CRACK ANALYSIS IN BEAMS USING NATURAL FREQUENCIES THROUGH FINITE ELEMENT ANALYSIS

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Abstract— *A strong interest has developed within the past several years in the dynamic behavior of turbo machinery with cracked shafts. The presence of cracks causes changes in the physical properties of a structure which introduces flexibility, and thus reducing the stiffness of the structure consequently it leads to the change in the dynamic response of the beam. Crack depth and location are the main parameters for the vibration analysis of cracked structures. So it becomes very important to monitor the changes in the response parameters of the structure to access structural integrity, performance and safety. Now a days, the procedures that are often used for crack detection are those which are called direct procedures, such as ultrasonic, X-rays, etc. However these methods have proved to be inoperative and unsuitable in some particular cases. Since they require minutely detailed periodic inspections, which are very costly. In order to avoid these costs, during the last decades, people searched for more efficient procedure in crack detection through vibration analysis. In the present study, vibration analysis of cantilever beam with and without crack is investigated by free vibration on steel and eglass/epoxy composite beam in ANSYS software. The cracks at different locations such as 100mm, 300mm, 500mm, 700mm and 900mm from the fixed end with different crack depths such as 2.5mm, 5mm, 7.5mm, 10mm and 12.5mm from the top surface are taken. The natural frequencies and mode shapes are predicted from the successful execution of ANSYS software in each case and the results are compared.*

KeyWords— ANSYS; FEM; Cantilever Beam; Natural Frequency

1. INTRODUCTION

Being very commonly used in steel construction and machinery industries, health monitoring and the analysis of damage in the form of crack in Beam structures poses a vital mean. Since long efforts are on their way to find a feasible solution for crack detection in beam structures in this regard many approaches have so far being taken place. When a structure suffers from damages, its dynamic properties can change. Crack damage leads to reduction in stiffness also with an inherent reduction in natural frequency and increase in modal damping. The work gives a feasible relationship between the modal natural frequency and the crack depth at different location. Since free vibration analysis has frequently become a topic of many studies therefore attention is focused it only. Crack localization and sizing in a beam from the free and forced response measurements method is indicated by Karthikeyan et al. [1]. In the beam Timoshenko beam theory is used for modeling transverse vibrations. FEM is used for the free and forced vibration analysis of the cracked beam and open transverse crack is selected for the crack model .Being iterative in nature the iteration starts with a guess for the crack depth ratio and iteratively estimates the crack location and crack depth until the desired convergence for both is reached. In the most general terms, damage can be defined as changes appearing in a system that may affect its current or future performance. From this definition of damage once can see that damage is not meaningful without a comparison between two different states of the system, one of which is assumed to represent the initial (pristine) state, and the other the damaged state. The definition of damage can also be limited to changes to the material and/or geometric properties of the system, including changes to the boundary conditions and system connectivity, which adversely affect the current or future performance of that system. The basic premise in modal analysis based damage detection is that damage will significantly change the stiffness, mass, or energy dissipation properties of a system, which in turn, modifies the measured dynamic response of the system. One of the most challenging aspects of modal analysis based damage detection is that damage is typically a local phenomenon and may not significantly influence the lower-frequency response of the structure that is normally measured during FFT analyzer tests.

