Detection of Crack Location and Crack Depth in Cantilever Structure by Using Fuzzy Logic Technique

Miss. More R. B.[1], Dr. Zope S.B.[2]

[1] P. G. Student, Mechanical Engineering, SVCET, Rajuri, Maharashtra, India
[2] Project Guide, Mechanical Engineering, SVCET, Rajuri, Maharashtra, India

ABSTRACT

Fault Diagnosis is one of the important aspect in structural engineering for safety reasons. A crack in structural components introduce the flexibility and it will influence the vibration parameters of that component. The presence of damage leads to alteration in natural frequencies and mode shapes. The conventional methods of fault diagnosis are available but main problem is to detect existence of crack with its location and depth. We used the changes in natural frequencies because of crack presence as a basic criteria. Theoretical calculations are done to find out first three natural frequencies by using Euler's equation. ANSYS workbench 15.0 is used to find natural frequencies along with the experimentation on FFT Analyzer. Experimental analysis conduct on total ten beam models having square cross section. One beam is considered as uncracked beam and other nine beam are cracked beam. Cracks of 0.35mm width are produced on these nine beam by wire cutting machine. Fuzzy logic toolbox in Matlab 7.10.0(R2010a) is used as a solution for detection of crack location and crack depth. Gaussian membership function is used for input and Trapezoidal membership function is used for output. Fuzzy rules are formed from the information provided by the Finite element analysis and experimental analysis. Fuzzy controller use three input variables i.e. normalized frequencies of first, second and third mode of vibration and two output variables i.e. relative crack location and relative crack depth. The presented system is used to detect existence of a crack together with its location and depth in the structure.

Keyword: - *Crack location, Crack depth, FFT Analyzer, Fuzzy logic model, Gaussian membership function, Trapezoidal membership function.*

---

1. INTRODUCTION

Crack is defined as any deviation introduced to a structure, both intentionally or unintentionally, which adversely impact the current or future efficiency of that system. It is clear from this definition that a comparison is needed between two states of a structure. Cracks are the most encountered damage varieties in the structures because of fatigue or manufacturing defects. Crack will initiate in a structure when the stresses near the crack area will exceed the permissible limit. Cracks observed in structural elements may come up because of fatigue cracks that take location below service conditions for this reason of the confined fatigue force; they may also be as a result of mechanical defects, such as cracks in turbine blades of turbine engines, compressor blades or may be because of defects because of manufacturing processes. Beams are broadly used as machine elements and structural elements in civil, mechanical, naval and aeronautical engineering & relatively difficult design parameters of turbine blades or compressor blades such that tapered beam of uniform thickness. In many applications non-uniform beams and applications to satisfy designated sensible requisites and achieve a higher distribution of force and weight. These machine and structural factors are designed with extra care for distinctive load, with just right range of safety factors, and are inspected most often. Still there are unexpected sudden failures. In order to attain the maximum reliability of machinery and structures, there is not any method except monitoring the health of susceptible important components. This leads to continuous gathering of knowledge of alterations in their static and dynamic behavior damage identification based upon changes in characteristics of vibration is one of the few approach that monitor changes in the structure on a global basis. Structural damage detection making use of vibration test knowledge has been acquired great attention from many researchers in last few decades. A wide variety of highly effective non-destructive evaluation tools are available. They are efficient but expensive, time consuming & laborious, designated for slender beam like components. Thus vibration based method based on measurement of natural frequencies is usually a potential method for crack detection.

In this paper efforts have been made to present various cost effective reliable analytical numerical and experimental techniques developed by various researchers for vibration analysis of damaged beams by crack. In this paper the effect of various parameters like crack size, crack location of beam on modal parameters subjected to vibration of a damaged beam also have been reviewed.

2. LITERATURE REVIEW

[1]Dayal R. Parhi and Sasanka Choudhury (2013) proposed theory predicated on Crack detection of a cantilever beam utilizing kohonen network techniques. The result shows that detection of damage in beam type structural elements is very essential to eschew a major failure or contingency. For non-destructive testing of cracked cantilever beam, vibration predicated methods make an excellent technique.

