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Experimental Investigation of Crack in Brass Cantilever Beam Using Natural Frequency as Basic Criteria

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ABSTRACT

The effects of various parameters like crack location, crack depth on the changes in Natural Frequencies of the beam is studied. An experimental setup is designed in which a brass cantilever beam with cracks is excited by a power exciter and accelerometer attached to the beam provides the response. The experimental results of frequencies can be obtained from digital storage oscilloscope (DSO). It is found that, presence of crack in a beam decreases the natural frequency which is more pronounced when the crack is near the fixed support than the free end and the crack depth is more. Then the inverse problem is introduced, as the detection of cracks is very difficult through naked eye and the non-destructive method of detecting cracks which are used is very much costly. Here the first three Natural Frequencies are used to detect the crack depth and location of crack in the beam. The first three natural frequencies were considered as basic criterion for crack detection.

Cracks in structural members lead to local changes in their stiffness, flexibility and consequently their static and dynamic behaviour is affected. The influence of cracks on dynamic characteristics like natural frequencies, modes of vibration of structures has been the subject of many investigations. The flexibility matrix method is used to calculate the stiffness of the cracked beam here. The effects of various parameters like crack location, crack depth on the changes in Natural Frequencies of the beam is studied. It is found that, presence of crack in a beam decreases the natural frequency which is more pronounced when the crack is near the fixed support than the free end and the crack depth is more. Then the inverse problem is introduced, as the detection of cracks is very difficult through naked eye and the non-destructive method of detecting cracks which are used is very much costly. Here the first three Natural Frequencies are used to detect the crack depth and location of crack in the beam. It is found that the method is capable of predicting the crack location and depth for cracks. This work may be useful for improving online conditioning and monitoring of machine components and integrity assessment of the structures.

INTRODUCTION

The presence of crack in structure changes its dynamic characteristics. The change is characterized by change in modal parameters like modal frequencies, modal value and mode shapes associated with each modal frequency. Mechanical structures in service life are subjected to combined or separate effects of the dynamic load, temperature, corrosive medium and other type of damages. The importance of an early detection of cracks appears to be crucial for both safety and economic reasons because fatigue cracks are potential source of catastrophic structural failure. Damage identification methods are mainly based upon the shifts in natural frequencies or changes in mode shapes. NDT methods are often employed for detection of cracks in machine and structural components. All of these NDT techniques require that the location of the damage is known a priori and that the portion of the structure being inspected is readily accessible. In order to detect a crack by this method, the whole component requires scanning. Their adoption becomes uneconomical for long beams and pipelines which are widely used in power plants, railway tracks, long pipelines etc. This makes the process tedious and time consuming. The drawbacks of traditional localized NDT methods have motivated development of global vibration based damage detection methods. It is well known that when a crack develops in a component it leads to changes in its vibration parameters, e.g. a reduction in the stiffness and increase in the damping and a reduction in the natural frequency. They may enable determination of location and size of a crack from the vibration data collected from a single or at most a few, points on the component. These changes are mode dependent. Hence it may be possible to estimate the location and size of the crack by measuring the changes in vibration parameters. The technique using changes in natural frequencies as the crack detection criterion has received considerable attention. The choice of using the natural frequency as a basis in the development of NDE (Non destructive evaluation) is most attractive. This is due to the fact that the natural frequencies of a beam can be measured from one single location on the beam, thus offering scope for the development of a fast and global NDE technique. Considerable efforts being made to make the method useful in practice. It results in a considerable saving in time, labour and cost for long beam like components, such as rails, pipelines, etc. A system of classification for damage-identification methods, as presented by Rytter (1993), defines four levels of damage identification, as follows:

- Level 1: Determination that damage is present in the structure
- Level 2: Determination of the geometric location of the damage
- Level 3: Quantification of the severity of the damage
- Level 4: Prediction of the remaining service life of the structure

The literature in this review can be classified mostly as Level 1, Level 2, or Level 3 methods because these levels are most often related directly to structural dynamics testing and modelling issues. Level 4 predictions are generally categorized with the fields of fracture mechanics, fatigue life analysis, or structural design assessment and, as such, is not addressed in the structural vibration or modal analysis literature.

LITERATURE REVIEW

For the literature review primarily various journals selected. The brief reviews of these papers are as follow.

