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Experimental Investigation of Crack detection of Cantilever Beam-FFTAnalyser

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Abstract:*Cracks in the machine changes dynamic characteristics like reduction of model frequency. It changes the stiffness of the structure. Due to these cracks, fatigue occurs in the machine, it get failure. The change in dynamic behavior in structure helps to identify the crack parameters like crack location and size. In this study Experimental Modal Analysis (EMA) was performed on cracked beams and a healthy beam. The first three natural frequencies were considered as a basic criterion for crack detection. By evaluating first three natural frequencies using vibration measurements, the crack curves equivalent to stiffness were plotted and the three curves intersection in the plotshow the crack location and size. In this Experiment, test was performed on the cantilever beams with a single crack using FFT set up. These cracks were located at different position and having varying sizes. The Calculated natural frequencies were compared with natural frequency obtained by ANSYS software. The result obtained from experimentation and FEA analysis was good.*

Keywords:*Cracks, cantilever beams, natural frequency, FFT analyzer*

I. Introduction

Mechanical elements in service life subjected to combined or separate effects of the dynamic load, temperature, corrosive medium and other type of damages. When any mechanical element or component is subjected to repeated load, then there will be possible of fatigue failure. The mode of fatigue failure of a component is nothing but the cracks develop on their surface. The importance of an early detection of cracks appears to be crucial for both safety and economic reasons because fatigue cracks are potential sources of catastrophic structural failure. This method of crack detection on cantilever beam is totally depends on changes in vibration parameter of the component means changes in natural frequencies. NDT methods are regularly used for detection of cracks in the machine and structural components. NDT techniques require that the location of the destruction is known a priori and that the portion of the element being inspected is readily available. In order to detect a crack by this method, the whole component requires to scan. Their implementation becomes inefficient for long beams and pipelines which are widely used in power plants, railway tracks, long pipelines, etc. This makes the process time consuming. The drawbacks of traditional localized NDT methods have motivated the development of global vibration based damage detection methods.

Therefore, there is a need to understand the dynamics of cracked elements. When a structure or elements undergoes from damage, its dynamic properties can change. Specifically, crack damage cause a stiffness reduction, with an inherent reduction in natural frequencies, as well as increase in modal damping and a change the mode shapes. From these changes the crack position and magnitude can be identified. Since the reduction in natural frequencies can be easily observed, many researchers use this feature. The choice of using the natural frequency as a basis in the development of NDE (Nondestructive evaluation) is most attractive. Because of this, the natural frequencies of a beam measured from one single location on the same beam, thus offer scope for the development of a fast NDE technique.Considerable efforts being made to make the method useful in practice. It results in a considerable saving in time, labor and cost for long beam like components, such as rails, pipelines, etc. Natural frequency of the beam has also been determined and verified experimentally.

II. Literature Review

Swamidas et al. [1] Reported in his experimental investigations of the effects of cracks and damages on the integrity of structures, with a view to detect, quantify, and determine their extents and locations. Two sets of aluminum beams were used for this experimental study. Each set consisted of seven beams, the first set was fixed ends, and the second set was simply supported. The Cracks initiated at seven different locations from one end to the other end (along the length of the beam) for each set, with crack depth ratio ranging from 0.1d to 0.7d (d is the beam depth) in steps of 0.1, at each crack location. Measurement of the acceleration frequency responses at seven different points on each beam model is taken using a dual channel frequency analyzer. The damage detection systems used in this study depended on the changes in the first three natural frequencies and the corresponding amplitude of the measured acceleration frequency response functions.Deokar et. Al. [2] has found on different beams which were cracked at different location and different depth. They were doing vibration analysis on these beams and concluded that the natural frequency of the component has decreased as crack depth increase at various locations.A most of the work conducted on natural frequency and mode shape based damage detection method.Some of the approaches used the methods which are iterative and requires an initial guess. As a result the error in the solution is remarkably influenced by the initial guess. Most of the researchers studied the effect of a single crack on the dynamics of structures. A lot of studies using natural frequency as a damage detection tool are being carried out in the vibration based damage detection field. Recently, a new vibration based damage detection technique used by.Rao, Govardhana (2009) UK [3]. In Vibration Analysis of Beam analyze the vibration characteristics of beams. All real physical structures, when subjected to loads, behave dynamically, in addition to this inertia force, from Newton's second law, are equal to the mass times the acceleration. If the loads or displacements are applied very slowly, the inertia force is neglected and a static load analysis can be justified. Hence, dynamic analysis leads the static analysis. Many developments have been carried out in order to try to find the effects produced by dynamic loading. Examples of structures where it is particularly important to consider the dynamic loading effects are the construction of the buildings, long bridges under wind-load conditions and buildings in the earthquake zones, etc.Vibration parameters of a component changed due to development of crack, that has it resulte in a reduction in stiffness and increasing damping.These changes are mode dependent, it becomes possible to estimate the location and size of crack by measuring changes in vibration parameters. The vibration parameters are structural parameters like mass, stiffness and flexibility or modal parameters such as natural frequencies, modal damping values and mode shapes. Crack detection using vibration methods requires one parameter as a basis for crack detection [B.P.Nandwana and S.K.Maiti-1997] G.M.Owolabi (2003) reported on his experimental investigation of the effects of cracks and damages on the integrity of structures, with a view to detect, quantify, and determine their extents and locations. Two sets of aluminum beam used for the experimental study. Each set consisted of seven beams, the first set was fixed ends, and the second set was simply supportedCracks were initiated at seven different locations from one end to the other end (along the length of the beam) for each set, with crack depth ratios ranging from 0.1d to 0.7d (d -the beam depth) in steps of 0.1, at each crack location. Measurements of the acceleration frequency responses at seven different points on each beam model taken three natural frequencies and the corresponding amplitudes of the measured acceleration frequency response functions using a dual channel frequency analyzer. The damage detection schemes used in this study depended on the measured changes in the first three natural frequencies.

