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Analysis of Crack for Varying Depth and Location by FEA and Experimental Vibration Analysis Method

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ABSTRACT:
It is difficult to obtain the optimum performance of a machine because of crack. At present most of the machine elements are unexpectedly fails due to material fatigue. Therefore detection of crack and its position is the main topic of discussion for various researchers across the globe. The dynamic behavior of a whole structure is affected due to the presence of a crack as the stiffness of that structural element is altered. The cracks in the structure change the frequencies, amplitudes of free vibration and dynamic stability areas to an inevitable extent. So a diagnosis of the changes allows the experimenter to identify the cracks without aborting the system applications. The effect of an open crack on the modal parameters of the cantilever beam subjected to free vibration is analyzed and the results obtained from the numerical method i.e. finite element method (FEM) and the experimental method are compared. It is concluded that results obtained from experiment have a very good agreement with the results obtained from FEM and the structure vibrates with more frequency in the presence of a crack away from the fixed end.

KEYWORDS: Vibration, Natural frequency, Crackdepth, Crack location, Mode Shapes.

1) INTRODUCTION:

In the recent decades, fiber reinforced composite materials are being used more frequently inmany different engineering fields. The automobile, aerospace, naval, and civil industries all usecomposite materials in some way. Composite materials aregaining popularity because of highstrength, low weight, resistance to corrosion, impact resistance, and high fatigue strength. Otheradvantages include ease offabrication, flexibility in design, and variable material properties tomeet almost any application.

The airplane F.111 was one of the first models to incorporate this technology. As anotherexample, the airplane Boeing 767 has 2 tons in composite materials. The possibilityto combine high strength and stiffness with low weight has also got the attention of theautomobile industry. The Ford Motor Company developed in 1979 a car with some componentsmade from composite materials. The prototype was simply 570 kg lighter than the version insteel, only the transmission shaft had a reduction of 57% of its original weight.

The most common structural defect is the existence of a crack. Cracks are present instructures due to various reasons. The presence of a crack could not only cause a localvariation in the stiffness but it could affect the mechanical behavior of the entire structure toa considerable extent. Cracks may be caused by fatigue under service conditions as a resultof the limited fatigue strength. They may also occur due to mechanical defects. Anothergroup of cracks are initiated during the manufacturing processes. Generally they are small insizes. Such small cracks are known to propagate due to fluctuating stress conditions. If thesepropagating cracks remain undetected and reach their critical size, then a sudden structuralfailure may occur.

Vibration- based methods can be classified into two categories: linear and nonlinear approaches. Linear approaches detect the presence of cracks in a target object by monitoring changes in the resonant frequencies in the mode shapes or in the damping factors. Depending on the assumptions, the type of analysis, the overall beam characteristics and the kind of loading or excitation, a number of research papers containing a variety of different approaches have been reported in the relevant literature. Damage can be analyzed through visual inspection or by the method of measuring frequency, mode shape and structural damping. Damage detection by visual inspection is a time consuming method and measuring of mode shape aswell as structural deflection is difficult rather than measuring frequency. The presence of crack induces local flexibility, which affects the dynamic behavior of the whole structure as a result the reduction occurs in natural frequency and mode shape.

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By considering the changes in those parameters crack can be identified in terms of crack depth and crack location.

1.1 PROBLEM STATEMENT:

The vibration analysis whether can be used as non-destructive testing method to identify and detect the damage beam. From the vibration analysis, the dynamic characteristic such as natural frequencies and their mode shape analysis can be used for detection of the cracks. The failure of the crack beam is governed by the stresses in the vicinity of the crack tip. Checking of Vibration analysis as important information can be helpful for crack and fracture identification of the engineering structures. Present work deals with the natural frequency of cracked composite cantilever beam are studied by FFT analyzer to establish the relationship of crack depth with natural frequency and to find the significance and relation between location of crack and natural frequency range

1.2 OBJECTIVES:

Due to the impact loading on cantilever beam cracks are developed in that beam. It is necessary to measure the depth of crack and location of cracks to avoid accident. The main objective of this project is –

1. Establish the relationship of crack depth with natural frequency
2. To find out the significance and relation between location of crack and natural frequency range.
3. To validate the tested results by FEA software.
4. To conclude the work, its perspectives and scope.

2. FINITE ELEMENT MODELLING:

The ANSYS 15 finite element program was used for vibration analysis of different configurations. Wemodelled the crack with a 0.5mm width on the top surface of the beam and a crack going through the depth of thebeam. A 20-node three-dimensional structural solid element under SOLID 95 was selected to model the beam.