[2]Pankaj Charan Jena, Dayal R. Parhi, Goutam Pohit (2012) concluded on his paper on faults detection of a single cracked beam by theoretical and experimental analysis utilizing vibration signatures that approach evolved in this paper intimate location, size and depth of the open crack in beam of different end conditions.

[3]H. Nahvi and M. Jabbari (2005) finds results that the finite element model of the cracked beam is constructed and used to determine its natural frequency and mode shapes. From the theoretical calculations and experimental measurements, it is found that the not only crack location but also crack size affect the first and second natural frequencies of the cantilever beam.

[4] A. Dixit (2011) has given crack live that relates the strain energy, to the crack location and magnitude. The strain energy expression is calculated exploitation modes and natural frequencies of broken beams that area unit derived supported single beam analysis considering each decrease in mass and stiffness. The tactic is applicable to beams, with notch like non-propagating cracks, with absolute boundary conditions. The analytical expressions derived for mode shapes, curvature shapes, natural frequencies and improved strain energy based mostly harm live, area unit verified exploitation experiments.

[5] Sadettin Orhan (2007) studied the order to identify the crack in a cantilever beam. The study results suggest that free vibration analysis provides proper information for the detection of single and two cracks, whereas coerced vibration can detect only the single crack condition.

3. MATERIAL AND THEORETICAL ANALYSIS

Structural steel beams have been considered for making specimens. Total 10 specimens were cut to the size as length 700 mm and square cross section area is 10mm×10mm.One beam is considered as uncracked and other nine are crack beam. Cracks of 0.35mm are produced by the wire cutting machine. The modulus of elasticity and densities of beams have been measured to be 210GPa and 7850 Kg/m3 respectively. Theoretical analysis is done by Euler’s beam theory.

Material Geometry

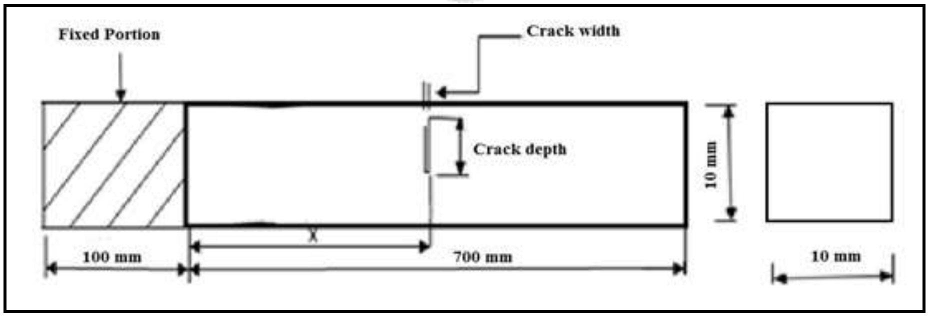

Fig-1: Cracked Square Beam Specimen

Theoretical analysis is done by Euler's beam theory. First three mode of natural frequencies are calculated by this theory. FNF, SNF, TNF are first three natural frequencies in hertz and RCD, RCL are relative crack depth and relative crack location respectively.

Table-1: Different Beam models with dimension and natural frequencies

Beam model no.	**Material**	**Cross section dimension (mm)**	**Cracked/ Uncracked**	**RCD**	**RCL**	**FNF**	**SNF**	**TNF**
1	Structural Steel E= 210×10^9 N/m^2, ρ = 7850 Kg/m^3, Length = 0.7m.	10×10	Uncracked	0	0	17.071	106.691	299.221
2		10×10	Cracked	0.1	0.25	17.070	106.687	299.200
3		10×10	Cracked	0.2	0.25	17.068	106.670	299.170
4		10×10	Cracked	0.3	0.25	17.058	106.617	299.014
5		10×10	Cracked	0.1	0.50	17.070	106.687	299.200
6		10×10	Cracked	0.2	0.50	17.068	106.670	299.170
7		10×10	Cracked	0.3	0.50	17.058	106.617	299.014
8		10×10	Cracked	0.1	0.75	17.070	106.687	299.200
9		10×10	Cracked	0.2	0.75	17.068	106.670	299.170
10		10×10	Cracked	0.3	0.75	17.058	106.617	299.014