2. LITERATURE SURVEY

Kisa et.al[1] presented a novel numerical technique applicable to analyze the free vibration analysis of uniform and stepped cracked beams with circular cross section. In this approach in which the finite element and component mode synthesis methods are used together, the beam is detached into parts from the crack section. These substructures are joined by using the flexibility matrices taking into account the interaction forces derived by virtue of fracture mechanics theory as the inverse of the compliance matrix found with the appropriate stress intensity factors and strain energy release rate expressions. Orhan Sadettin[2] has studied the free and forced vibration analysis of a cracked beam was performed in order to identify the crack in a cantilever beam. Single- and two-edge cracks were evaluated. Dynamic response of the forced vibration better describes changes in crack depth and location than the free vibration in which the difference between natural frequencies corresponding to a change in crack depth and location only is a minor effect. Chasalevris Athanasios C et.al[3] have studied the dynamic behavior of a cracked beam with two transverse surface cracks. Each crack is characterized by its depth, position and relative angle. A local compliance matrix of two degrees of freedom, bending in the horizontal and the vertical planes is used to model the rotating transverse crack in the shaft and is calculated based on the available expressions of the stress intensity factors and the associated expressions for the strain energy release rates. Nahvi and Jabbari M[4] have developed an analytical, as well as experimental approach to the crack detection in cantilever beams by vibration analysis. An experimental setup is designed in which a cracked cantilever beam is excited by a hammer and the response is obtained using an accelerometer attached to the beam. To avoid non-linearity, it is assumed that the crack is always open. To identify the crack, contours of the normalized frequency in terms of the normalized crack depth and location are plotted.

Loutridis et.al[5] presented a new method for crack detection in beams based on instantaneous frequency and empirical mode decomposition is proposed. The dynamic behaviour of a cantilever beam with a breathing crack under harmonic excitation is investigated both theoretically and experimentally. Ertugrul et.al[6] have studied to obtain information about the location and depth of cracks in cracked beams. For this purpose, the vibrations as a result of impact shocks were analyzed. The signals obtained in defect-free and cracked beams were compared in the frequency domain. The results of the study suggest to determine the location and depth of cracks by analyzing the from vibration signals. Patil, Maiti S.K[7] have utilized a method for prediction of location and size of multiple cracks based on measurement of natural frequencies has been verified experimentally for slender cantilever beams with two and three normal edge cracks. The analysis is based on energy method and representation of a crack by a rotational spring. For theoretical prediction the beam is divided into a number of segments and each segment is considered to be associated with a damage index. The damage index is an indicator of the extent of strain energy stored in the rotational spring. The crack size is computed using a standard relation between stiffness and crack size. Number of measured frequencies equal to twice the number of cracks is adequate for the prediction of location and size of all the cracks. Dharmaraju et.al[8] have used Euler–Bernoulli beam element in the finite element modeling. The transverse surface crack is considered to remain open. The crack has been modeled by a local compliance matrix of four degrees of freedom. This compliance matrix contains diagonal and off-diagonal terms. A harmonic force of known amplitude and frequency is used to dynamically excite the beam. The present identification algorithms have been illustrated through numerical examples. Jeon-Tae Kim et.al[9] have evaluated frequency based damage detection method and the mode shape based damage detection method for several damage scenarios by locating and sizing damage in numerically simulated prestressed concrete beams for which two natural frequencies and mode shapes were generated from finite element models. The result of the analyses indicates that the FBDD method and the MBDD method correctly localize the damage and accurately estimate the sizes of the cracks simulated in the test beam.

Darpe et.al[10] have studied simple Jeffcott rotor with two transverse surface cracks. The stiffness of such a rotor is derived based on the concepts of fracture mechanics. Subsequently, the effect of the interaction of the two cracks on the breathing behavior and on the unbalance response of the rotor is studied. J.K.Sinha et.al[11] Presented simplified approach to modeling cracks in beams undergoing transverse vibration is presented. The modeling approach used Euler Bernoulli beam elements with small modifications to the local flexibility in the vicinity of cracks. This crack model is then used to estimate the crack locations and sizes, by minimizing the difference between the measured and predicted natural frequencies via model updating. Yang X.F et.al[12] have developed an energy-based numerical model is to investigate the influence of cracks on structural dynamic characteristics during the vibration of a beam with open crack. Upon the determination of strain energy in the cracked beam, the equivalent bending stiffness over the beam length is computed. S.Chinchalkar[13] described a numerical method for determining the location of a crack in a beam of varying depth when the lowest three natural frequencies of the cracked beam are known. The crack is modeled as a rotational spring and graphs of spring stiffness versus crack location are plotted for each natural frequency. The point of intersection of the three curves gives the location of the crack. P.N.Saavedra, L.A.Cuitino[14] presented theoretical and experimental dynamic behaviour of different multi beams systems containing a transverse crack and the additional flexibility that crack generates in its vicinity was evaluated using strain energy density function given by linear fracture mechanic theory Based on this flexibility, a new cracked finite element stiffness was deduced, which was subsequently used in the FEM analysis of crack system. .D.Pantliou et.al[15] they considered a homogeneous, isotropic, elastic bar of orthogonal shape with a single-edge crack under alternating uniform axial stress. The analytical determination of the dynamic characteristics of the cracked structure yielded the damping factor of the bar, the material damping factor and a good correlation of depth of crack with the damping factor. Experimental results on cracked bars were in good correlation with the analysis.