Specifications of Sample Beam:

Thickness of beam= 0.014m

Length of the beam = 0.450 m

Width of beam: 0.025m

Young's modulus = 34000MPa

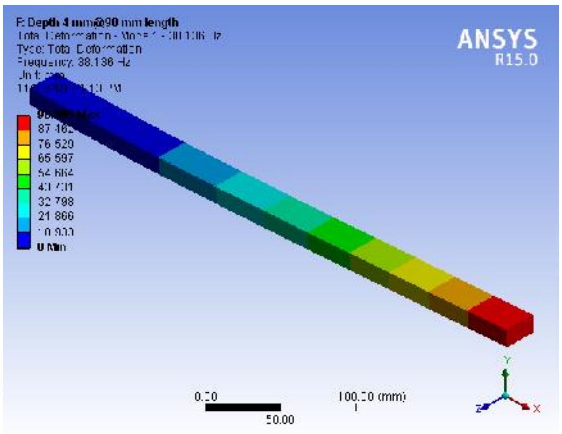
Poisson's Ratio = 0.217

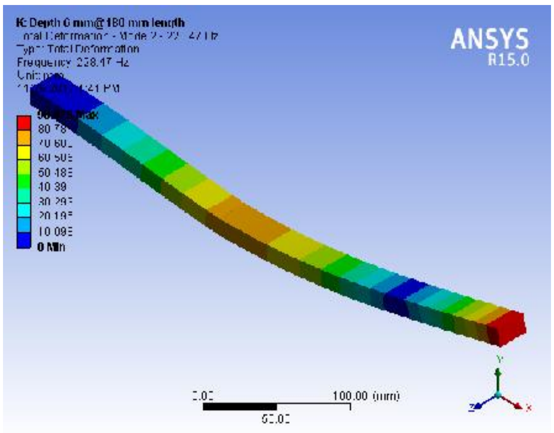
Density = 2600 kg/m^3

End condition of the beam = One end fixed and other end free (Cantilever beam).

2.1 Beam analysis by FEA:

The following analysis is made for three cracks at 90, 180 and 270 mm distance from fixed end and depth of the crack is 4mm, 6mm and 8mm respectively.. Different mode shapes along with frequency of vibration is given as below:





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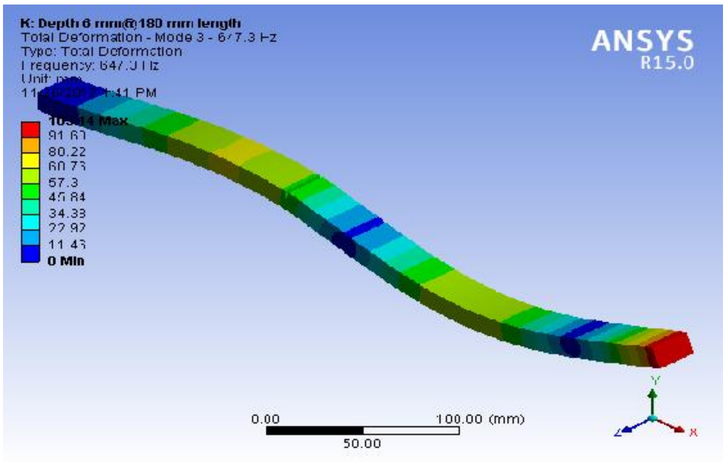


Figure 2.1: First, Second and Third Mode Shape of Cracked Beam for 90 mmLocation and 4mm Depth.

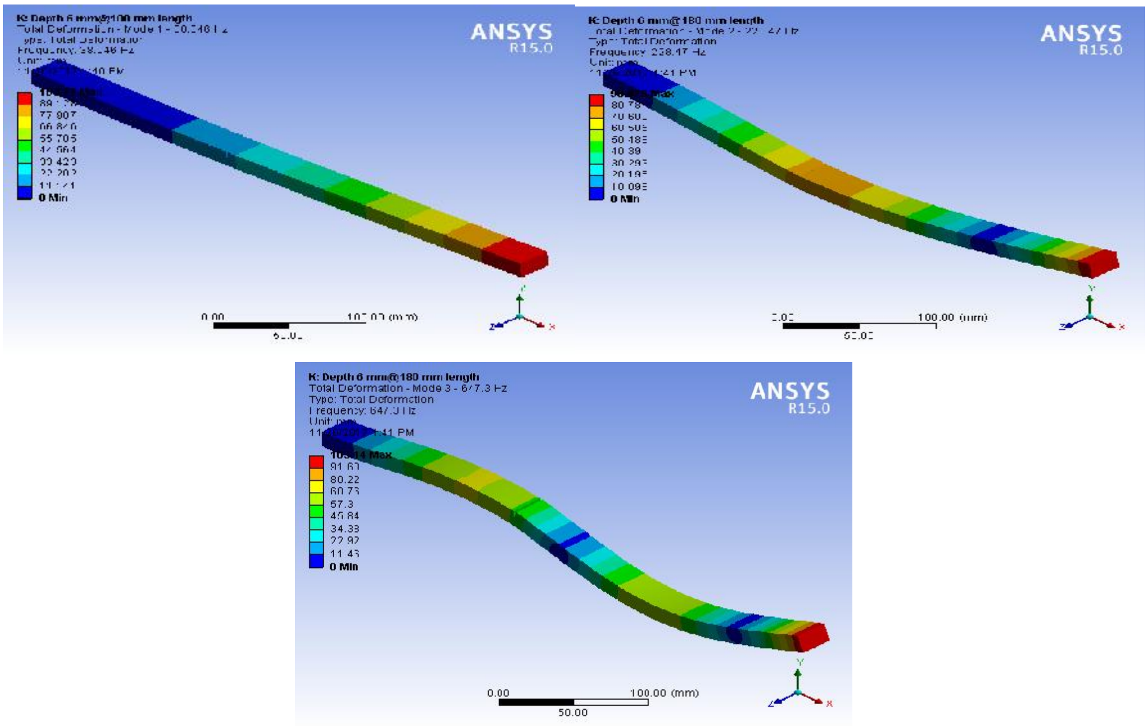
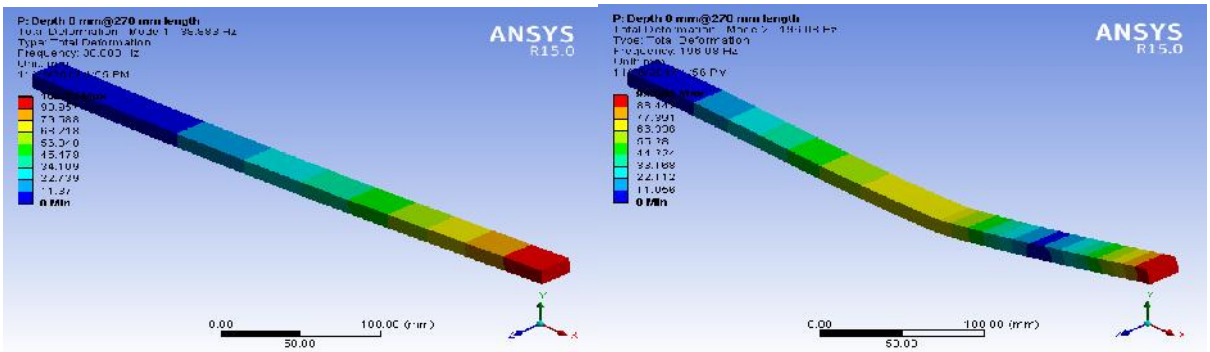


