Vibration Analysis of Fixed-Fixed Beam with varying crack depth

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***Abstract*— *Structures under repeating loading conditions undergoes crack or damage in over stressed areas. To ensure the safety of the structures, it is important to know whether their members are free of cracks and should any be present, to detect their location and provide safety measures. Transverse crack is a common occurrence present in Fixed-Fixed Beam. The development of crack in a beam leads to catastrophic failure, which will affect the local stiffness of the beam. Structural Health Monitoring gives the promise for improving the structural performance with excellent results. Condition monitoring by using vibration analysis is a technique used in health monitoring in the damage detection. The objective of this study is to obtain information about the depth of cracks in cracked beams. For this purpose, the Experimental modal test is done to analyse the vibration signals. The natural frequencies at different mode shapes in defect-free and cracked beams were compared. The results of the study suggest determining the depth of cracks by analysing the vibration signals. Experimental results and simulations obtained by the FEA software ANSYS are in good agreement.*

Keywords— *Vibration analysis, FFT analyser, Fixed-Fixed beam, Modal Analysis, FEA.*

I. INTRODUCTION

The presence of cracks in a structural member such as beam causes the reduction in stiffness of the structure which in turn mainly depends on the location and depth of the cracks. These varieties significantly affect the vibrational behaviour of the whole structure. A structure is subjected to various sorts of loadings, for example, pressure, twisting, torsion or consolidated heaps of strain and torsion or bowing and torsion.

The crack assessment methods are needed for the safety of structure. There are different methods for crack detection such as ultrasonic method, magnetic methods but have not proved to be effective in the field due to high level noise which exist in complex structures. Vibration analysis is an important method for Condition Monitoring of structure.

The objective of this study is to analyse the vibration behaviour of Fixed-Fixed beam both experimentally and using FEA software ANSYS subjected to single crack under free vibration cases. Besides this, information about the depth of cracks in cracked Fixed-Fixed beams can be obtained using this technique. Using vibration analysis for early detection of cracks has gained popularity over the years. Dynamic characteristics such as natural frequency and mode shapes of damaged and undamaged materials are different. For this reason, material faults can be detected, especially in beams, which are very important construction elements because of their wide spread usage in construction and machinery. Crack formation due to cycling loads leads to fatigue of the structure and to discontinuities in the interior configuration. Cracks in vibrating components can initiate catastrophic failures. Therefore, there is a need to understand the dynamics of cracked structures. When a structure suffers from damage, its dynamic properties can change. Specifically, crack damage can cause a stiffness reduction, with an inherent reduction in natural frequencies, an increase in modal damping, and a change in the mode shapes. From these changes the crack location can be identified. Since the reduction in natural frequencies can be easily observed, most researchers use this feature. Natural frequency of the beam has also been determined and verified using FEA software ANSYS.

The research work in few decades has been published on the detection and diagnosis of crack developed by using vibration method. The literature survey of some papers given below:

Pankaj Kumar, Tejas Vispute,et al.[1] : Their work is on Modal behaviour of Beam type structures. Beams under study include Cantilever, Simply Supported and Fixed beam. Mode shapes and natural frequencies of these three types of beams are obtained using Theoretical analysis, Simulation in ANSYS and Experiment using FFT analyser. Allan Mann [2]: worked on Cracks in steel structures. This paper discusses the historical background of cracking, explains causes and suggests avoidance measures. M.S.Mhaske, R.S.Shelke[3]: Their research has focused on using different modal parameters like natural frequency, mode shape and damping to detect crack in beams. In this work, simulation is done by utilizing investigation programming ANSYS to discover the adjustment in regular frequencies and in addition mode shapes for the defective and uncracked cantilever and fixed-fixed beam. The position, depth proportion, orientation and number of splits are incredibly impact the dynamic reaction of the structure. Priyanka P. Gangurde , S.N.Shelke, R.S.Pawar.[4]: Their work is on the natural frequency of cracked and uncracked beam having one end fixed and other is simply supported is investigated numerically by using ANSYS software. The cracked beam having triangular crack of depth 2 mm. Luay S. Al-Ansari , Muhannad Al-Waily , Ali M. H.Yusif Al-Hajjar[5]: Their research is on the natural frequency of a cracked simply supported beam (the crack is in many places and in different depths) is investigated analytically ,experimentally and numerically by ANSYS program, and the results are compared. An examination made between systematic outcomes from ANSYS with experimental comes about, where the greatest error rate is around (7.2 %). Mr. Gade Ganesh G, Prof. Mhaske M. S.[6]: They had discussed the crack detection of cantilever beam using the various vibration based Crack/damage diagnosis techniques presented by various researchers for cracked structures. V. D. Jadhav et al.[7]: Their work says that , a systematic approach to study and analyse the crack in cantilever beam is established . The review depends on estimation of characteristic recurrence, a worldwide parameter that can be effectively measured anytime helpfully on the structure. Khalate A.B., Bhagwat V.B.[8]: They had carried out large amount of research on the detection of crack using the vibration based techniques also other methods are developed to find the crack locations by researchers. Tejas Kishor Patil , Prof. Ajeet B. Bhane.[9]: Their review work is on the crack detection procedure by using vibration and wavelet technique is discussed . Split changes over the straight issue to nonlinear issue and affects the natural frequency. So in this paper they have talked about the different techniques to discover defects on beam like destructive testing and non-destructive testing. Irshad.A.Khan, Dayal.R.Parhi[10]: They had made Finite Element Analysis of Double Cracked Beam and its Experimental Validation .

In above literature review many researchers used various methods for crack diagnosis of steel structure but vibration analysis method is most common and widely used method. Many researchers have worked on the Theoretical analysis, Simulation in ANSYS and Experiment using FFT analyser to obtain mode shapes and natural frequencies of vibrating beams.

II. EXPERIMENTAL SETUP

An experimental set up is designed & developed for measuring vibration response of the fixed-fixed beam by using FFT analyser. The artificial 'V' notch (transverse crack) is developed on beam by wire cut EDM method. A piezoelectric accelerometer of FFT analyser is placed on the beam to measure the vibration. The modal test is performed on fixed-fixed beam and on the beam having 'V' notch crack. The dynamic characteristics of beam are obtained for healthy and defective beam with varying crack depth.

The numbers of specimens of beam used for experimentation are 4. Out of 4 specimens one is healthy and remaining specimens are having cracks with different crack depth. The crack sizes used are- 1mm x 1mm, 1mm x 2 mm, 1mm x 3mm. The crack position is at centre of fixed fixed beam i.e. at 300 mm. Experimental setup is as shown in Figure I and The properties of Fixed-Fixed M.S. Beam are given in Table I.

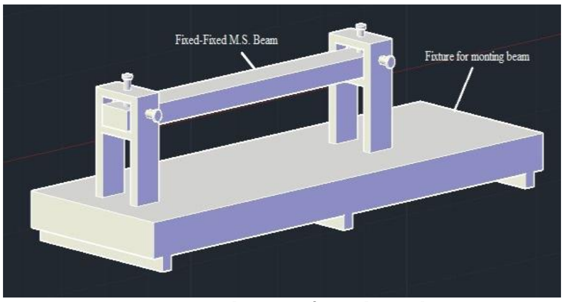

Fig. I: Experimental Setup of Fixed-Fixed M.S. Beam

Table I: Properties of Fixed-Fixed M.S. Beam

Parameters	Symbol	Value
Material	M.S.	Mild Steel
Total Length	L	0.6 m
Width	B	0.040 m
Thickness	T	0.015 m
Young's Modulus	E	2.1 x 109 N/m^2
Mass Density	ρ	7860 kg/m^3
Poisson's ratio	μ	0.3

Readings are taken on experimental setup by performing modal analysis using FFT analyser and following of graphs are observed.