4. FINITE ELEMENT ANALYSIS OF SHAFT BEAM

Finite Element Analysis of cantilever beam is done by using ANSYS workbench 15.0 software. Following steps show the guidelines for carrying out Modal analysis.

i. Generation of model in Designing software.
ii. Start ANSYS workbench 15.0.
iii. Select Modal Analysis System.
iv. Enter material specifications in Engineering Data.
v. Import geometry which is already made in CATIA.
vi. Open Model which has geometry of beam.
vii. Mesh the model with fine.
viii. Update analysis setting.
ix. Insert boundary conditions.
x. Give free vibration on beam.
xi. Evaluate all the results.
xii. Result summary.
xiii. Generate a report of the analysis results.

Some of the Results obtained by the finite element analysis are presented here which will represent the natural frequency of respective mode in the left side. First three natural frequencies are calculated by this method. This also represent how every specimen behave after the presence of crack with different crack location and crack depth. All frequencies are in hertz.

Result of Finite Element Analysis

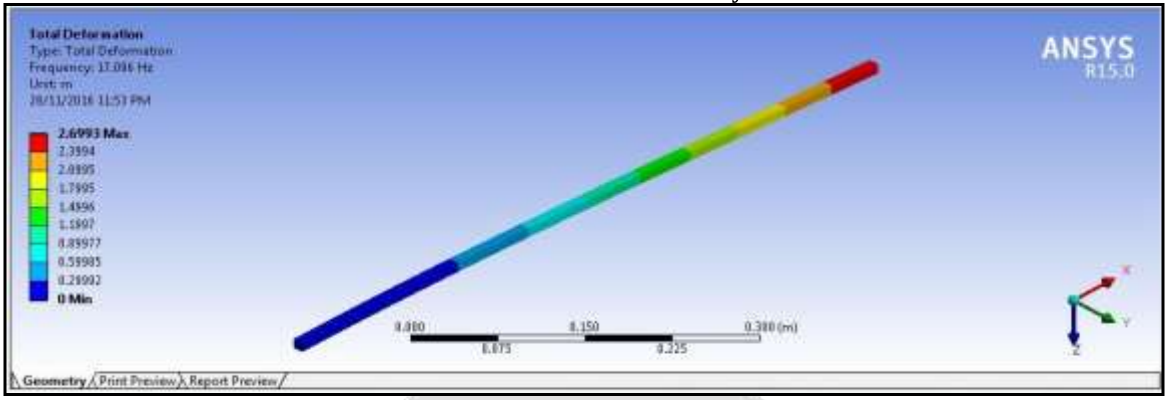
Total Deformation
Type: Total Deformation
Frequency: 17.086 Hz
Unit: m
28/11/2016 11:53 PM

Fig-2: First Mode of Vibration for uncracked beam

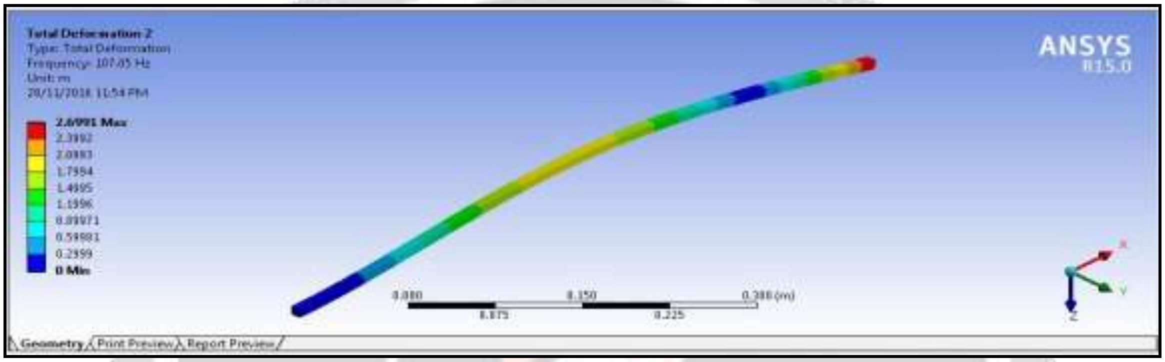
Total Deformation 2
Type: Total Deformation
Frequency: 107.05 Hz
Unit: m
28/11/2016 11:54 PM