III. Experimental Set-Up And Procedure

Experimental Model Description

Mild steel beams used for the experimental investigation. The set consisted of 10 beam models with the fixed-free ends. Each beam model, cross-sectional area 11mm X 11mm with a length of 300 mm from fixed end. The following material properties: Young's modulus, E= 210GPa, density, =7850Kg/m3, the Poisson ratio, μ=0. 30

Fig1. Experimental set-up

Experimental Procedure

The fixed–free beam model clamped at one end, in at the vice. Then the beam was excited with an impact hammer. The first three natural frequencies of the without crack beam were measured. Then, cracks were generated to the desired depth using a wire cut EDM. The crack remained open during dynamic testing. Total 10 beam models are tested with cracks at different locations, starting from a location near to fixed end. The crack varied from 1.5mm to 6mm at each position. Each model was excited by an impact hammer. This served as the input to the system. It is to be noted that the model was excited at a point, which was a few millimeters away from the center of the model. This was done to avoid exciting the beam at a nodal point (of a mode), since the beam would not respond for that mode at that point. The dynamic responses of the beam are measured by using light, accelerometer placed on the model as indicated in Fig. The response measurements are acquired, one at a time, using the FFT analyzer.

IV. Results And Discussions

Experiment Methodology

For cantilever beam has an infinite degree of freedom, therefore it may an infinite number of natural frequencies. By observing the graph or data sheet we can easily calculate the natural frequency for different mode shapes. But we are interested in only first three natural frequencies therefore we determined the first 3 natural frequencies only. By observing the peaks in graphs we can determine the natural frequency. Each peak denotes one natural frequency.For first three peaks we measure respective natural frequencies.Following graph shows the frequency response curve for standard specimen. By observing the graph, we determined first 3 natural frequencies. The same procedure is applied for determining the natural frequencies of cracked beam. The Graph is for specimen having crack depth 4 mm having location 120 mm from fixed end.The experimental results were tabulated, in the form of frequency ratio (ratio of the natural frequency of the cracked beam to that of the un-cracked beam) versus the crack depth for various crack locations. The tables I–III show the variation of the frequency ratio as a function of the crack depth and crack location for beams with fixed-free ends.

Modal Analysis Result

From a modal analysis of a specimen of cracked and un-cracked beam the natural frequencies determined and it is tabulated in the table of varying crack location from 30 mm to 250 mm against crack depth from 2mm to 6 mm for each mode separately.Fig shows the results of modal analysis for standard specimen and specimen having a crack at the 120 mm location of depth 4mm

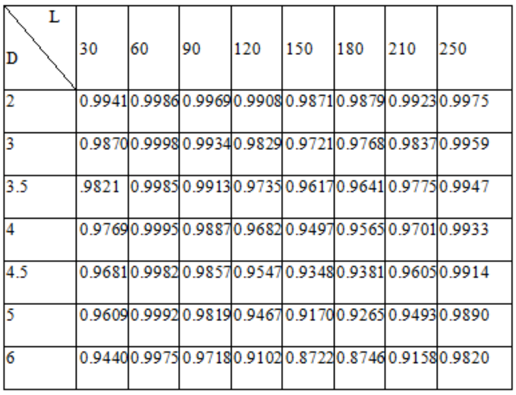
For Standard Specimen natural frequencies are:-
For 1st MODE = 3.2315Hz
For 2nd MODE=20.127Hz
For 3rd MODE=55.811Hz

