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Crack Detection in stepped Cantilever Beam

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Abstract- Crack changes the dynamic behavior of the structure and by examining this change, crack size and position can be identified. Non destructive testing (NDT) methods are used for detection of crack which are very costly and time consuming. Currently research has focused on using modal parameters like natural frequency, mode shape and damping. To detect crack in beams. In this paper a method for detection of open transverse crack in a slender Euler–Bernoulli beam is presented. Experimental Modal Analysis (EMA) was performed on cracked beams and a healthy beam. The first three natural frequencies were considered as basic criterion for crack detection. To locate the crack, 3D graphs of the normalized frequency in terms of the crack depth and location are plotted. The intersection of these three contours gives crack location and crack depth. Out of several case studies conducted the results of one of the case study is presented to demonstrate the applicability and efficiency of the method suggested.

Index Terms- Crack, Euler–Bernoulli, mode shape, natural frequency.

1. INTRODUCTION

1.1 Motivation.

The physical discontinuity occured in the geometry of the structures or machine components is termed as ‘Crack or Damage’. These cracks occured in the structures or machine components have various causes. They may be fatigue cracks that take place under service conditions as a result of the limited fatigue strength. They may also be due to mechanical defects as in case of turbine blades of jet turbine engines. In these engines, the cracks are caused by sand and small stones sucked from the surface of the runway. Another group involve cracks which are inside the material and are created as a result of manufacturing processes.In order to overcome above mentioned difficulties, a number of crack detection techniques have been developed. Non-destructive testing methods for crack diagnosis have a lot of practical utilities. Number of such methods are available. The important ones among them are the ultrasonic testing, X-ray technique, magnetic particle method, dye penetrant technique etc. But these have drawbacks like the necessity to have access to all parts of component and the necessity to inspect the component individually. Again the size of structure under inspection limits the suitability of common NDT’s. It is a tedious, time consuming job to apply common NDT’s to large structures like long pipelines, rail tracks, electric transmission towers etc.

1.2 Aim & Scope:

The proposed method is based on the analysis of changes observed in the parameters of dynamic system because of crack. There are number of parameters to analyse but in proposed methodology, modal frequency parameter is selected because modal frequencies are properties of whole component, so only one test is required to assess the integrity of complete component. Crack induces local flexibility in the structures at crack location and due to this modal frequencies are reduced. The reduction in modal frequencies depends on crack depth, crack location and number of cracks.

The measurement of natural frequencies of a machine component at two or more stages of its life offers the possibility of locating damage in the component and of determining severity of the damage. If one set of frequencies is measured before the component was put into service, subsequent frequency measurements could be used to test whether the structure is still sound..

2. LITERATURE SURVEY

The methods of detecting location and size of a crack based on vibration measurements are relatively new. Only in the last two decades, some work has been done on the possibility of using vibration as a basis for crack detection. The presence of crack changes the parameters of a dynamic system. These are modal and structural parameters. The modal parameters include modal frequencies, mode shapes and modal damping values. On the other hand, structural parameters include stiffness or flexibility, mass and damping matrices. The technique utilizes one or more of these parameteres for crack detection.A.V. Deokar et.al [1] in his paper study of effect of cracks on vibration response of a structure is important for developing vibration signature based crack detection method. It is observed that, presence of crack causes the reduction in stiffness of the structure and hence the reduction in the natural frequencies. Again it affects each mode of vibration differently. Particularly the stress is given on natural frequency as a crack detection parameter. In this chapter, various approaches and methods cited in literature to correlate cracks and modal parameters are discussed.F.K. Choy et.al [2] in his paper capability of identifying both location and severity of damages of faulted elements in a structural system is greatly needed under the present demands of constantly maintaining the safety of civil engineering structures. Presented in this paper is a methodology based on vibration theory that can be used for the detection of faults in a beam of either uniform or non uniform cross section and under a variety of boundary conditions, including simple support, cantilever support, and beam on elastic foundation.Theoretical developments of the methodology are presented first, followed by numerical experiments to demonstrate the feasibility of the method. Numerical experiments include various damage scenarios such as those faults occurring in a beam section as well as in a sub grade foundation. Furthermore, damage scenarios involving both single fault and multiple faults are also presented.

2.2Crack Assessment Based On Vibration Measurement:

Depending on the vibration parameter used for the crack detection process the methods are broadly classified as under:

•Methods based on change of natural frequencies
•Methods based on vibration mode shapes and
•Methods based on structural parameters.