J N Mahto et. al.[1] it was observed that the dynamic behaviour of a structure changes due to the presence of a crack. Analysis of such phenomena is useful for fault diagnosis and the detection of cracks in structures. An experimental setup is designed in which an aluminium cantilever beam with cracks is excited by a power exciter and accelerometer attached to the beam provides the response. The cracks are assumed to be open to avoid non-linearity. The effects of crack and positions on the fundamental frequencies of slender cantilever beams with edge cracks are investigated experimentally.

Kisa et. al.[2] The vibration characteristics of a cracked Timoshenko beam are analysed. The study integrates the FEM and component mode synthesis. The beam divided into two components related by a flexibility matrix which incorporates the interaction forces. The forces were derived from fracture mechanics expressions as the inverse of the compliance matrix is calculated using stress intensity factors and strain energy release rate expressions.

J N Mahto[3] were investigated, efforts have been made to find effect material on cantilever beam under vibration. Specimens were modelled and analysed using FEM package. Analysis was done by setting maximum frequency value as 60 Hz. It was found that a cantilever beam attains different modes of vibration. For mode-I of vibration the value of 'strain energy' and 'deflection of beam' along the cantilever beam from fixed end towards free end were obtained and tabulated. Aluminium, Copper and Steel were selected as three different materials for analysis. Numerical data obtained from FEM analysis were further tabulated and plotted for further useful analysis. Using numerical techniques, polynomial equations were also developed so that intermediate data can be determined.

J.K.SINHA et al. [4] have developed a simplified approach to model cracks in beams undergoing transverse vibration which uses Euler-Bernoulli beam elements with modifications of flexibility near the cracks and this developed model was interns used to estimate the crack size and location

H.NAHVI et al. [5] have proposed an approach to identify crack location and depth in a cantilever open cracked based on measured frequencies and mode shapes of the beam. The crack is identified by plotting contours of normalized frequency with normalized crack depth and location and by finding the intersection of contours with constant modal frequency planes.

EXPERIMENTAL ANALYSIS

A brass beam specimens of dimension (300 mm × 16 mm × 16 mm) with a transverse crack is taken for the experimental analysis for determining the natural frequencies at different crack locations and crack depths. These specimens are allowed to vibrate under 1st, 2nd and 3rd mode of vibrations. The experimental results of corresponding amplitudes are recorded in the digital storage oscilloscope at various locations along the length of the beam.

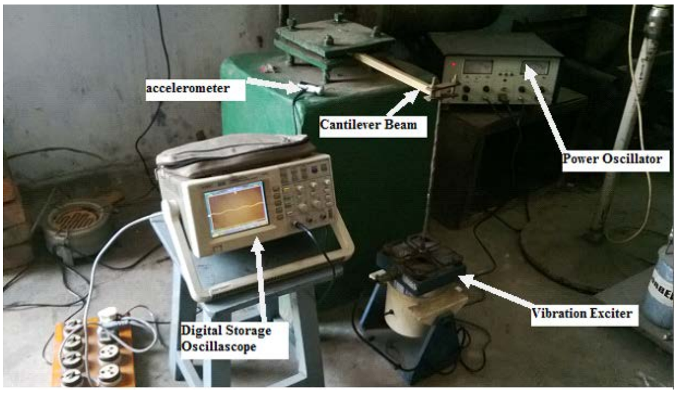

Fig: - 1 Experimental Setup

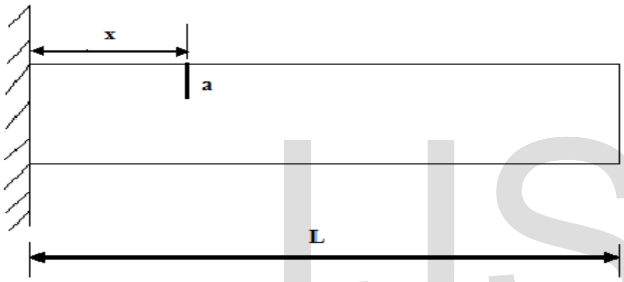

Fig: - 2 Schematic diagram for location of cracks in specimen

RESULT AND DISCUSSION

Results

The experimental data from the curve-fitted results were tabulated, and plotted in the form of frequency ratio (w_c/w) (ratio of the natural frequency of the cracked beam to that of the un-cracked beam) versus the crack depth (a) for various crack location (L). Tables 1-3 show the variation of the frequency ratio as a function of the crack depth and crack location for beams with fixed-free ends.