TABLE I Frequency for First Mode

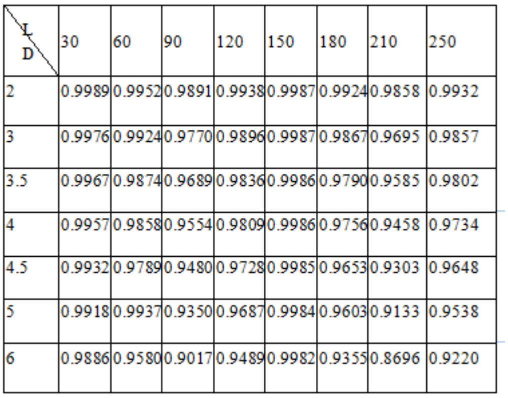
L D	30	60	90	120	150	180	210	250
2	0.9837	0.9864	0.9904	0.9937	0.9960	0.9975	0.9984	0.9989
3	.9633	0.9735	0.9797	0.9890	0.9924	0.9973	0.9978	0.9989
3.5	.9484	0.9597	0.9722	0.9824	0.9898	0.9947	0.9975	0.9989
4	0.9322	0.9506	0.9631	0.9791	0.9866	0.9948	0.9969	0.9989
4.5	0.9056	0.9304	0.9519	0.9694	0.9825	0.9913	0.9963	0.9989
5	0.8811	0.9161	0.9382	0.9637	0.9773	0.9907	0.9955	0.9988
6	0.8173	0.8599	0.8996	0.9348	0.9627	0.9817	0.9929	0.9987

In determining the location and crack depth it observes that, the each frequency of each mode for each location and for each depth by dividing to it by respective mode frequencies was normalized. These results are shown in the table 1, 2 and 3

TABLE II Frequency for Second Mode**TABLE III** Frequency for Third Mode



L D	30	60	90	120	150	180	210	250
2	0.9941	0.9986	0.9969	0.9908	0.9871	0.9879	0.9923	0.9975
3	0.9870	0.9998	0.9934	0.9829	0.9721	0.9768	0.9837	0.9959
3.5	.9821	0.9985	0.9913	0.9735	0.9617	0.9641	0.9775	0.9947
4	0.9769	0.9995	0.9887	0.9682	0.9497	0.9565	0.9701	0.9933
4.5	0.9681	0.9982	0.9857	0.9547	0.9348	0.9381	0.9605	0.9914
5	0.9609	0.9992	0.9819	0.9467	0.9170	0.9265	0.9493	0.9890
6	0.9440	0.9975	0.9718	0.9102	0.8722	0.8746	0.9158	0.9820



L D	30	60	90	120	150	180	210	250
2	0.9989	0.9952	0.9891	0.9938	0.9987	0.9924	0.9858	0.9932
3	0.9976	0.9924	0.9770	0.9896	0.9987	0.9867	0.9695	0.9857
3.5	0.9967	0.9874	0.9689	0.9836	0.9986	0.9790	0.9585	0.9802
4	0.9957	0.9858	0.9554	0.9809	0.9986	0.9756	0.9458	0.9734
4.5	0.9932	0.9789	0.9480	0.9728	0.9985	0.9653	0.9303	0.9648
5	0.9918	0.9937	0.9350	0.9687	0.9984	0.9603	0.9133	0.9538
6	0.9886	0.9580	0.9017	0.9489	0.9982	0.9355	0.8696	0.9220

From the table it is analyzed that, the effect of crack depth on natural frequency. Fig.2 the graphs shows the natural frequency decreases as depth increases, also analyzed that, the effect of crack depth on natural frequency for different location and plotted on a graph for each mode.

From the graph of 1st mode, it is observed that, for crack location 30 mm the variation of frequency is larger and decreases as depth increase. While for 250 mm location crack, it almost remains constant for all crack depth.