These are explained in the following sections.

2.2.1 Methods based on change of natural frequencies:

Mostly modal frequencies are used for monitoring the crack because modal frequencies are properties of whole component. The natural frequency of a component decreases as a result of crack.

Many methods have been developed to detect and locate the crack by measuring changes in the natural frequencies. One of the earliest works regarding the crack detection using vibration is done by Adams and Cawley et.al. In their work, a theoretical model based on the receptance technique for analysis of structures that can be treated as a one dimensional is presented.

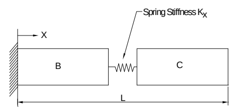


Figure 2.1 Structure with spring representation of damage

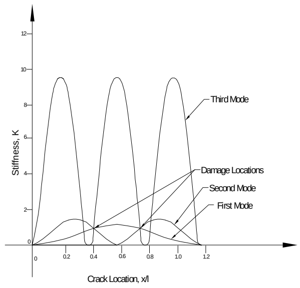


Figure 2.2 Damage Location in a Straight bar

If Kx is infinite, there is no damage, while decreasing values of Kx indicate increasing damage. If the parts B and C of the bar on either side of the crack having receptances β and γ respectively, then the natural frequencies of the cracked bar are such that the following equation is satisfied:

$$\beta_{xx} + \gamma_{xx} + \frac{1}{K_x} = 0 \qquad \text{------- (2.1)}$$

$$\frac{EA}{K_x} = \frac{1}{\lambda}\left[\cot \lambda x + \cot(\lambda(l - x))\right] \text{-------(2.2)}$$

3.THEORETICAL ANALYSIS FOR CRACK ASSESSMENT

3.1 Introduction:

The literature survey implies the vibrational frequency measurement based crack assessment of large structures as a faster, feasible and reliable for single crack assessment in beams (cantilever, simply supported etc.).

3.2 Free Vibrations Of Beam:

The beam represents one of the most important structural members in engineering design and construction. There is no design in which the beam problems in one form or other do not arise. Its importance can be gauged not only from the vastness of literature that exists on the subject but also from the depth and thoroughness with which beam analysis has been carried out.

In considering the vibration of the beam, we neglect rotary inertia and shear deflection; and only consider the deflection due to bending. This model of beam is called the ‘Euler-Bernoulli model’.

3.3 Equation Of Motion Of Euler-Bernoulli for beam:

Letting ρ be the volume density of the beam material, 'A' the cross sectional area, 'EI' the modulus of flexural rigidity and 'y' the transverse deflection.

Then the strain energy V of the flexural deformation of the beam is given by equation $V = \frac{EI}{2}\int_0^1 (y_{xx})^2\,dx$ ---------(3.1)

The expression for the kinetic energy T is given by,

$$T = \frac{\rho A}{2}\int_0^1 {y_t}^2\,dx \quad \text{---------(3.2)}$$

Formulating the Lagrangian L from Eq. 3.1 and Eq. 3.2 and applying the Hamilton's principle,

3.3.1Dynamic Response Of Cantilever Beam:

The general differential equation governing transverse vibration of a beam is given as

$$\frac{\partial^2 y}{\partial t^2} + a^2 . \frac{\partial^4 y}{\partial x^4} = 0 \quad \text{--------(3.6)}$$

where $a = \sqrt{\frac{EI}{\rho A}}$

And x = Distance from one of the ends of beam to the desired point on the beam

y = Amplitude of vibration measured at position x

E = Modulus of elasticity of the beam material

I = Moment of inertia of the beam

ρ = Density of the beam material

A = Cross-sectional area of the beam

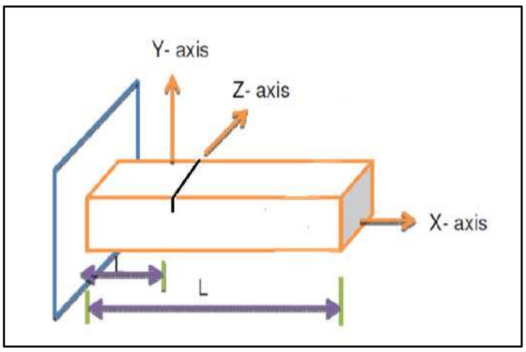
3.4. Assessing a Crack In Beam Structures:

The lateral vibrations of beam in XY plane is often modeled by Euler-Bernoulli beam. The beam equation for such vibration is as derived in section 3.2.1

$$\frac{\partial^2 y}{\partial t^2} + a^2 \frac{\partial^4 y}{\partial x^4} = 0 \quad \text{--------- (3.15)}$$