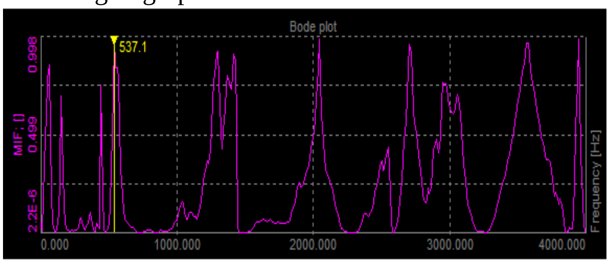

Fig. II (a): First natural frequency for healthy beam

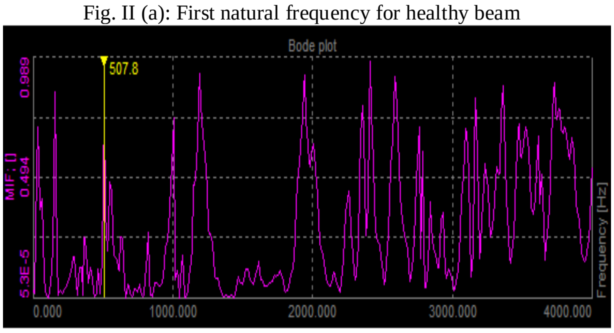

Fig. II (b): First natural frequency for crack size 1x1 mm^2 beam

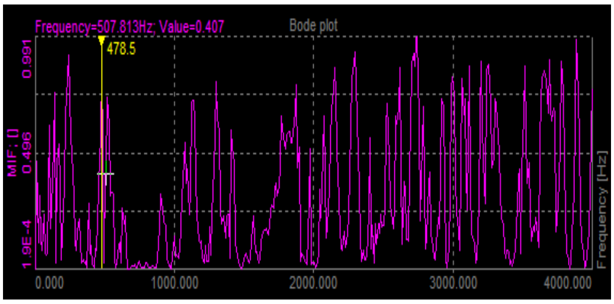

Fig. II (c): First natural frequency for crack size 1x2 mm^2 beam

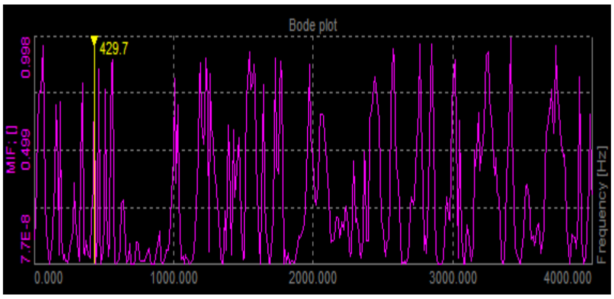

Fig. II (d): First natural frequency for crack size 1x3 mm^2 beam

Above are signals obtained from FFT analyser by modal analysis. These graphs are MIF vs frequency. MIF closer to value 1 represents natural frequency. In Fig. II (a) value of first natural frequency is 537.1 Hz and in next consecative Fig.II (b), (C) and (d) this first natural frequency is decreasing. Simillarly first five natural frequencies are choosen where the modeshape changes for healthy and cracked beams.

III. FEA SIMULATION USING ANSYS

FEA software i.e. ANSYS is used for the analysis purpose. ANSYS is engineering simulation software based on the finite element method and is capable of performing static (stress) analysis, thermal analysis, modal analysis, frequency response analysis, transient simulation and also coupled field analysis. For present study, modal analysis is done for two cases i.e. Fixed-Fixed healthy beam and Fixed-Fixed cracked beams. The dimensions and properties of beam used for analysis are as in above Table I. Modelling and simulation is done in ANSYS 14.5 workbench.