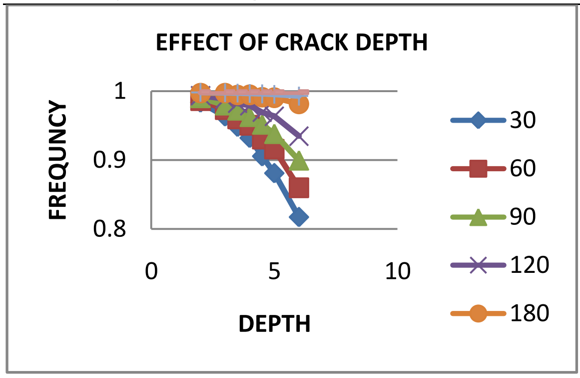


Fig .2. Fundamental natural frequency ratio in terms of crack depth for various crack positions (x=30, 60, 90, 120, 180, 210, 250 mm) for 1st mode

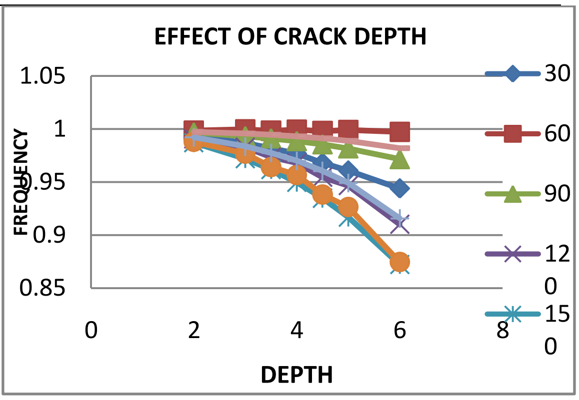


Fig. 3. Second natural frequency ratio in terms of crack depth for various crack positions (x=30, 60, 90,120,180,210,250mm) for 2nd mode

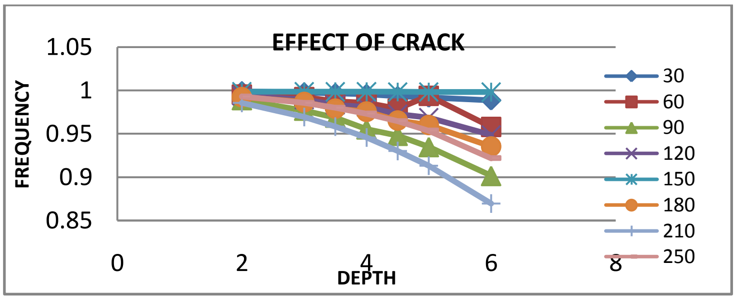


Fig .4. Third natural frequency ratio in terms of crack depth for variousCrack positions (x=30, 60,90,120,180,210,250mm) for3rd mode

Crack depth and location identification:

With the help of MINITAB software we plot contour lines. Contour line is a graph of depth verses location for a particular natural frequency, in which crack location is on the X-axis and crack depth is on the Y-axis. We have inputted all data of normalized natural frequencies for all crack depth and location for each mode separately. Then by giving input of a natural frequency of each mode we plotted contour lines. The three contour lines gave justone common point of intersection, which indicates the crack location and the crack depth. Since the frequencies depend on the crack depth and location, these values can be uniquely determined by the solution of a function having solutions one order higher (in this case, three) than the number of unknowns (in this case, too, namely crack depth and location) to be determined. This is the reason for the requirement of three modes. If there were more parameters that influence the response (besides the crack depth and location), then one will require more modes to identify the unknown crack depth and crack location. The selected a specimen having crack depth 4 mm at crack location 120mm. To prove this we have taken normalized frequencies of above selected specimen for each mode i.e.0.9791, 0.9682 and 0.9809. For each normalized frequency we obtained contour lines.