Changes in Natural Frequency

The amount of literature related to damage detection using shifts in natural frequencies is quite large. The observation that changes in structural properties cause changes in vibration frequencies was the impetus for using modal methods for damage identification and health monitoring. Because of the large amount of literature, we have not included all papers on this subject. An effort has been made to include the early work on the subject, some papers representative of the different types of work done in this area, and papers that are considered by the authors to be significant contributions in this area. There are a large number of papers that only duplicate previous work. These papers are largely excluded from this review, but are cited in a list of additional publications following the main reference list. Also, many papers present only applications of these methods to different structures, rather than new theoretical work on the use of frequency shifts in damage detection.

It should be noted that frequency shifts have significant practical limitations for applications to the type of structures considered in this review, although ongoing and future work may help resolve these difficulties. The somewhat low sensitivity of frequency shifts to damage requires either very precise measurements or large levels of damage.

Fig. 3 to 5 shows the plots of the first three frequency ratios as a function of crack depths for some of the crack positions. Fig. 6 to Fig. 8 shows the frequency ratio variation of three modes in terms of crack position for various crack depths respectively. From Fig. 6 to Fig. 8. it is observed that, for the cases considered, the fundamental natural frequency was least affected when the crack was located at 265 mm from fixed end. The crack was mostly affected when the crack was located at 25 mm from the fixed end. Hence for a cantilever beam, it could be inferred that the fundamental frequency decreases significantly as the crack location moves towards the fixed end of the beam. This could be explained by the fact that the decrease in frequencies is greatest for a crack located where the bending moment is greatest. It appears therefore that the change in frequencies is a function of crack location. From Fig. 7. it is observed that the second natural frequency was mostly affected for a crack located at the center for all crack depths of a beam due to the fact that at that location the bending moment is having large value. The second natural frequency was least affected when the crack was located at 265 mm from fixed end. From Fig. 8. it is observed that the third natural frequency of beam changed rapidly for a crack located at 150 mm. The third natural frequency was almost unaffected for a crack located at the center of a cantilever beam; the reason for this zero influence was that the nodal point for the third mode was located at the center of beam.

X	2 mm	4 mm	6 mm	7.5 mm	9 mm	11 mm
25 mm	0.9856	0.9765	0.9489	0.9068	0.8498	0.7256
70 mm	0.982	0.9798	0.9662	0.9163	0.8621	0.7589
110 mm	0.9756	0.9799	0.9785	0.9365	0.8768	0.7861
150 mm	0.9941	0.9923	0.9862	0.945	0.901	0.8365
200 mm	0.9963	0.9929	0.9865	0.969	0.9412	0.9215
265 mm	0.999	0.9898	0.9865	0.9812	0.9781	0.9702

TABLE: - 1 Fundamental Natural Frequency Ratio (ω_c/ω) As A Function of Crack Location (L) and Crack Depth (a)

TABLE:-2 Second Natural Frequency Ratio (ω_c/ω) As A Function of Crack Location (L) And Crack Depth (a)

X	2 mm	4 mm	6 mm	7.5 mm	9 mm	11 mm
25 mm	0.9721	0.9485	0.9211	0.8945	0.8635	0.8163
70 mm	0.9686	0.9541	0.9219	0.9115	0.8897	0.8347
110 mm	0.9678	0.954	0.9387	0.9361	0.9015	0.8669
150 mm	0.995	0.9763	0.9568	0.9423	0.9389	0.8998
200 mm	0.9804	0.9638	0.965	0.9687	0.9521	0.946
265 mm	0.9916	0.9845	0.981	0.9763	0.9711	0.9468

TABLE:-3 Third Natural Frequency Ratio (ω_c/ω) As A Function of Crack Location (L) And Crack Depth (a)

X	2 mm	4 mm	6 mm	7.5 mm	9 mm	11 mm
25 mm	0.95224	0.9174	0.9001	0.8825	0.8611	0.8343
70 mm	0.9564	0.9291	0.9079	0.90042	0.8748	0.834
110 mm	0.9615	0.93382	0.9143	0.9027	0.88145	0.8411
150 mm	0.9678	0.9394	0.9259	0.92178	0.9015	0.85621
200 mm	0.97983	0.9467	0.9298	0.9391	0.9009	0.8713
265 mm	0.9914	0.96477	0.938	0.9476	0.9259	0.90789

From Fig. 3 it is observed that, for the cases considered, the fundamental natural frequency was least affected when the crack depth was 2 mm. The crack was mostly affected when the crack depth was 11 mm. Hence for a cantilever beam, it could be inferred that the fundamental frequency decreases significantly as the crack depth increase of beam depth. This could be explained by the fact that the decrease in frequencies is greatest for a more crack depth because as more material gets removed the stiffness of the beam decrease and hence the natural frequency. It appears therefore that the change in frequencies is a function of crack depth also.