Fig-3: Second Mode of Vibration for uncracked beam

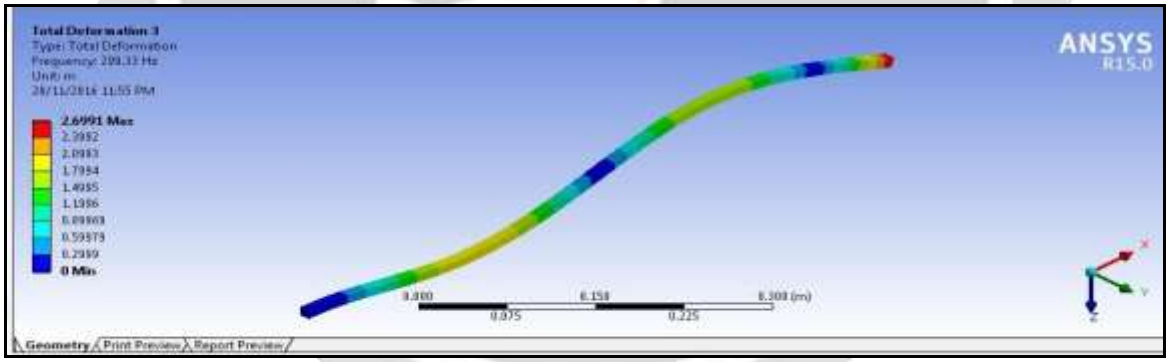
Total Deformation 3
Type: Total Deformation
Frequency: 299.33 Hz
Unit: m
28/11/2016 11:55 PM

Fig-4: Third Mode of Vibration for uncracked beam

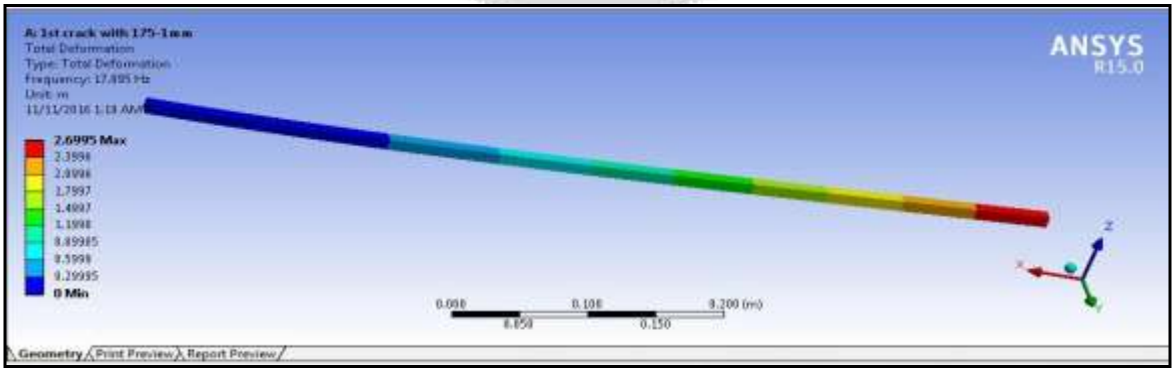
A: 1st crack with 175-1mm
Total Deformation
Type: Total Deformation
Frequency: 17.895 Hz
Unit: m
11/11/2016 1:18 AM

Fig-5: First Mode of Vibration for first cracked beam

Table-2: Natural frequencies for the beam models by using Finite Element Method

Beam model no.	RCD	RCL	FNF	SNF	TNF
1	0	0	17.096	107.05	299.33
2	0.1	0.25	17.095	107.01	299.01
3	0.2	0.25	17.090	106.83	297.91
4	0.3	0.25	17.089	106.52	295.32
5	0.1	0.50	17.090	106.96	299.20
6	0.2	0.50	17.072	106.46	299.19
7	0.3	0.50	17.041	105.69	299.15
8	0.1	0.75	17.083	107.01	299.11
9	0.2	0.75	17.019	106.98	298.27
10	0.3	0.75	16.911	106.95	296.81