The geometry of the cantilever beam subjected to free vibration is outlined as follows:

Length of the beam (l) = 1000mm

Width of the beam (w) = 50mm

Depth of the beam (d) = 25 mm

MECHANICAL PROPERTIES OF STEEL

Young’s modulus of elasticity (E) =210Gpa

Density of the material (ρ) =7800Kg/m3

Poisson’s ratio (ν) =0.28

MECHANICAL PROPERTIES OF COMPOSITE MATERIAL

TABLE-1 MECHANICAL PROPERTIES OF COMPOSITE FIBERS

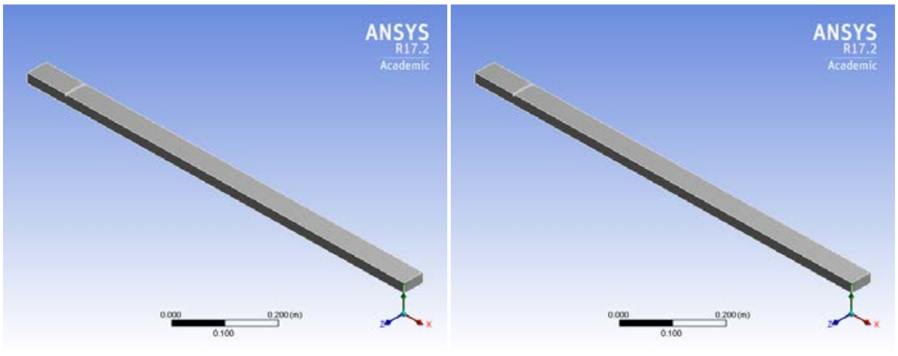
Type of fiber	Young's Modulus E_f (GPa)	Poisson's ratio ν_f	Density ρ_f(kg/m^3)
E-Glass	72.4	0.28	2.54X10^3

TABLE-2 MECHANICAL PROPERTIES OF COMPOSITE RESIN

Type of resin	Young's Modulus E_m (GPa)	Poisson's ratio ν_m	Density ρ_m (kg/m^3)
Epoxy	3.4	0.3	1.28X10^3