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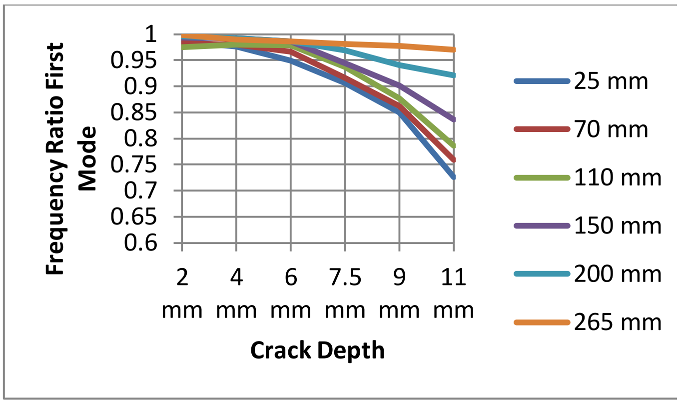

Fig: - 3 Fundamental natural frequency ratio in terms of crack depth for various crack positions

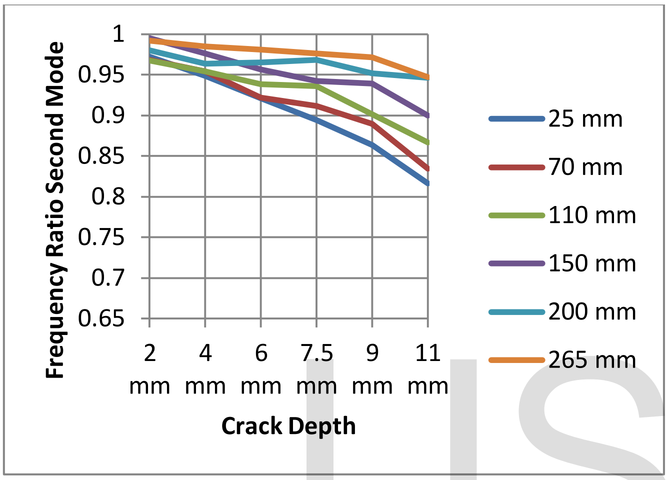

Fig: - 4 Second natural frequency ratio in terms of crack depth for various crack positions

From Fig. 4 it is observed that the second natural frequency was mostly affected for a crack depth of 11 mm at the crack location 150 mm. From Fig. 5. it is observed that the third natural frequency of beam changed rapidly for a crack depth of 11 mm. Fig. 9 to Fig. 11 show the three dimensional plots of Normalized Frequency versus Crack Location and Crack Depth for first, second and third mode respectively for crack location of 150 mm and crack depth of 7.5 mm. To get these three dimensional plots. In Fig. 9 to Fig. 11, the contour line is not present due to the presence of node points.

Crack Identification Technique Using Changes in Natural Frequencies

As stated earlier, both the crack location and the crack depth influence the changes in the natural frequencies of a cracked beam. Consequently, a particular frequency could correspond to different crack locations and crack depths. This can be observed from the three-dimensional plots of the first three natural frequencies of cantilever beams as shown in Fig. 9 to Fig. 11. On this basis, a contour line, which has the same normalized frequency change resulting from a combination of different crack depths and crack locations could be plotted in a curve with crack location and crack depth as its axes.