Figure 2.2: First, Second and Third Mode Shape of Cracked Beam for 180 mmLocation and 6mm Depth.



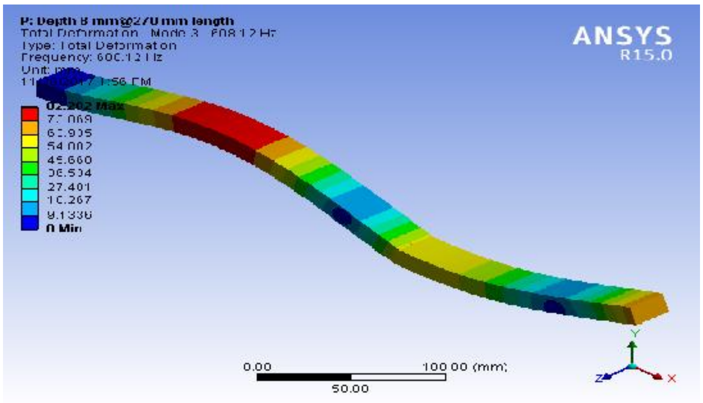


Figure 2.3: First, Second and Third Mode Shape of Cracked Beam for 270 mmLocation and 8mm Depth.

2.1.1 Results obtained by Using FEA

Table 2.1: Natural Frequencies by FEA Analysis for 4mm Crack Depth

Crack Location(X) in (mm)	Crack Depth (a) in (mm)	Natural Frequency Fn1(Hz)	Natural Frequency Fn2(Hz)	Natural Frequency Fn3(Hz)
No Crack	No Crack	40.265	247.54	673.1
90	4	38.136	247.46	662.74
180	4	39.386	239.33	661.55
270	4	40.045	236.41	655.59

Table 2.2: Natural Frequencies by FEA Analysis for 6mm Crack Depth

Crack Location (X) in (mm)	Crack Depth (a) in (mm)	Natural Frequency Fn1(Hz)	Natural Frequency Fn2(Hz)	Natural Frequency Fn3(Hz)
No Crack	No Crack	40.265	247.54	673.1
90	6	35.426	247.35	650.05
180	6	38.046	228.47	661.55
270	6	39.72	222.68	637.13

Table 2.3: Natural Frequencies by FEA Analysis for 8mm Crack Depth

Crack Location (X) in (mm)	Crack Depth (a) in (mm)	Natural Frequency Fn1(Hz)	Natural Frequency Fn2(Hz)	Natural Frequency Fn3(Hz)
No Crack	No Crack	40.265	247.54	673.1
90	8	30.892	247.09	629.39
180	8	35.422	211.5	627.56
270	8	38.883	196.08	609.12

3. Experimental Analysis

3.1 Experimental model description:

After the getting the values of natural frequencies by FEA analysis, the values were cross checked bydoing experiment using FFT, to check how the values of the natural frequency can varyexperimentally.

In the experimental setup there is composite cantilever beam of cross section b= 0.025m, h= 0.014m and length L=0.450m. An accelerometer is attached to the beam to note down the natural frequency of the beam. An impact hammer is used to induce vibration to the beam.

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Figure 3.1 Experimental Setup of FFT analyzer

The beam is struck lightly with the impact hammer and natural frequencies of the beam is recorded by FFT in the computer and noted down.