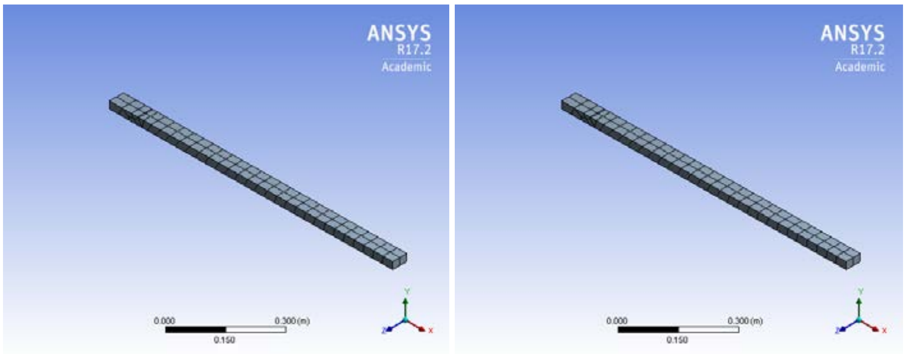
The Volume fraction of fiber (Vf) and Volume fraction of matrix (Vm)is considered in this present work.
Vf= 0.5, Vm= 0.5
Longitudinal Modulus (E1)
E1 = Ef ν f + Em ν m(for long fibers)
E1 =η0ηl Ef ν f + Em ν m (for short fibers)
Where
ηl=Length correction factor(if the length of the fiber >1mm, ηl=1)
η0= fiber orientation distribution factor.
= 0.0 align fibers in transverse direction
= 1/5 random orientation in any direction (3D)
= 3/8 random orientation in plane (2D)
= 1/2 biaxial parallel to the fibers
= 1.0 unidirectional parallel to the fibers
E1 =η0ηl Ef ν f + Em ν m
E1 =(0.2) (72.4)(0.5) + 3.4(0.5)
E1 = 8.94 GPa
Poisson's ratio (ν12)
ν 12 = Vm ν f + Vf ν m
ν 12 = 0.28(0.5) + 0.3(0.5)
ν 12 = 0.29
Density(ρC)
ρC=ρf ν f +ρm ν m
ρC =0.5 (2.54X103) + 0.5 (1.28X103)
ρC = 1910 kg/m3

3. MODELLING OF CANTILEVER BEAMS



(a) Steel cracked (b) Eglass/Epoxy cracked

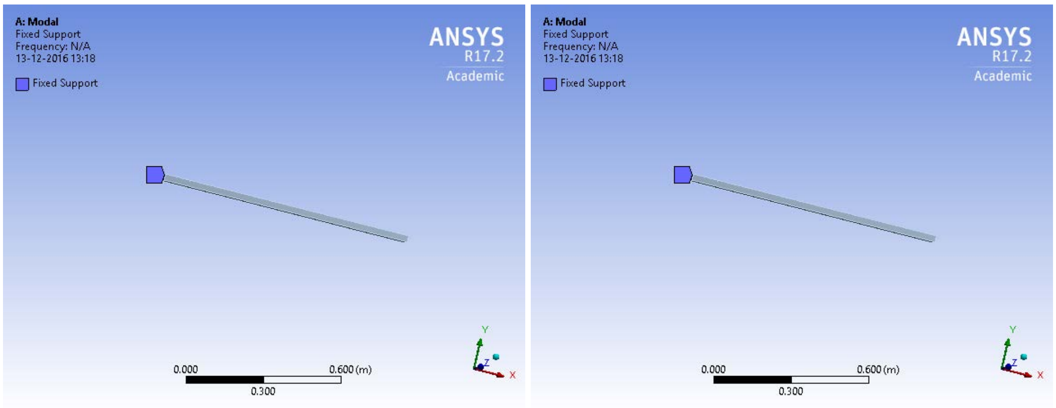
Fig.1: (a) Model of steel cracked cantilever beam
at ζ=100mm, dc=2.5mm (b)Model of Eglass/epoxy composite cracked cantilever beam at ζ=100mm, dc=2.5mm



(a) Steel Cracked (b) Eglass/Epoxy cracked

Fig 2: (a) Meshed model of steel cracked cantilever beam at ζ=100mm, dc=2.5mm (b) Meshed Model of Eglass/epoxy composite cracked cantilever beam at ζ=100mm, dc=2.5mm

The one end of the beam is constrained all degree of freedom (Left) and other end of the beam is free to vibrate (Right).