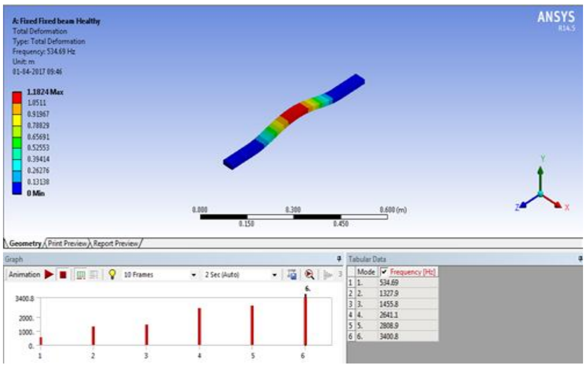

Fig. III (a): First mode shape and natural frequency for healthy beam

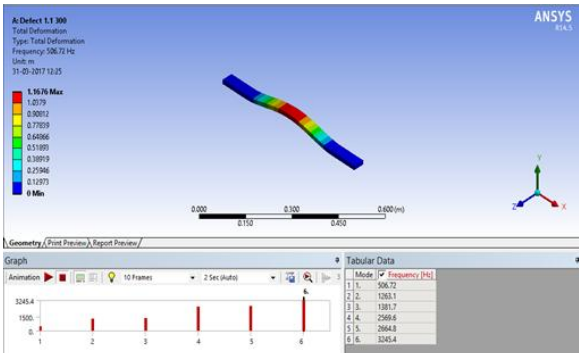

Fig. III (b): First mode shape and natural frequency for crack size 1x1 mm^2 beam

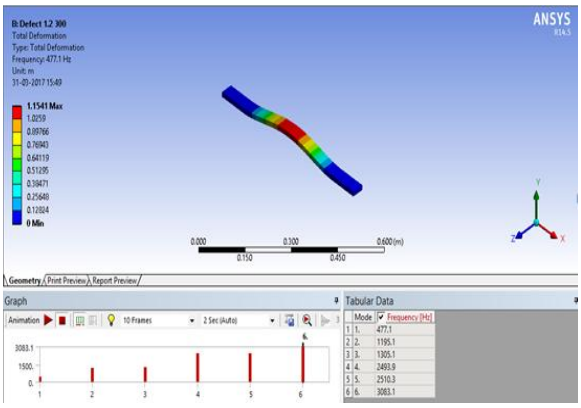

Fig. III (c): First mode shape and natural frequency for crack size 1x2 mm^2 beam

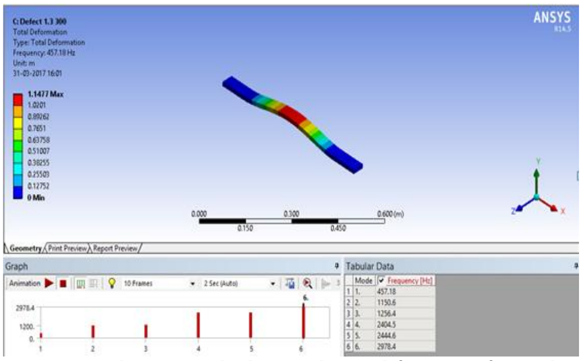

Fig. III (d): First mode shape and natural frequency for crack size 1x3 mm^2 beam

Above are mode shape and natural frequencies obtained from ANSYS by modal analysis. In Fig. III (a) value of first natural frequency is 534.69 Hz and in next consecative Fig.III (b), (C) and (d) this first natural frequency is decreasing. Simillarly first five natural frequencies and respective mode shapes are also found for healthy and cracked beams.

IV. RESULTS AND DISCUSSION.

Results of experimentation and ANSYS simulation are obtained. The effect of crack depth on natural frequencies and mode shapes of fixed-fixed beam is determined by using modal analysis.

By performing modal test experimentally using FFT analyser readings are taken and following results are obtained for healthy and cracked beams. Natural frequencies at different mode shapes for healthy and cracked beams are tabulated in Table II-

Table II: Natural frequencies (Hz) at different mode shapes experimentally

Mode shape	Heathy beam	Crack 1x1 mm2	Crack 1x2 mm2	Crack 1x3 mm2
1	537.1	507.8	478.5	459
2	1367.2	1269.5	1250	1191.4
3	1435.5	1386.7	1298.8	1259.8
4	2705.1	2597.5	2519.5	2441.4
5	2841.8	2744.1	2587.9	2460.9

From above readings it is observed that for healthy beam the first natural frequency is 537.1 Hz and for cracked beams the first natural frequency decreases as the crack size goes on increasing. Same trend is observed for other mode shapes.