3.2Results obtained by Experimental Analysis:

Table 3.1: Natural Frequencies by Experimental Analysis for 4mm Crack Depth

Crack Location (X) in (mm)	Crack Depth (a) in (mm)	Natural Frequency Fn1(Hz)	Natural Frequency Fn2 (Hz)	Natural Frequency Fn3 (Hz)
No Crack	No Crack	45.8	278.4	709.3
90	4	34.2	275.9	703.1
180	4	41.5	258.8	695.8
270	4	43.9	236.8	673.8

Table 3.2: Natural Frequencies by Experimental Analysis for 6mm Crack Depth

Crack Location (X) in (mm)	Crack Depth (a) in (mm)	Natural Frequency Fn1(Hz)	Natural Frequency Fn2(Hz)	Natural Frequency Fn3(Hz)
No Crack	No Crack	45.8	278.4	709.3
90	6	31.7	256.3	695.8
180	6	39.1	239.3	676.3
270	6	41.5	231.9	654.3

Table 3.3: Natural Frequencies by Experimental Analysis for 8mm Crack Depth

Crack Location (X) in (mm)	Crack Depth (a) in (mm)	Natural Frequency Fn1(Hz)	Natural Frequency Fn2(Hz)	Natural Frequency Fn3(Hz)
No Crack	No Crack	45.8	278.4	709.3
90	8	29.3	246.6	673.8
180	8	34.2	234.4	656.7
270	8	36.6	210.0	617.7

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3.3: Sample Result Displayed on the Display unit of FFT Analyzer:

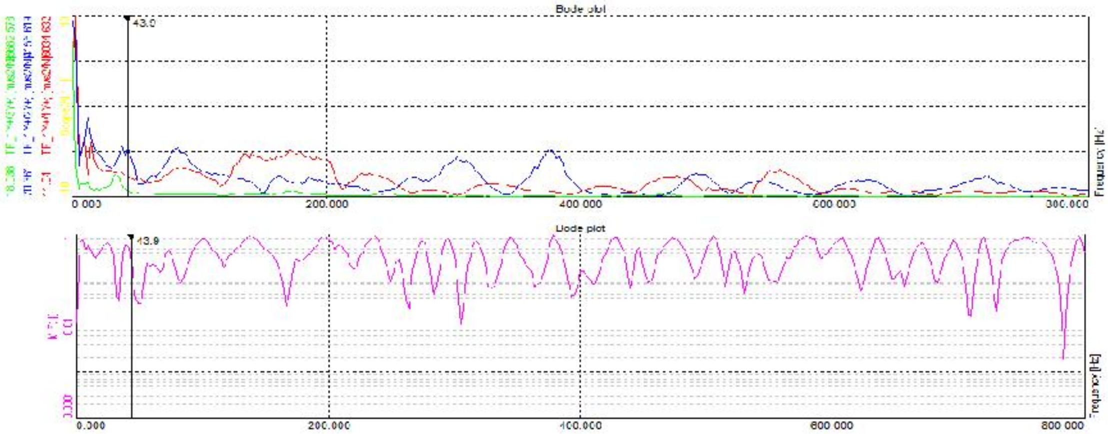

Figure 3.2: First Natural Frequency of Cracked Beam for 270 mm location and 4mm Crack Depth

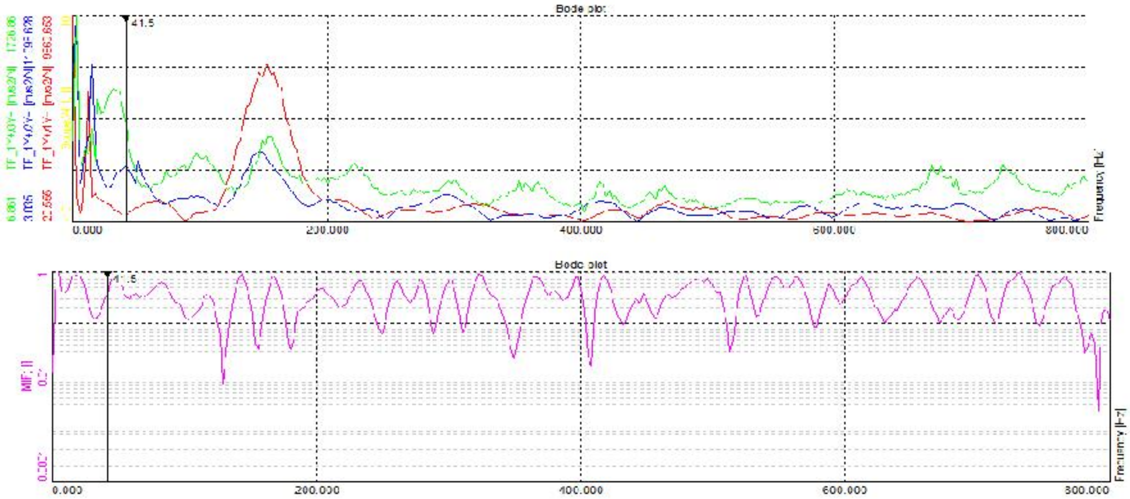

Figure 3.3: First Natural Frequency of Cracked Beam for 270 mm location and 6mm Crack Depth