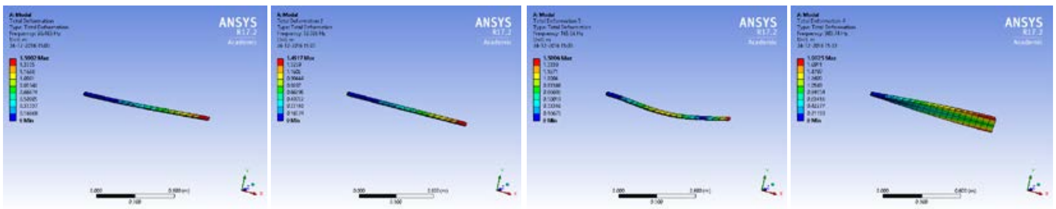


(a) Steel Cracked (b) Eglass/Epoxy cracked

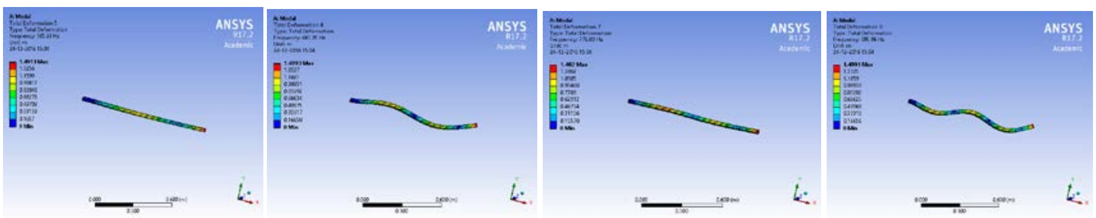
Fig3: (a) Boundary conditions of steel cracked cantilever beam at ζ=100mm, dc=2.5mm (b) Boundary conditions of Eglass/epoxy composite cracked cantilever beam at ζ=100mm, dc=2.5mm

4. Results & Discussion

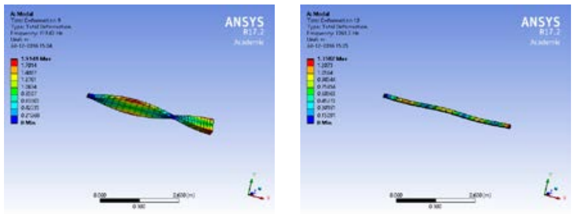
Mainly the cantilever beam is modeled for steel and Eglass/epoxy composite with a crack located at 100mm from the fixed end with 2.5mm crack depth. Mesh is generated and boundary conditions are applied. In this present, free vibrational analysis is done on meshed cantilever beam. The natural frequencies are obtained in ANSYS software for each case.