Where

$$a^2 = \frac{EI}{\rho A}$$



By method of separation of variables, the formal solution of this equation is

$$d^4U_1/d\beta^4 + \lambda_1^4 U_1 = 0, \qquad 0 \leqslant \beta \leqslant e/L,$$
$$d^4U_2/d\beta^4 + \lambda_1^4 U_2 = 0, \qquad e/L \leqslant \beta \leqslant \beta_1, \qquad \beta_1 = L_1/L,$$
$$d^4U_3/d\beta^4 + \lambda_2^4 U_3 = 0, \qquad \beta_1 \leqslant \beta \leqslant \beta_2, \qquad \beta_2 = L_2/L,$$
$$d^4U_4/d\beta^4 + \lambda_3^4 U_4 = 0, \qquad \beta_2 \leqslant \beta \leqslant 1,$$

$$\lambda_1^4 = \omega^2\rho A_1 L^4/EI_1,\ \lambda_2^4 = \omega^2\rho A_2 L^4/EI_2,\ \lambda_3^4 = \omega^2\rho A_3 L^4/EI_3 \text{ and } \beta = x/L.$$

$$\left|\begin{array}{cccccccc}
1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \cosh\alpha_1 & \sinh\alpha_1 & \cos\alpha_1 & \sin\alpha_1 \\
0 & 0 & 0 & 0 & \sinh\alpha_1 & \cosh\alpha_1 & -\sin\alpha_1 & \cos\alpha_1 \\
0 & 0 & 0 & 0 & \cosh\alpha_1 & \sinh\alpha_1 & -\cos\alpha_1 & -\sin\alpha_1 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\cosh\alpha & \sinh\alpha & \cos\alpha & \sin\alpha & -\cosh\alpha & -\sinh\alpha & -\cos\alpha & -\sin\alpha \\
\cosh\alpha & \sinh\alpha & -\cos\alpha & -\sin\alpha & -\cosh\alpha & -\sinh\alpha & \cos\alpha & \sin\alpha \\
\sinh\alpha & \cosh\alpha & \sin\alpha & -\cos\alpha & -\sinh\alpha & -\cosh\alpha & -\sin\alpha & \cos\alpha \\
\frac{K}{\lambda_1}\sinh\alpha+\cosh\alpha & \frac{K}{\lambda_1}\cosh\alpha+\sinh\alpha & -\frac{K}{\lambda_1}\sin\alpha-\cos\alpha & \frac{K}{\lambda_1}\cos\alpha-\sin\alpha & -\frac{K}{\lambda_1}\sinh\alpha & -\frac{K}{\lambda_1}\cosh\alpha & \frac{K}{\lambda_1}\sin\alpha & -\frac{K}{\lambda_1}\cos\alpha
\end{array}\right.$$

$$\left.\begin{array}{cccccccc}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \cosh\lambda_3 & \sinh\lambda_3 & -\cos\lambda_3 & -\sin\lambda_3 \\
0 & 0 & 0 & 0 & \sinh\lambda_3 & \cosh\lambda_3 & \sin\lambda_3 & -\cos\lambda_3 \\
-\cosh\alpha_2 & -\sinh\alpha_2 & -\cos\alpha_2 & -\sin\alpha_2 & 0 & 0 & 0 & 0 \\
-F_1\sinh\alpha_1 & -F_1\cosh\alpha_2 & F_1\sin\alpha_2 & -F_1\cos\alpha_2 & 0 & 0 & 0 & 0 \\
-G_1\cosh\alpha_2 & -G_1\sinh\alpha_2 & G_1\cos\alpha_2 & G_1\sin\alpha_2 & 0 & 0 & 0 & 0 \\
-H_1\sinh\alpha_2 & -H_1\cosh\alpha_2 & -H_1\sin\alpha_2 & H_1\cos\alpha_2 & 0 & 0 & 0 & 0 \\
\cosh\alpha_3 & \sinh\alpha_3 & \cos\alpha_3 & \sin\alpha_3 & -\cosh\alpha_4 & -\sinh\alpha_4 & -\cos\alpha_4 & -\sin\alpha_4 \\
\sinh\alpha_3 & \cosh\alpha_3 & -\sin\alpha_3 & \cos\alpha_3 & -F_2\sinh\alpha_4 & -F_2\cosh\alpha_4 & F_2\sin\alpha_4 & -F_2\cos\alpha_4 \\
\cosh\alpha_3 & \sinh\alpha_3 & -\cos\alpha_3 & -\sin\alpha_3 & -G_2\cosh\alpha_4 & -G_2\sinh\alpha_4 & G_2\cos\alpha_4 & G_2\sin\alpha_4 \\
\sinh\alpha_3 & \cosh\alpha_3 & \sin\alpha_3 & -\cos\alpha_3 & -H_2\sinh\alpha_4 & -H_2\cos\alpha_4 & -H_2\sin\alpha_4 & H_2\cos\alpha_4 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{array}\right| = 0, \quad (18)$$