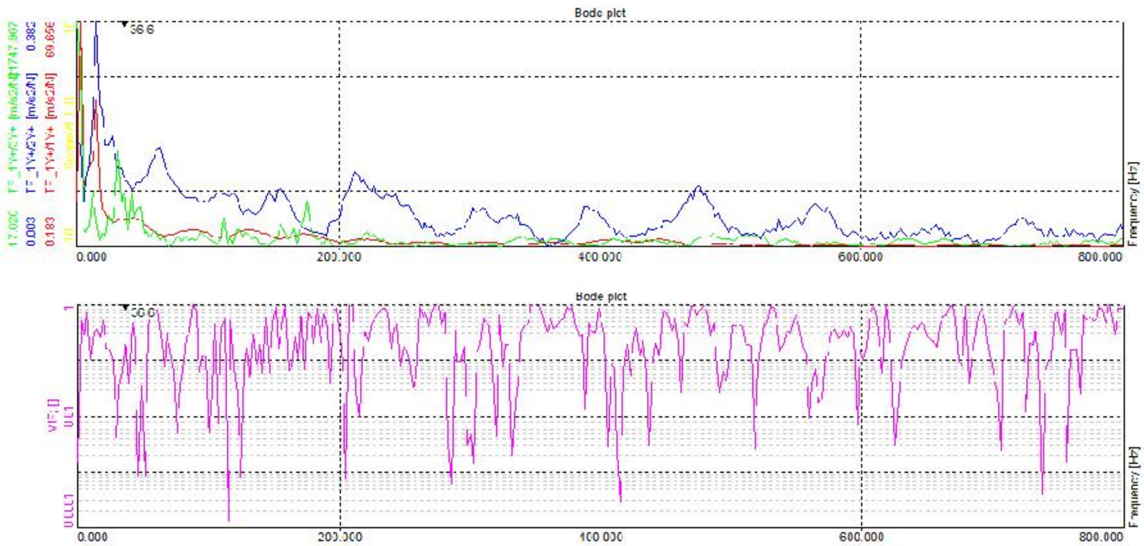

Figure 3.4: First Natural Frequency of Cracked Beam for 270 mm location and 8mm Crack Depth

4. Results and Discussion:

4.1 Comparison of the results of experimental and numerical analysis for cracked beam:

Table 4.1: Consolidated Result of Experiment and FEA for 4mm Crack Depth

Crack Location (X) in(mm)	Crack Depth (a) in (mm)	By experimental Analysis			By Numerical (FEM Software) analysis		
		Natural Frequency Fn1(Hz)	Natural Frequency Fn2(Hz)	Natural Frequency Fn3(Hz)	Natural Frequency Fn1(Hz)	Natural Frequency Fn2(Hz)	Natural Frequency Fn3(Hz)
No Crack	No Crack	45.8	278.4	709.3	40.265	247.54	673.1
90	4	34.2	275.9	703.1	38.136	247.46	662.74
180	4	41.5	258.8	695.8	39.386	239.33	661.55
270	4	43.9	236.8	673.8	40.045	236.41	655.59

Table 4.2: Consolidated Result of Experiment and FEA for 6mm Crack Depth

Crack Location (X) in(mm)	Crack Depth (a) in (mm)	By experimental Analysis			By Numerical (FEM Software) analysis		
		Natural Frequency Fn1(Hz)	Natural Frequency Fn2(Hz)	Natural Frequency Fn3(Hz)	Natural Frequency Fn1(Hz)	Natural Frequency Fn2(Hz)	Natural Frequency Fn3(Hz)
No Crack	No Crack	45.8	278.4	709.3	40.265	247.54	673.1
90	6	31.7	256.3	695.8	35.426	247.35	650.05
180	6	39.1	239.3	676.3	38.046	228.47	661.55
270	6	41.5	231.9	654.3	39.72	222.68	637.13

Table 4.3: Consolidated Result of Experiment and FEA for 8mm Crack Depth

Crack Location (X) in(mm)	Crack Depth (a) in (mm)	By experimental Analysis			By Numerical (FEM Software) analysis		
		Natural Frequency Fn1(Hz)	Natural Frequency Fn2(Hz)	Natural Frequency Fn3(Hz)	Natural Frequency Fn1(Hz)	Natural Frequency Fn2(Hz)	Natural Frequency Fn3(Hz)
No Crack	No Crack	45.8	278.4	709.3	40.265	247.54	673.1
90	8	29.3	246.6	673.8	30.892	247.09	629.39
180	8	34.2	234.4	656.7	35.422	211.5	627.56
270	8	36.6	210.0	617.7	38.883	196.08	609.12

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The natural frequency predicted experimentally and by FEM are in good match, as manufacturing techniques adopted for composite beams greatly peep into it. Properties of material refer to standard material along with the accurate microstructure whereas test specimens are practical materials where standard conditions are difficult to maintain which is revealed by observing microstructure. This is the important reason behind the variation in natural frequencies determined experimentally. The cracks introduced are saw cut while efforts were made to simulate the hairline crack, but saw cutafter polishing gets widen and may remove more mass leading to further reduction in natural frequency and causing the variation in experimental results.

It is evident from the above tables that experimental and numerical results are in good agreement. Tables (4.1-4.3)depict three sets of data i.e. 1st, 2nd & 3rd natural frequencies corresponding to experimental and numericalanalysis.Moreover the natural frequency of the cantileverwith crack decreases as compared to the beam without crack and for the same cantilever, natural frequencyincreases with increase in the distance of crack position from the fixed end. Crack near to fixed end it imparts more reduction in natural frequency.