(a) First mode (b) Second mode (c) Third mode (d) Fourth mode

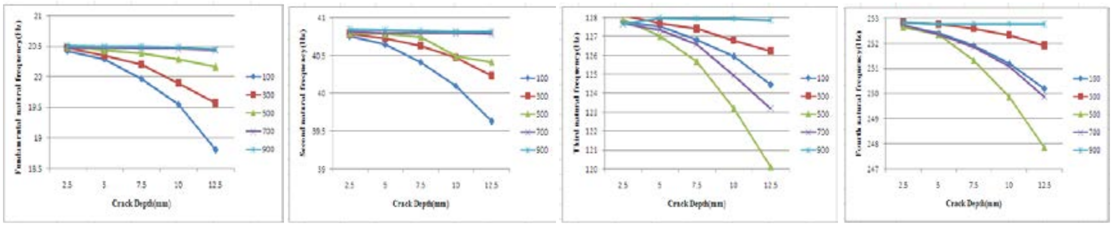


e) Fifth mode (f) Sixth mode (g) Seventh mode (h) Eighth mode

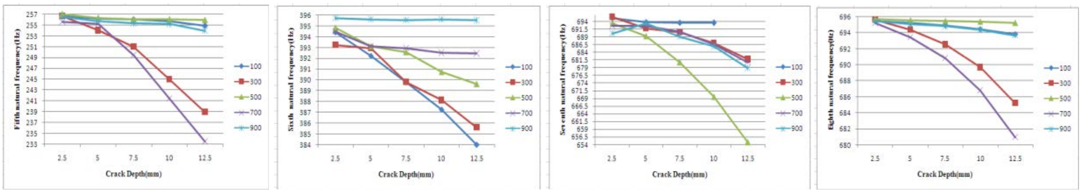


(i)Ninth mode (j) Tenth mode

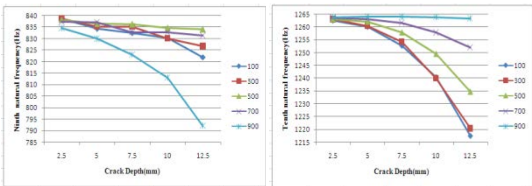
Fig 4: one to Tenth mode shape of eglass/epoxy composite cracked cantilever beam at ζ=100mm, dc=2.5mm



(a)First (b) Second (c) Third (d) Fourth

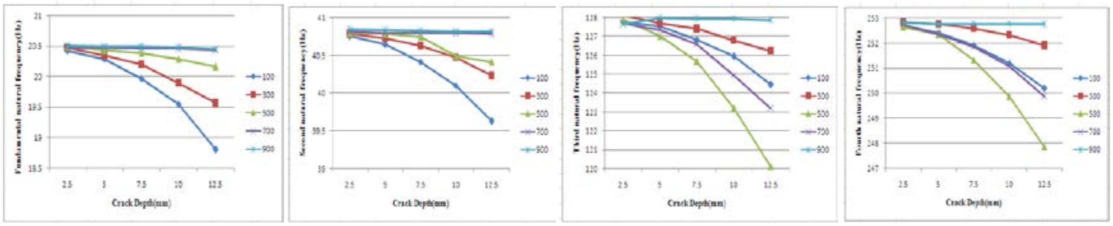


(e) Fifth (f) sixth (g) seventh (h) eighth

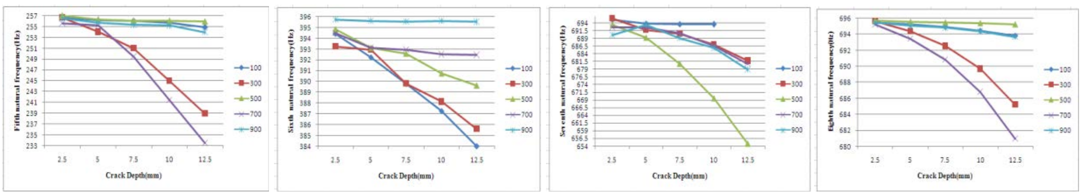


(i) Ninth (j) tenth

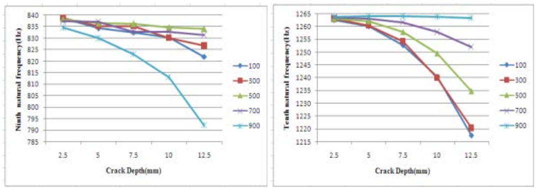
Fig 5: Natural frequency of steel cantilever beam in terms of crack depth for various crack positions



(b)First (b) Second (c) Third (d) Fourth



(e) Fifth (f) sixth (g) seventh (h) eighth



(ii)Ninth (j) tenth

Fig 7: natural frequency of eglass/epoxy composite cantilever beam interms of crack depth for various crack positions

5. CONCLUSION

The most common structural failure is the existence of a crack. Cracks are present in structures due to various reasons. The presence of a crack could not only cause a local variation in the stiffness but it could affect the mechanical behavior of the entire structure to a considerable extent. The presence of crack in structure member introduces local flexibilities which can be computed and used in structural analysis. It is shown that the natural frequency changes substantially due to the presence of cracks. The changes depending upon the location and size of the cracks.

The natural frequency of steel cantilever beam is lower than the natural frequency of an eglass/epoxy composite cantilever beam. In free vibration, the frequency of a beam with a crack is lower than that of the beam without a crack. When the crack positions are constant, the natural frequencies of a cracked beam decreases as the crack depth increases because the material gets removed the stiffness of the beam. The natural frequency shift (difference between frequencies) decreases for same depth of crack as the position of the crack changes along the length from fixed end to free end of a cantilever beam. The change in frequency is not only a function of crack depth and crack location but also of the mode number.