5. EXPERIMENTAL SETUP

Experimental set up mainly consists of FFT Analyzer. We have considered the cantilever condition, therefore one end should be fixed. Specimen is hold in between in two heavy plates. For determining exact natural frequencies of all beam models, base should be enough rigid such that it will not introduce any other external vibrations instead of vibration of beam models itself. Torque wrench is used to tight the nut with equal torque so that equal pressure will be maintained on the part of the beam. To apply the excitation to the beam an impact hammer is used. Here we have used ENDEVCO impact hammer. The DYTRAN accelerometer is fixed on the beam near the clamped end to monitor its vibration. This uses a piezoelectric element to measure acceleration. For frequency determination OR34 FFT analyzer with 4 channels input module, Data acquisition and analysis software is used. Provide impacts by the impact hammer on the cantilever beam such that every time transverse vibration should be produced. Each model was excited by an impact Hammer.

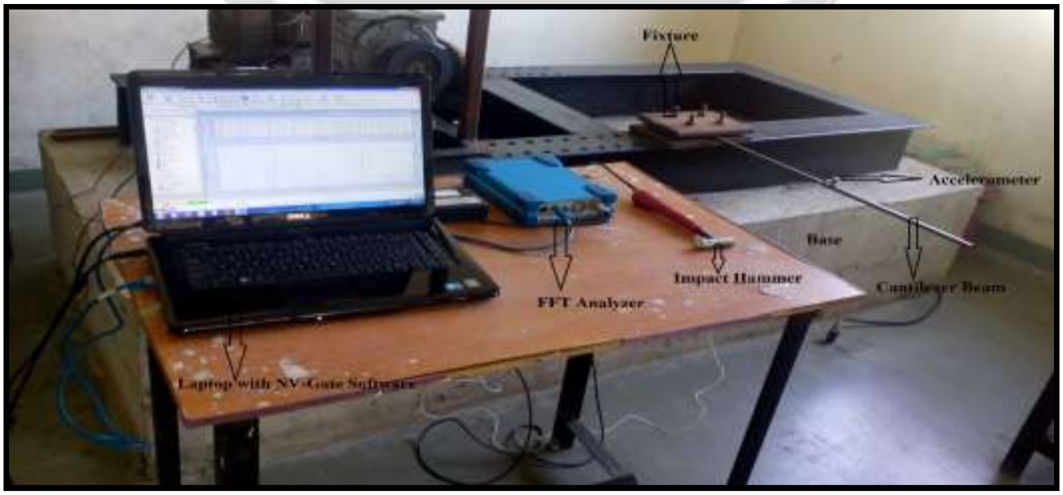

Fig-5: Experimental Setup

Signals from the impact hammer and the accelerometer will be received by the vibration analyzer for each impact. The curve known as Frequency Response Function (FRF) will be generated by the software that is used to find the natural frequencies of the cantilever beam. Observe the curve and read frequencies that correspond to peaks of the FRF. Change the frequency view as amplitude and phase. We get the frequency response function (FRF), a magnitude and phase plot with coherent plot. The peaks observed in FRF are the natural frequencies of the beam. All the components as explained above are connected neatly having a laptop loaded with software for modal analysis.

Table-3: Natural frequencies of beam model in Hz by using FFT Analyzer

Beam model no.	RCD	RCL	FNF	SNF	TNF
1	0	0	17	107	298
2	0.1	0.25	16.97	106.9	297.9
3	0.2	0.25	16.95	106.6	297.0
4	0.3	0.25	16.93	106.4	295.0
5	0.1	0.50	16.85	106.0	298.0
6	0.2	0.50	16.80	105.0	297.9
7	0.3	0.50	16.70	104.0	297.7
8	0.1	0.75	16.50	107.0	297.0
9	0.2	0.75	16.20	104.0	296.0
10	0.3	0.75	16.00	103.0	295.0