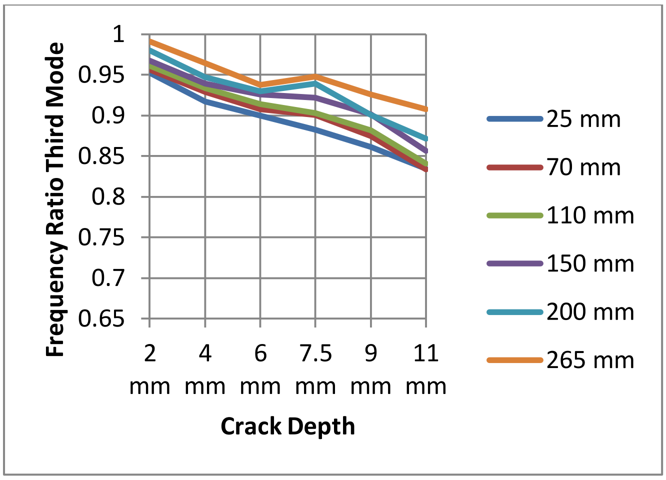

Fig:- 5 Third natural frequency ratio in terms of crack depth for various crack positions

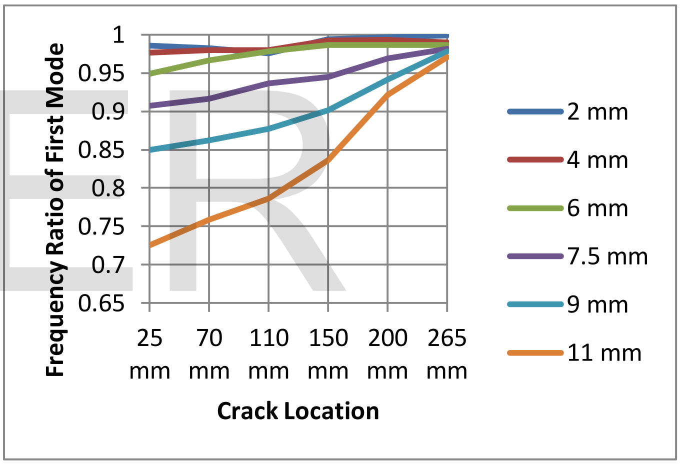

Fig:- 6 First Mode Frequency Ratio in Terms of Crack Position for Various Crack Depths

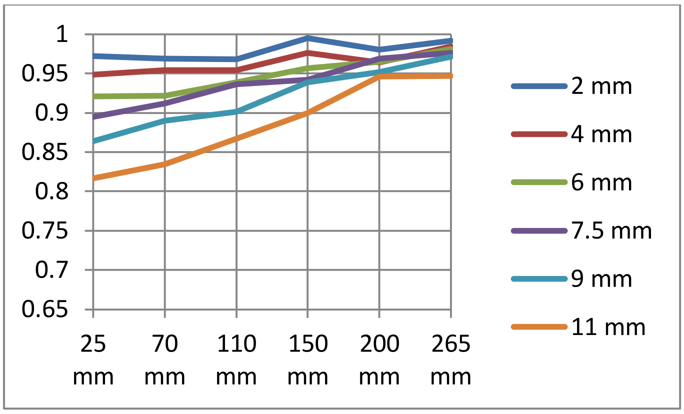

Fig :- 7 Second Mode Frequency Ratio in Terms of Crack Position for Various Crack Depths

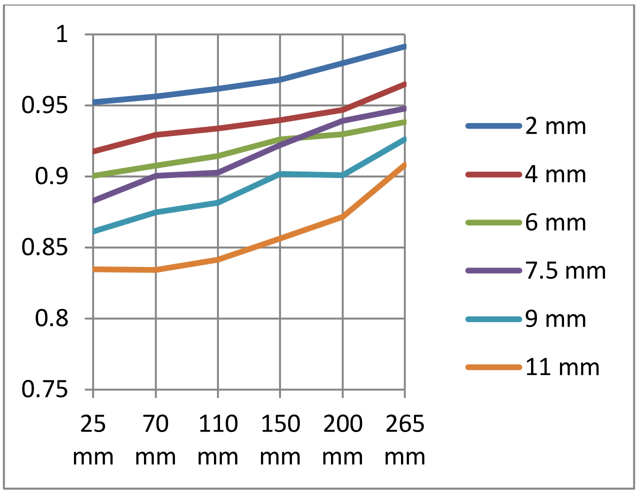

Fig :- 8 Third Mode Frequency Ratio in Terms of Crack Position for Various Crack Depths