4. MODELING OF STEPPED CANTILEVER BEAM

Solid Modeling Of Stepped Cantilever Beam CATIA is very powerful tool. You can harness this power to capture the design intent of your models by acquiring an understanding of fundamental concepts that define the software and why exist. This lesson discusses these concepts in detail. You should keep them in mind as you progress through this chapter.

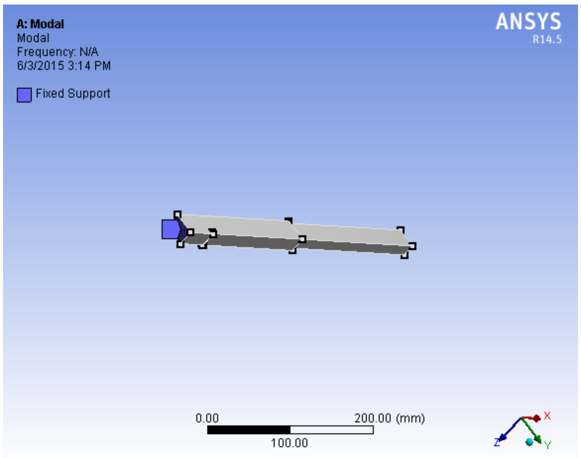
Design Concepts: You can design many different types of models in CATIA. However, before you

begin your design project, you need to understand a few basic design concepts:
Design Intent: Before you design your model, you need to identify the design intent. Design intent defines the purpose and function of the finished product based on product specifications or requirements. Capturing design intent builds value and longevity into your products. The key concept is at the core of the CATIA feature based modeling. Feature-based modelling: CATIA part modeling begins with the creating individual geometric features one after another. These features become interrelated to other features as reference them during the design process.

Parametric design:The interrelationships between features allow the model to become parametric. So, if you alter one feature and that change directly affects other related (dependent) features, then CATIA dynamically changes those related features. This parametric ability maintains the integrity of the part and preserves your design intent.Associativity: CATIA maintains design intent outside Part mode through associativity. As you continue to design the model, you can add parts, or electrical wiring. All of these functions are fully associative within CATIA. So, if you change your design at any level, your project will dynamically reflect the changes at levels, preserving design intent.

4.4 Assessment Of ANSYS Results:
The data from the ANSYS package 12.0 results were tabulated, and plotted (in a three dimensional plot) in the form of frequency ratio (ωc/ω) (ratio of the natural frequency of the cracked beam to that of the uncracked beam) versus the crack depth (a) for various crack location (x). Tables 4.2 show the variation of the frequency ratio as a function of the crack depth and crack location for beams with fixed-free ends.
Finite element model of a uniform cantilever beam imposing boundary conditions is shown in Fig. 4.2. A finite element package, ANSYS 12.0 is used to compute the eigen frequency changes for a mild steel cantilever beam with combination of various crack depth ratios and non-dimensional crack locations. The results of those are given in Table 4.1
While applying the method to the present problem, it is found that the three curves do not intersect at a common point in a number of cases. In order to avoid this difficulty, a scheme, which is a sort of calibration of modulus of elasticity, suggested by Adams and Cawley [1] is employed. The modulus of elasticity used as an input in the analytical approach (equation 3.19) for each mode is calculated using the FEM based uncracked natural frequency for the corresponding mode.

4.5 Conclosure:In this chapter, the analytical method for single discrete crack in a uniform cantilever beam is presented. In actual implementation of method, it is observed that the Young’s modulus, E has to be modified. This is to take care of error in stiffness of structure due to FEM modeling. The outcome of the method is satisfactory as seen in tabulated results.