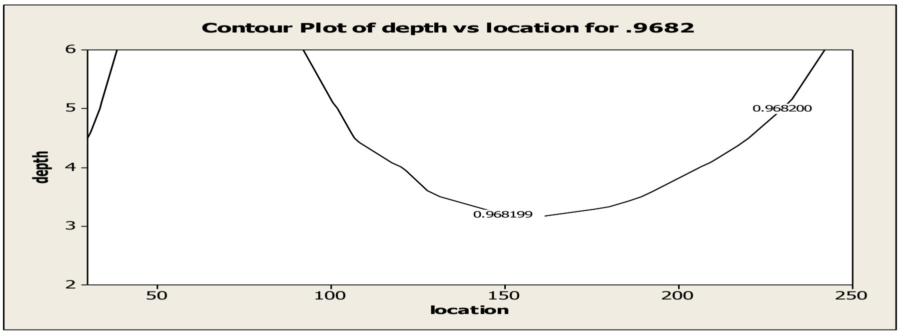


Fig.5. Frequency contour plot of mode-1 for normalized frequency 0.9791

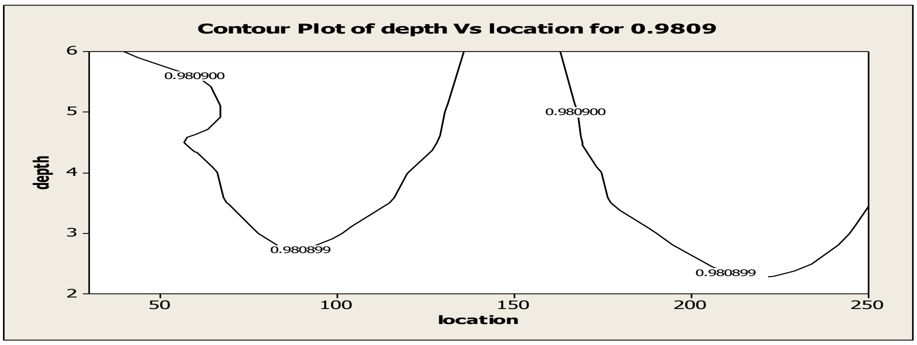


Fig.6. Frequency contour plot of mode-2 for normalized frequency 0.9682

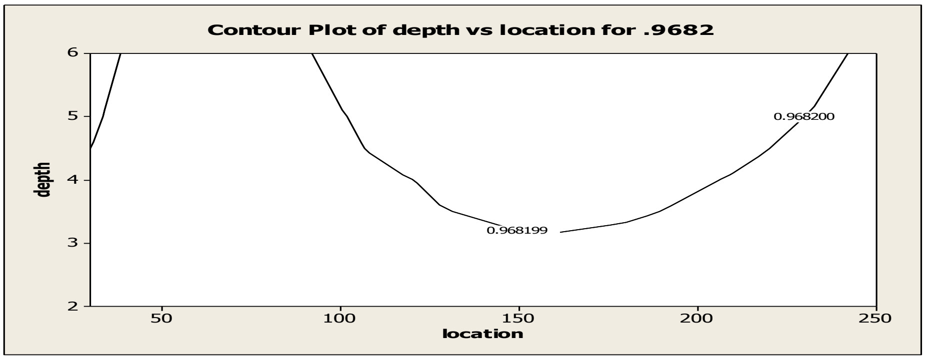


Fig.7. Frequency contour plot of mode-3 for normalized frequency 0.9809

Finally, submerged all these 3 contour lines on a single plot of the crack location verses crack depth to obtain the required crack location and crack depth. All these 3 contour lines for each mode coincide at a particular point. This point on X-axis gives required crack location and Y-axis intercept gives crack depth. For our example, it exactly coincides to 120 mm on X-axis and 4 mm on Y-axis. Hence it is proved accurate.

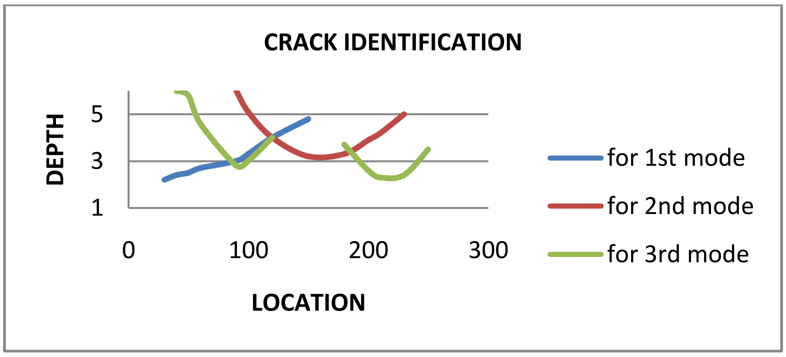


Fig.8. Crack identification technique by using frequency contours of the first three modes of the beam (mode 1, normalized frequency (0.9682); mode 2, normalized frequency (0.9791); and 3: mode 3, normalized frequency (0.9809).

V. Conclusion

From the results it is evident that the vibration behavior of the beams is very sensitive to the crack location, depth and mode number. A simple method for predicting the location and depth of the crack based on changes in the natural frequencies of the beam is checked. This method is feasible due to the fact that under robust test and measurement conditions, the measured parameter of frequencies are getting same values, it means that the values for frequency is within a tolerance level, also the similar beams are tested and responses measured. The experimental result of crack location and crack depth is very close to the actual crack size and location of the corresponding test specimen.

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