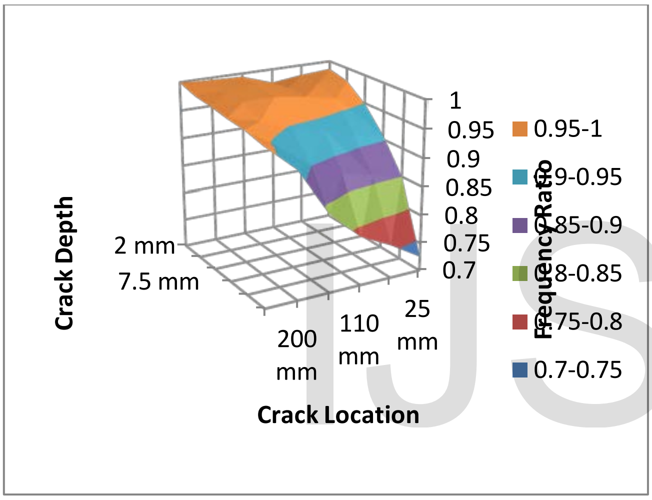

Fig:- 9 Three-dimensional plot with contour lines of normalized natural frequency versus crack location and crack depth for first mode for crack location of 150mm and crack depth of 7.5 mm

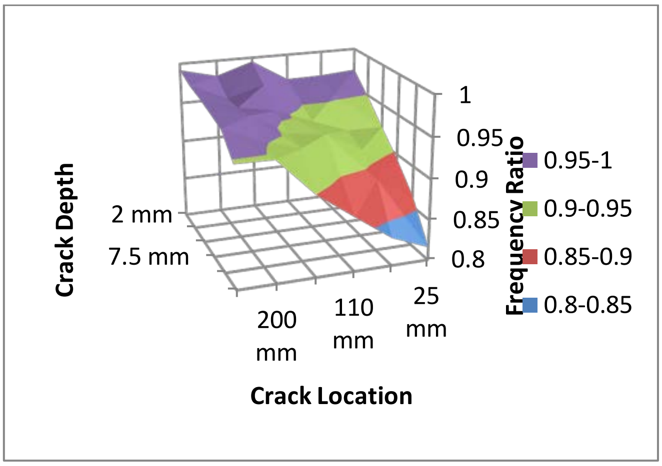

Fig :- 10 Three-dimensional plot with contour lines of normalized natural frequency versus crack location and crack depth for second mode for crack location of 150 mm and crack depth of 7.5 mm

For a beam with a single crack with unknown parameters, the following steps are required to predict the crack location, and depth, namely,

1. Measurements of the first three natural frequencies
2. Normalization of the measured frequencies
3. Plotting of contour lines from different modes on the same axes
4. Location of the points of intersection of the different contour lines.

The points of intersection, common to all the three modes, indicate the crack location, and crack depth. This intersection will be unique due to the fact that any normalized crack frequency can be represented by a governing equation that is dependent on crack depth (a), crack location (L). Therefore a minimum of three curves is required to identify the two unknown parameters of crack location and crack depth.

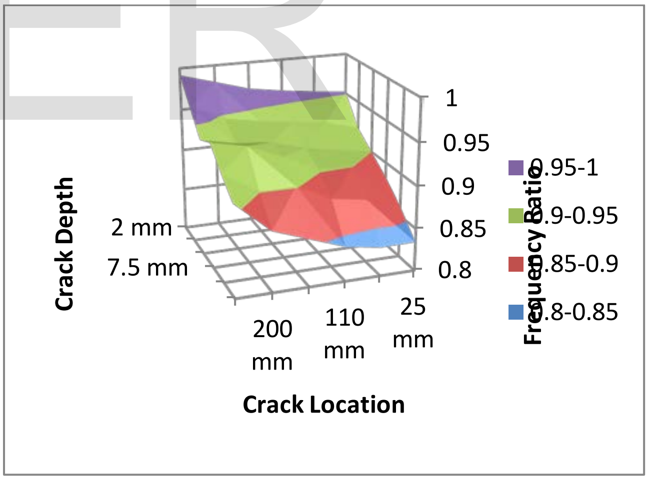

Fig:- 11 Three-dimensional plot with contour lines of normalized natural frequency versus crack location and crack depth for third mode for crack location of 150 mm and crack depth of 7.5 mm

From Tables 1-6, it is observed that for a crack depth of 7.5 mm located at a distance of 150 mm from fixed end of the beam, the normalized frequencies are 0.9862 for the first mode, 0.9568 for the second mode and 0.9259 for the third mode. The contour lines with the values of 0.9862, 0.9568 and 0.9259 were retrieved from the first three modes with the help of MINITAB software as shown in Fig. 12 to

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Fig. 14. It could be observed that there are two intersection points in the contour lines of the first and the second modes. Consequently the contour of the third mode is used to identify the crack location (L=150 mm) and the crack depth (a=7.5 mm), uniquely. The three contour lines gave just one 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 than the number of unknowns to be determined. This is the reason for the requirement of three modes. If there were more parameters that influence the response then one will require more modes to identify the unknown crack depth and crack location.