6. CRACK DETECTION BY FUZZY LOGIC TECHNIQUE

Logic is the study of the methods and principles of reasoning in all its possible forms. Classical logic deals with propositions that are required to be either true or false. Proposition and its negation are required to assume opposite truth values. Classical logic is based on two value that every proposition is either true or false. Some application require functions outside the subset, it may become necessary to resort to alternative logics. This drawback is overcomed by the fuzzy logic. The fundamental difference between classical propositions and fuzzy propositions is in the range of their truth values. The degree of truth of each fuzzy proposition is expressed by a number in the unit interval [0, 1]. A fuzzy expert system is an expert system that uses a collection of fuzzy membership functions and rules, instead of Boolean logic, to reason about data. The rules in a fuzzy expert system are generally in the form as - If x is low and y is high then z = medium

A fuzzy set is a set that is defined by a membership function. A membership function assigned with each element in the set under consideration (the universal space) a membership grade, which is a value in the interval [0, 1]. Fuzzy logic starts with the concept of a fuzzy set. A fuzzy set is a set which does not consider the crisp, clearly specified boundary. A membership function (MF) is a curve that defines how each point in the input space is generalized to a membership value (or degree of membership) between 0 and 1. The standard fuzzy operations are generalizations of the corresponding classical set operations. The concept of a fuzzy number plays an important role in formulating quantitative fuzzy linguistic variables. This are variables whose states are fuzzy numbers. For FIS Editor, inputs are first, second and third natural frequency, enter as FNF, SNF, TNF respectively. Outputs are relative crack length and relative crack depth i.e. RCL and RCD respectively.

Fuzzy controller is used as a toolbox in Matlab. Here Matlab 7.10.0 (R2010a) is used. This toolbox has two FIS (Fuzzy Inference System) type one is Mamdani and other is Sugeno. Here Mamdani FIS is used because it gives the output which is easily understand by the users. Following steps are used to form fuzzy model:

i) Define linguistic variables and terms.
ii) Build up the membership functions for them.
iii) Construct set of fuzzy rules.
iv) Convert crisp data into fuzzy data sets using membership functions known as fuzzification
v) Evaluate rules in the rule base in interface engine.
vi) Combine results from each rule interface engine.
vii) Convert output data into non-fuzzy values known as defuzzification.

As per the input and output linguistic variables are formed. Our application decides which of membership has to use and how many rules has to form. Gaussian membership function is used for input and trapezoidal membership function is used for output. Based on the fuzzy subset the fuzzy rules are defined in a general form as follows:

If (FNF is FNFi) and (SNF is SNFj) and (TNF is TNFk) then (RCD is RCDijk and RCL is RCLijk) Where i= 1to 9, j=10 to 18, k=19 to 27. Every variables has the nine membership functions.

