as crack location moves away from fixed end, natural frequency increases gradually.

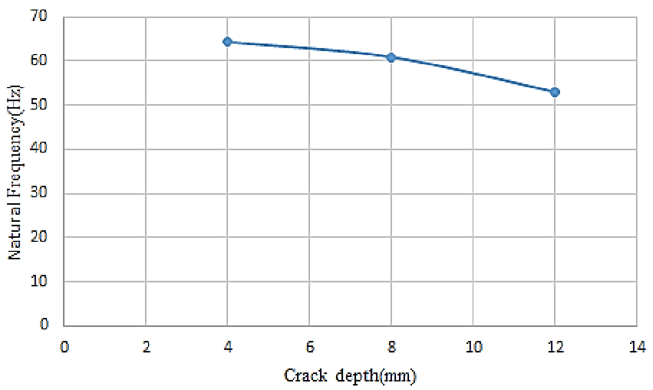


Fig.10 Crack depth Vs. first natural frequency for crack at 100mm distance from fixed end

From above Fig., it is observed that, as crack depth increases natural frequency decreases.

CONCLUSION

It is observed that the presence of crack affects the natural frequency, as a result the natural frequency decreases with the increase in crack depth and it is increases from increase in crack location. So it is concluded that the analysis of change of natural frequencies is effective for vibration analysis of crack in beam like structures. The FEA results will be compared with the experimental results after experimentation.

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