Case No.	Simulated crack data		Natural Frequencies (Hz)		
	Location®(L1/L2)	a/h Depth Ratio	F1	F2	F3
Uncracked			75.28	113.56	366.36
1	0.2	0.2	74.80	111.07	366.25
2	0.4	0.3	74.86	111.13	366.63
3	0.6	0.4	74.84	110.69	355.04

This is mainly in the form of PC (Laptop) when the excitation occurs to the structure the signals transferred to the portable PULSE and after conversion comes in graphical form through the software. Mainly the data includes graphs of force Vs time, frequency Vs time resonance frequency data etc. It is displayed in Fig.

5. RESULTS AND DISCUSSIONS

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The material data is as follows. Six crack locations are considered for prediction. The natural frequencies for both the uncracked and cracked geometries are computed by the finite element method. While applying the method to the present problem, it is found that the three curves do not intersect at a common point in a number of cases. In order to avoid this difficulty, a scheme which is a sort of calibration of modulus of elasticity suggested in reference is employed The modulus of elasticity used as an input in the analytical approach equation for each mode is calculated using the FEM based uncracked natural frequency for the corresponding mode.

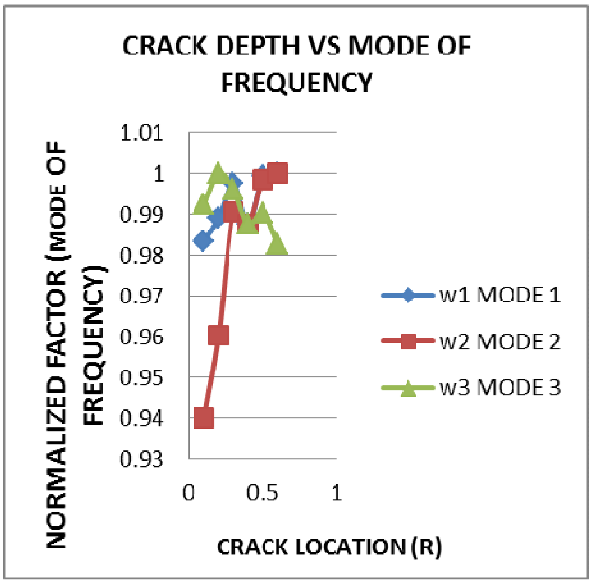

Fig. No. 12 Graph showing the variation of frequency mode for 3rd specimen showing the crack location.

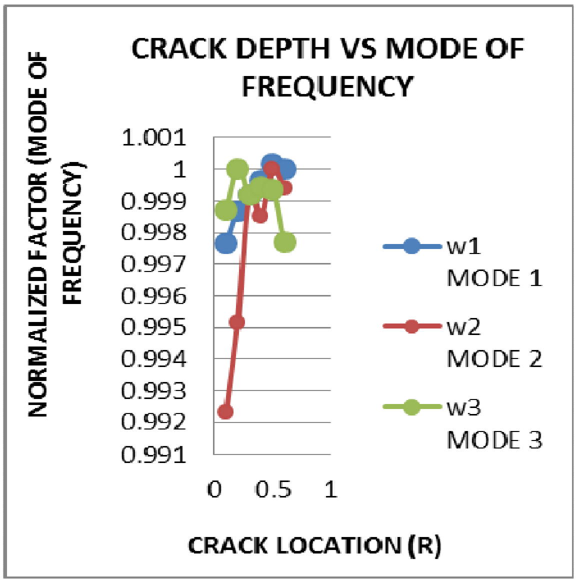

Fig. No. 10 The graph showing variation of frequency mode for 1st specimen showing crack location.

6. CONCLUSION

Detailed experimental investigations of the effects of crack on the first three modes of vibrating cantilever beams have been presented in this paper. From the results it is evident that the vibration behavior of the beams is very sensitive to the crack location, crack 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 also presented, and discussed. This procedure becomes

feasible due to the fact that under robust test and measurement conditions, the measured parameters of frequencies are unique values, which will remain the same (within a tolerance level), wherever similar beams are tested and responses measured. The experimental identification of crack location
and crack depth is very close to the actual crack size and location on the corresponding test specimen.
The frequencies of vibration of cracked beams decrease with increase in the depth of crack for crack at particular location.
The natural frequencies of a cantilever cracked beam decreases with increase in the number of cracks.
The frequencies decrease with increase in the relative depth of cracks at particular location of cracks.
The effect of crack is more pronounced when the cracks are near to the fixed end than at free end. Multiple cracks near the fixed end makes the beam more flexible than the same number of cracks at the free end of same intensity.

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