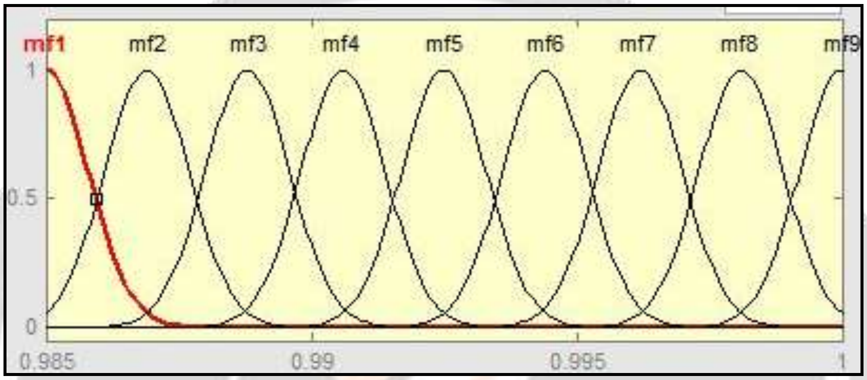

Fig-6: Gaussian membership function is used for frequencies

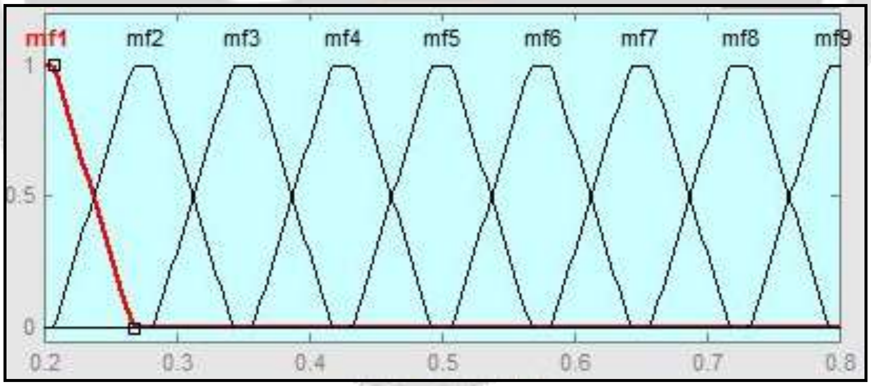

Fig-7: Trapezoidal membership function is used for RCD, RCL

To give the range we have calculated the normalized frequencies for all beam models so that exact detection of crack becomes easy. The frequency ratio (ω_C/ω) (ratio of the natural frequency of the cracked beam to that of the uncracked beam) for various crack. All this normalized frequencies are listed in table 4.

In Membership Function Editor, go to “Edit--Rules”. Here rule base is formed as per our application. We have used “IF-THEN” logic to obtain RCD and RCL. Use “AND” connection with “weight” as a one (1). In every variable select at least one membership function and press add rule, one by one add all rules by same method. After every FIS sub fuzzy system, go in ‘file’ option ‘Export to file’ to save the FIS file in MATLAB. Now all the output obtained by same procedure for all beam models using fuzzy logic are summarized in table 5. To develop the fuzzy logic model all variables should be enter in the toolbox. Same procedure is repeated for the all the variables. We can change here name of the variables and all membership functions. Here parameters of each membership function is also displayed. For next variable click twice on the next variable, previous one will be save automatically.

Table-4: Normalized frequencies of beam model

			Normalized Frequencies		
Beam Model No.	**RCL**	**RCD**	**First Mode**	**Second Mode**	**Third Mode**
1	0.0	0.0	1	1	1
2	0.25	0.1	0.9999	0.9996	0.9989
3	0.25	0.2	0.9996	0.9979	0.9953
4	0.25	0.3	0.9995	0.995	0.9866
5	0.50	0.1	0.9996	0.9992	0.9996
6	0.50	0.2	0.9986	0.9945	0.9995
7	0.50	0.3	0.9968	0.9873	0.9994
8	0.75	0.1	0.9992	0.9996	0.9993
9	0.75	0.2	0.9955	0.9993	0.9965
10	0.75	0.3	0.9892	0.9991	0.9916

Table-5: Crack Detection of beam models by using Fuzzy Logic Technique

Beam Model No.	**Input-Normalized Frequencies**			**Output**	
	First Mode	**Second Mode**	**Third Mode**	**RCL**	**RCD**
1	1	1	1	0	0
2	0.9999	0.9996	0.9989	0.275	0.102
3	0.9996	0.9979	0.9953	0.276	0.199
4	0.9995	0.995	0.9866	0.275	0.303
5	0.9996	0.9992	0.9996	0.5	0.101
6	0.9986	0.9945	0.9995	0.5	0.2
7	0.9968	0.9873	0.9994	0.5	0.303
8	0.9992	0.9996	0.9993	0.725	0.101
9	0.9955	0.9993	0.9965	0.723	0.199
10	0.9892	0.9991	0.9916	0.725	0.303

Comparison of theoretical value and Fuzzy Logic Results

Output obtained by the fuzzy logic model is compared with the theoretical values. It is represented in the following table.