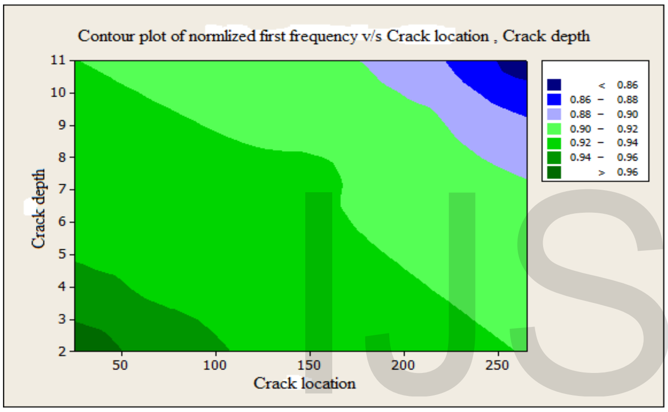

Fig:- 12 Frequency contour plot of mode-1 for normalized frequency 0.9862

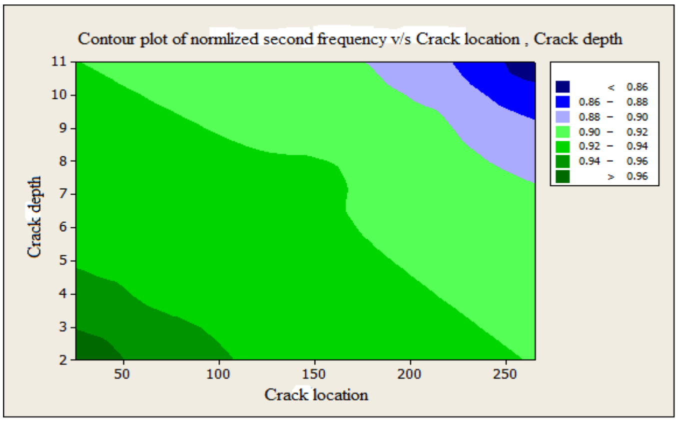

Fig:- 13 Frequency contour plot of mode-2 for normalized frequency 0.9568

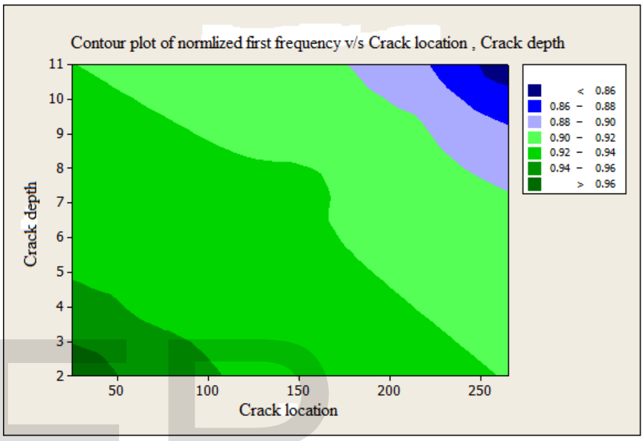

Fig:- 14 Frequency contour plot of mode-3 for normalized frequency 0.9259

Conclusion

A method for find the crack. The natural frequencies of beam structures to designated values are presented. The natural frequencies are varied from the crack extent and crack location of the beam structures. A method of modelling of transverse vibration of a beam of variable depth with an open edge crack has been presented the representation of a crack in a beam. The accuracy of the method in respect of detection of crack location is particularly encouraging. This can be exploited for detection of crack location by knowing the changes in its natural frequencies. The main conclusions of the study are as follows:

- An analytical solution for the study of vibration of beams with crack normal to its axis has been presented.
- The method predicts the location of a crack quite accurately. The scheme can be employed to locate an unknown crack in a beam.
- With the presence of crack in the beam the frequency of vibration decreases.
- It is found that, presence of crack in a beam decreases the natural frequency which is more pronounced when the crack is near the fixed support than the free end and the crack depth is more.
- It is found that the method is capable of predicting the crack location and depth for cracks.

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