4.2 Graphical Results Based on the Obtained Numerical and Experimental Data:

Following Fig.4.1, Fig. 4.2 and Fig. 4.3shows the variation of first natural frequency with crack location for crack depth 4mm, 6mm and 8mm respectively. From following figures, it is observed that, as crack location moves away from fixed end, natural frequency increases gradually. The results obtained by Finite element analysis and experimentally are compared and they are in good agreement with each other.

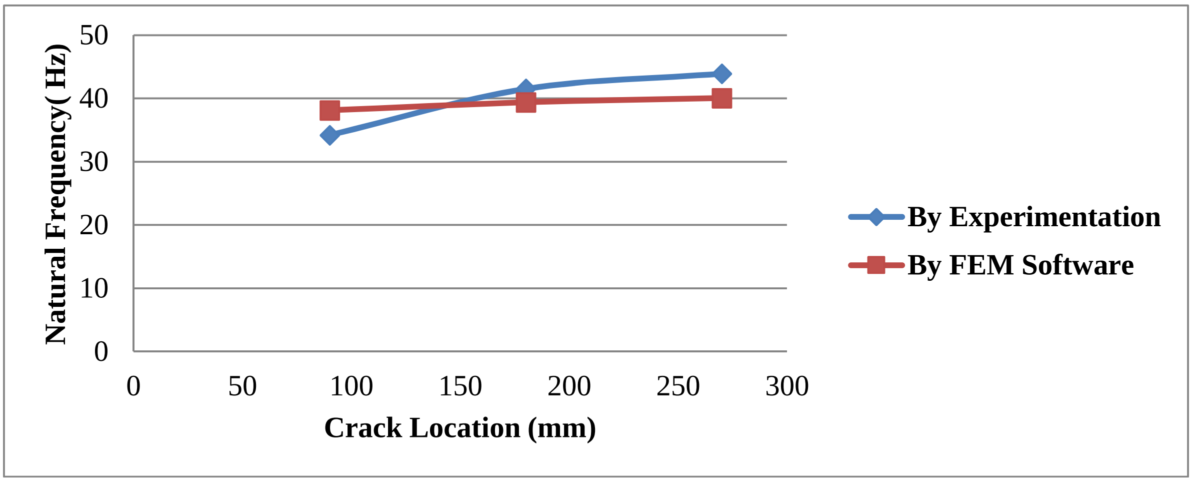

Figure 4.1: Crack LocationVs. FirstNatural Frequency for 4mm Crack Depth

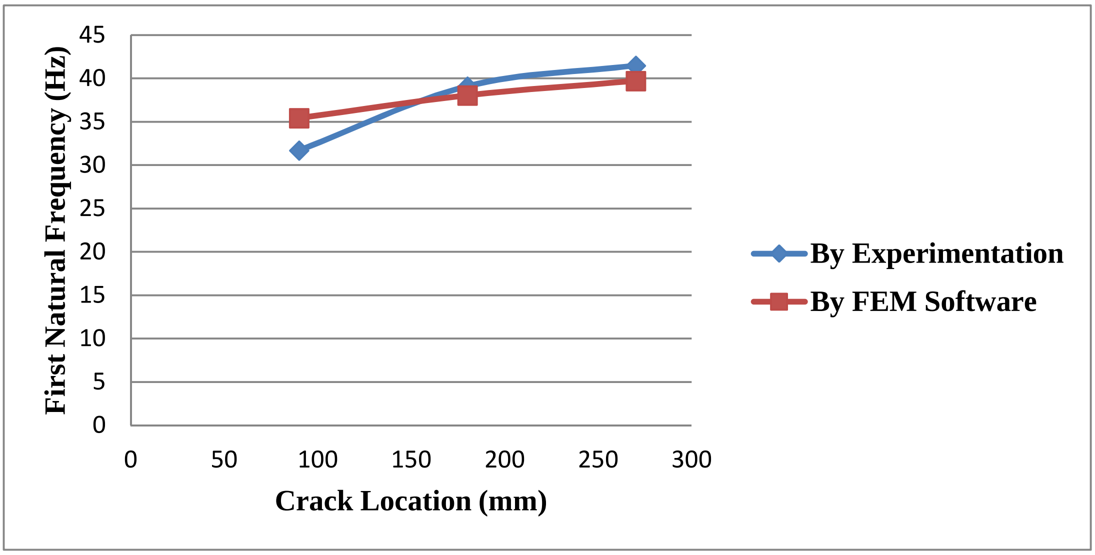

Figure 4.2: Crack LocationVs. FirstNatural Frequency for6mm Crack Depth

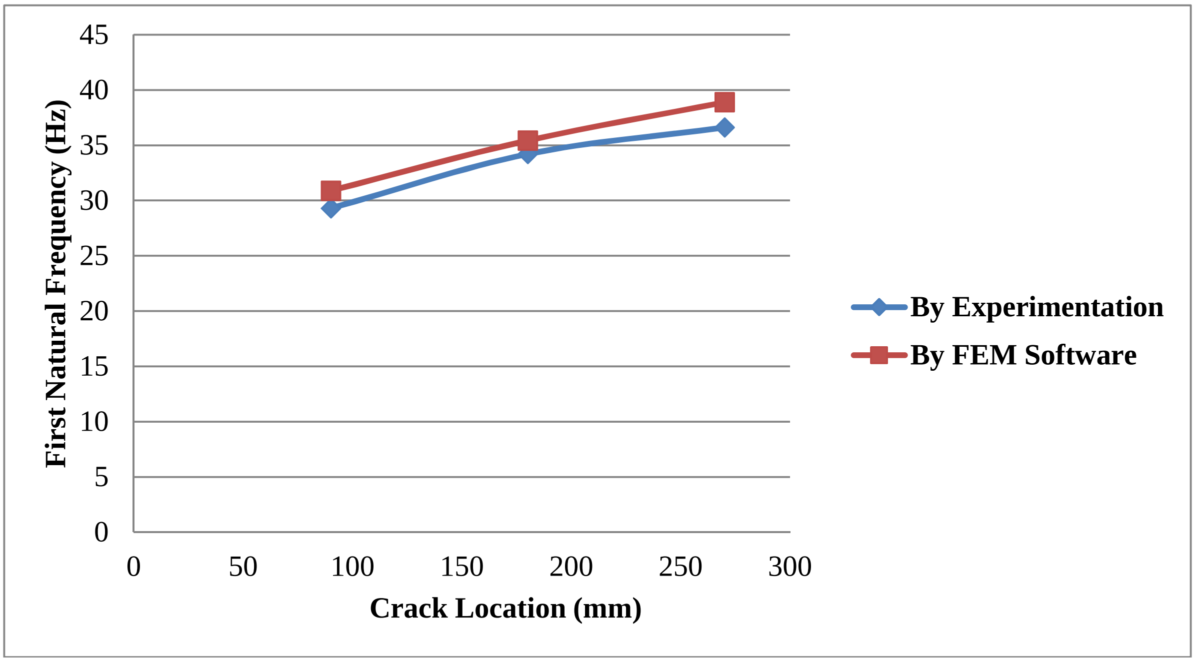

Figure 4.3: Crack LocationVs. FirstNatural Frequency for8mm Crack Depth

Following Fig. 4.4, Fig.4.5, and Fig.4.6 shows the variationof first natural frequency with crack depth, for cracklocation at 90mm, 180mm, and 270mm distancefrom fixed end respectively.From above figures, it is observed that, ascrack depth increases natural frequency decreases. The results obtained by Finite element analysis and experimentally are compared and they are in good agreement with each other