Table-6: Comparison of theoretical value and fuzzy logic result with percentage error

Beam Model No.	**Theoretical Value**		**Fuzzy Logic Result**		**Error (%)**	
	RCL	**RCD**	**RCL**	**RCD**	**RCL**	**RCD**
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.25	0.1	0.275	0.102	-10	-2
3	0.25	0.2	0.276	0.199	-10.4	0.5
4	0.25	0.3	0.275	0.303	-10	-1
5	0.50	0.1	0.5	0.101	0.0	1
6	0.50	0.2	0.5	0.2	0.0	0.0
7	0.50	0.3	0.5	0.303	0.0	-1
8	0.75	0.1	0.725	0.101	3.33	-1
9	0.75	0.2	0.723	0.199	3.6	0.5
10	0.75	0.3	0.725	0.303	3.33	-1

7. CONCLUSIONS

In this study the Euler's equation, Finite Element Analysis of a cantilever beam and experimentation on FFT analyzer with single transverse crack to find out first three was done. Comparison of all frequencies of healthy and cracked beam was done. Fuzzy logic is used for the detection of crack with its location and depth. Considering all the investigations, following conclusion are drawn:

i. Natural frequencies calculated by the theoretical method is only considering the crack depth without crack location.
ii. Natural frequencies calculated by the theoretical method, finite element method and experimentation are close to each other.
iii. For the same crack location as the crack depth increases, first three natural frequencies are gradually decreases.
iv. For the same crack depth as the crack location shift towards the fixed end, first natural frequency is gradually decreases.
v. For the same crack depth as the crack location shift towards the fixed end, second and third natural frequency alter in the sinusoidal manner.
vi. The effect of the crack near the fixed end is more than the crack away from the fixed end.
vii. Small change in first three natural frequencies represent the existence of the crack.
viii. Gaussian membership function for input and trapezoidal membership function for output have a good correlation to find out the exact location and depth of crack.
ix. Fuzzy logic results when compared with the theoretical ones, it is observed that fuzzy logic provides the exact location and depth of crack as output of the fuzzy model.
x. For forming the fuzzy model, trained operator is required because fuzzy model required the higher precision to give accurate output within nanosecond.

REFERENCES

1. Dayal R. Parhi, Sasanka Choudhury, "Crack detection of a cantilever beam using Kohonen network techniques‟, Global Advance Research Journal of Engineering, Technology and Innovation, Vol. 2(5), June 2013, pp. 153- 157
2. Pankaj Charan Jena, Dayal R. Parhi, Goutam Pohit, "Faults detection of a single cracked beam by theoretical and experimental analysis using vibration signatures," IOSR Journal of Mechanical and Civil Engineering (IOSR- JMCE), Volume 4, Issue 3,pp. 01-18,2012.
3. H. Nahvi and M. Jabbari (2005). "Crack detection in beams using experimental modal data and finite element model". International Journal of Mechanical Sciences Volume 47, Issue 10, Pages 1477-1497.
4. A.Dixit, S.Hanagud, "Single beam analysis of damaged beams verified using a strain energy based damage measure", International Journal of Solids and Structures, vol.48, 2011, pp. 592-602
5. Sadettin Orhan (2007). "Analysis of free and forced vibration of a cracked cantilever beam". NDT & E International Volume 40, Issue 6, Pages 443-450.
6. M Taghi V Baghmisheh, M Peimani, M H Sadeghi and M M Ettefagh (2008). "Crack detection in beam-like structures using genetic algorithms".Applied Soft Computing Volume 8, Issue 2, Pages 1150-1160
7. F Leonard, J Lanteigne, S Lalonde and Y Turcotte (2001). "Free vibration behavior of cracked cantilever beam and crack detection". Mechanical Systems and Signal Processing Volume 15, Issue 3, Pages 529-548.
8. M .Karthikeyan and R. Tiwari (2008). "Detection, localization, and sizing of a structural flaw in a beam based on forced response measurements –An experimental investigation". Mechanism and Machine Theory Volume 45, Issue 4, Pages 584-600.
9. S.P.Lele and S. K. Maiti (2002). "Modelling of transverse vibration of short beams for crack detection and measurement of crack extension". Journal of Sound and Vibration Volume 257, Issue 3, Pages 559-583.
10. W Dansheng, Z Hongping, C Chuanyao and X Yong (2007). "An impedance analysis for crack detection in the Timoshenko beam based on the anti-resonance technique". Acta Mechanica Solida Sinica Volume 20, Issue 3, Pages 228-235.