REFERENCES

[1] Kisa Murat and Gurel M. Arif, Free vibration analysis of uniform and stepped cracked beams with circular cross sections, International Journal of Engineering Science 45,(2007), pp.364–380.
[2] Orhan Sadettin, Analysis of free and forced vibration of a cracked cantilever beam, NDT and E International 40, (2007), pp.43-450.
[3] Chasalevris Athanasios C. and Papadopoulos. Identification of multiple cracks in beams under bending, Mechanical Systems and Signal Processing 20, (2006), pp.1631-1673.
[4] Nahvi and Jabbari M, Crack detection in beams using experimental modal data and finite element model, International Journal of Mechanical Sciences 47, (2005), pp.1477–1497
[5] Loutridis S, Douka E. and Hadjileontiadis., Forced vibration behaviour and crack detection of cracked beams using instantaneous frequency, NDT&E International, 38(5),(2005), pp. 411-419.
[6] Ertugrul Cam, Orhan Sadettin and Luy Murat, An analysis of cracked beam structure using impact echo method, NDT and E International 38 (2005), pp.368–373.
[7] Patil., Maiti S.K, Experimental verification of a method of detection of multiple cracks in beams based on frequency measurements, Journal of Sound and Vibration 281,(2005),pp.439–451.
[8] Dharmaraju N, Tiwari R. and Talukdar S, Identification of an open crack model in a beam based on force–response measurements, Computers and Structures 82, (2004),pp.167–179.
[9] Jeon-Tae Kim, Yeon-Sun Ryu, Hyun-Man Cho, Norris Stubbs, Damage identification in beam-type structures: frequency-based method vs mode shape-based method, Engineering Structures 25 (2003) 57-67.
[10] Darpe A.K, Gupta K., Chawla A, Dynamics of a two-crack rotor, Journal of Sound and Vibration, 259 (3), (2003), pp.649–675.
[11] J.K.Sinha, M.I.Friswell and S.Edwards, Simplified Models for the Location of Cracks in Beam Structures using Measured Vibration data, Journal of Sound and Vibration (2002) 251(1), 13-38.
[12] Yang X.F, Swamidas A.S.J. and Seshadri, Crack Identification in vibrating beams using the Energy Method, Journal of Sound and vibration 244(2), (2001), pp.339-357.
[13] S.Chinchalkar, Determination of crack location in beams using Natural Frequencies, Journal of Sound and Vibration (2001) 247(3), 417-429.
[14] P.N.Saavedra, L.A.Cuitino, Crack detection and vibration behaviour of cracked beams, Computers and Structures 79 (2001) 1451-1459.
[15] S.D.Pantliou, T.G.Chondros and V.C.Argyrakis, Damping factor as an Indicator of Crack Severity, Journal of Sound and Vibration (2001) 241(2), 235-245.
[16] Kisa M. And Brandon J, The Effects of closure of cracks on the dynamics of a cracked cantilever beam, Journal of Sound and Vibration, 238(1), (2000) pp.1-18.
[17] J.Fernadndez-Saez, L.Rubio et.al Approximate calculation of the Fundamental frequency for bending Vibrations of cracked beams, Journal of Sound and Vibration (1999) 225(2), 345-352.
[18] Ruotolo R, et al Harmonic analysis of the vibrations of a cantilevered beam with a closing crack, Computers and Structures, 61(6), (1996), pp.1057–1074.
[19] T.C.Tsai And Y.Z.Wang, Vibration Analysis and Diagnosis of a Cracked Shaft, Journal of Sound and Vibration (1996) 192(3), 607-620.
[20] W.M.Ostachowicz and M.Krawczuk, Analysis of the Effect of Cracks on the Natural Frequencies of a Cantilever Beam, Journal of Sound and Vibration (1991) 150(2), 191-201.