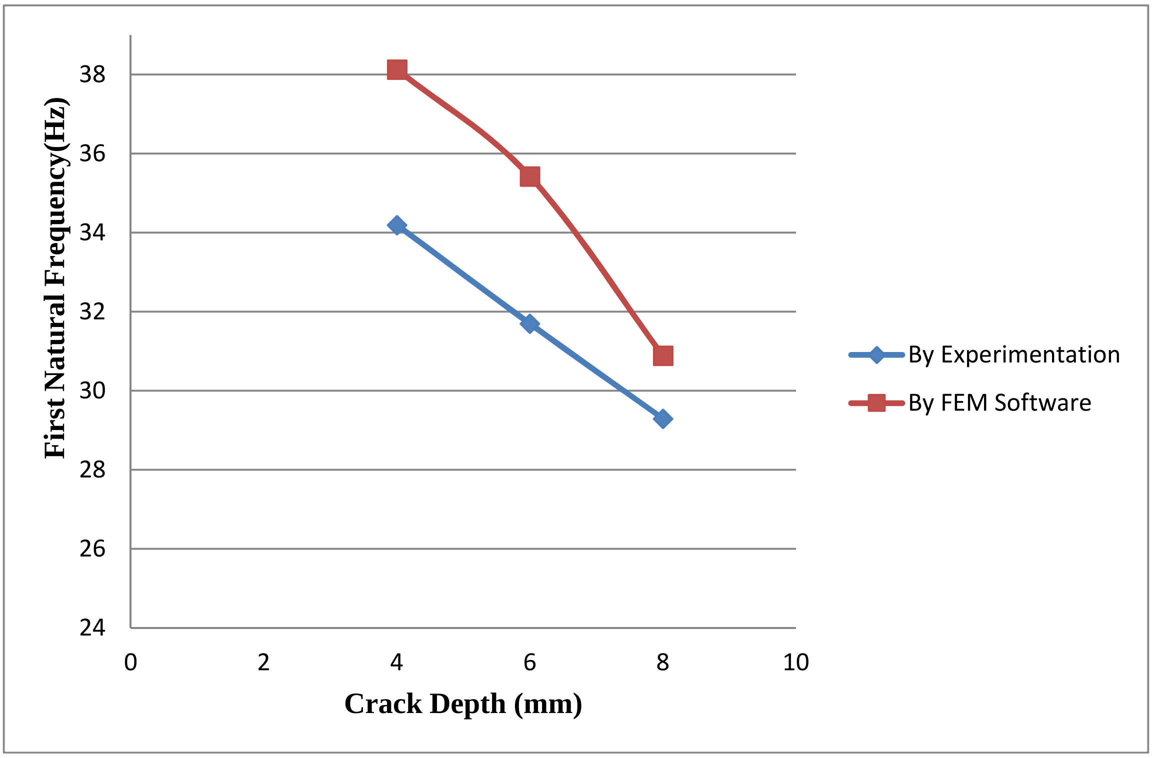

Figure4.4: Crack Depth Vs. Second Natural Frequency for Crack at 90mm Distance

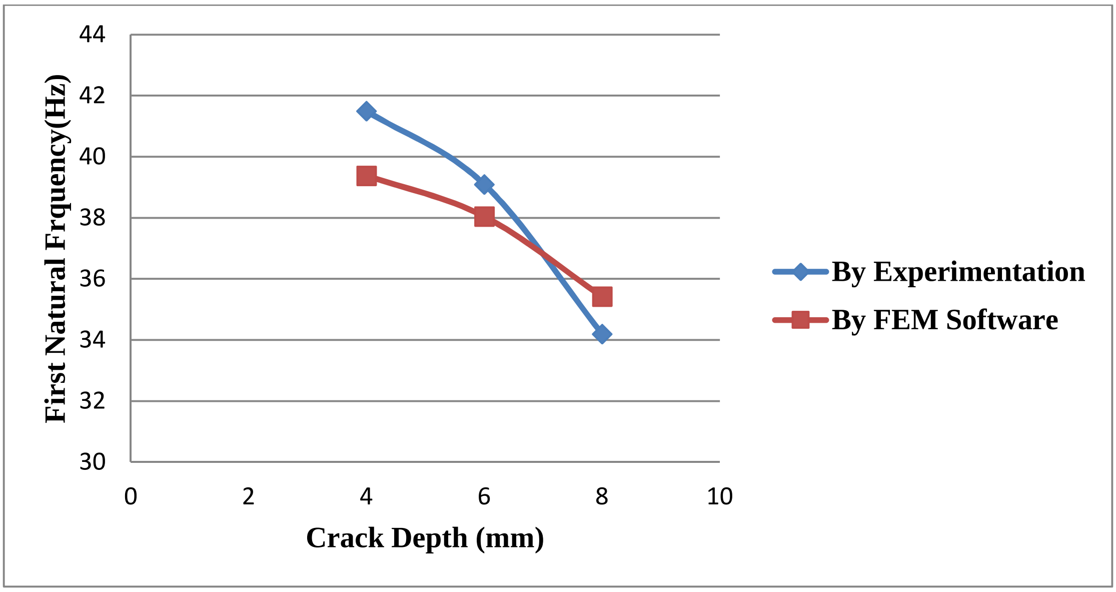

Figure4.5: Crack Depth Vs. Second Natural Frequency for Crack at 180mm Distance

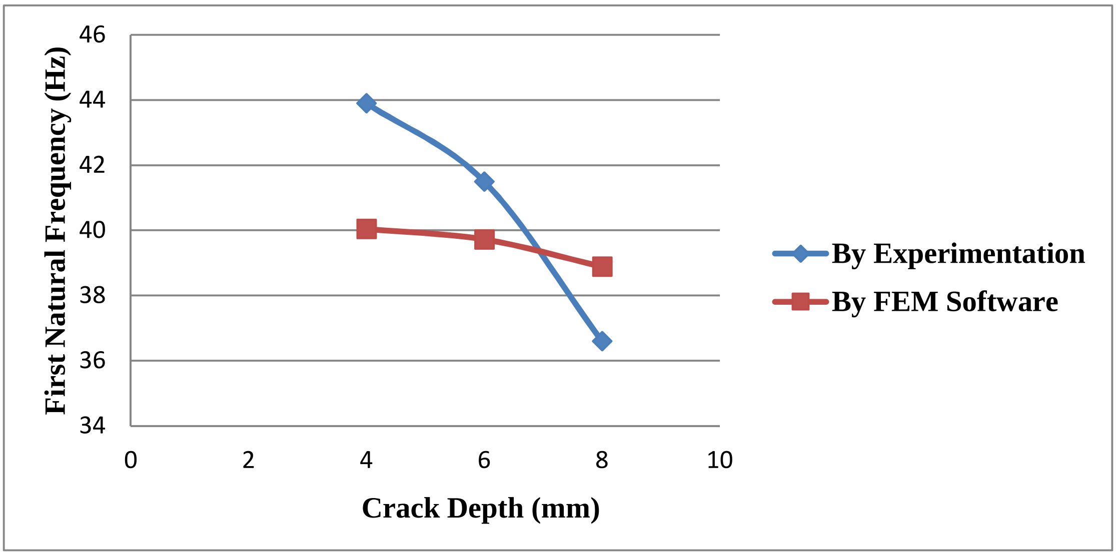

Figure4.6: Crack Depth Vs. Second Natural Frequency for Crack at 270mm Distance

5. Conclusion:

Present study concludes that the detection of cracks in cantilever beam by using vibration analysis technique in order to optimize the performance of machines and structures is more faster, accurate and efficient way. Identification of crack parameters is carried out by experimental setup which can give the more accurate locations and depth of cracks of that beam through this method. The experimentally predicted result should be in good agreement with actual values and justified through FEA software.

Graphs of crack depth vs. natural frequency and crack location vs. natural frequency clearly reveal relation between crack location and natural frequency and establish relationship of crack depth with natural frequency. Crack near to the fixed end gives the greater reduction in natural frequencies and the cracks away from the fixed end gives the higher frequency range and the larger crack depth reduces the natural frequency significantly than the smaller crack depth.

This has been confirmed and validated distinctly by comparing results obtained by using experimental data with results obtained through FEA software.

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