For better understanding results are also plotted in graphical format as shown in figure II

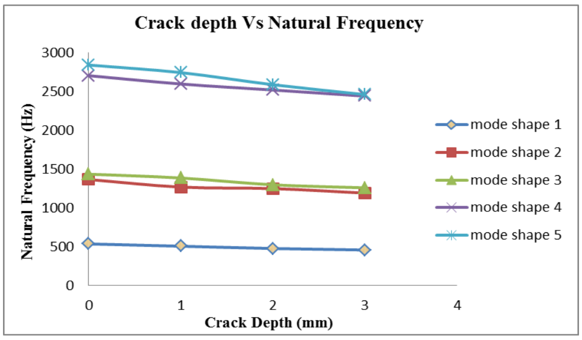

Figure II: Crack depth (mm) Vs Natural frequency (Hz) for first five mode shapes experimentally

By performing modal test analytically using FEA i.e. ANSYS following results are obtained for healthy and cracked beams. Natural frequencies at different mode shapes for healthy and cracked beams are tabulated in Table III-

Table III: Natural frequencies (Hz) at different mode shapes by ANSYS

Mode shape	Heathy beam	Crack 1x1 mm2	Crack 1x2 mm2	Crack 1x3 mm2
1	534.69	506.72	477.1	457.18
2	1327.9	1263.1	1195.1	1150.6
3	1455.8	1381.7	1305.1	1256.4
4	2641.1	2569.6	2493.9	2404.5
5	2808.9	2664.8	2510.3	2444.6

From above readings it is observed that for healthy beam the first natural frequency is 534.69 Hz and for cracked beams the first natural frequency decreases as the crack size goes on increasing. Same trend is observed for other mode shapes.

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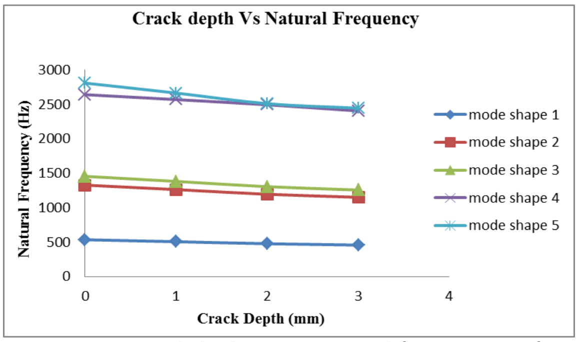

Figure III: Crack depth (mm) Vs Natural frequency (Hz) for first five mode shapes by ANSYS.

Results obtained from the FEA and experiment is compared. Results show that Experimental and FEA results are in good agreement. Frequencies of uncracked& cracked beam with different configurations (depth) for first, second, third, fourth and fifth mode of vibration with their percentage variation in Experimental and FEA results is listed below:

Table IV: Percentage variation in Natural frequencies (Hz) at different mode shapes of Experimental and FEA results

Mode Shape	Experimental	FEA	Percentage variation (%)
Healthy Beam			
1	537.1	534.69	0.44
2	1367.2	1327.9	2.87
3	1435.5	1455.8	-1.41
4	2705.1	2641.1	2.36
5	2841.8	2808.9	1.15
Crack size 1x1 mm2			
1	507.8	506.72	0.21
2	1269.5	1263.1	0.50
3	1386.7	1381.7	0.36
4	2597.5	2569.6	1.07
5	2744.1	2664.8	2.88
Crack size 1x2 mm2			
1	478.5	477.1	0.29
2	1250	1195.1	4.39
3	1298.8	1305.1	-0.48
4	2519.5	2493.9	1.016
5	2587.9	2510.3	2.99
Crack size 1x3 mm2			
1	459	457.18	0.39
2	1191.4	1150.6	3.42
3	1259.8	1256.4	0.26
4	2441.4	2404.5	1.51
5	2460.9	2444.6	0.66

Above table IV shows, first five natural frequencies percentage error for healthy and cracked fixed-fixed beam. It is observed that very small percentage errors are there in experimental and FEA results.

V. CONCLUSION.

1) It has been observed that the changes in natural frequencies are the important parameter that determines crack size.
2) Natural frequency is affected by depth of crack, increase in depth of crack decreases its natural frequency.
3) Experimental and FEA results are in good agreement.

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