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Investigation and Review on Crack Detection in Stepped Cantilever Beam

Prof. B.S. Allurkar[1], Shruddha S Patil [2],
Department of Mechanical Engineering [1], Associate Professor [1]
Mahatma Basaveshwar Education Society's College Of Engineering, Ambejogai.(MBES'sCOE, Ambejogai)
Department of Mechanical Engineering [2], PG Student [2]
Mahatma Basaveshwar Education Society's College Of Engineering, Ambejogai.(MBES'sCOE, Ambejogai)
Email: as4dmech@gmail[1],

Abstract- In this literature review we observed that the crack changes the dynamic behavior of the structure and by examining the change, the crack size and the position of the crack can be identified. Nondestructive 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. In this paper a method for detection of open transverse crack in a slender Euler–Bernoulli beam is presented. Referring the literature, an Experimental Modal Analysis (EMA) will be performed on cracked beams and a healthy beam 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.

The construction of supersonic aircraft structures and high speed rotating machines such as steam turbines, generators, motors and pumps used in process industries or in manufacturing plant etc., has become more complicated since last few decades. Although these machines are carefully designed for fatigue loading, possess high levels of safety, are constructed with high quality materials, and are thoroughly inspected prior to service as well as periodically during their operating lives, still there are instances of cracks or damage escaping inspection. However, failure of just one of these machines can disrupt an entire process with staggering losses in terms of production, manpower and equipment repair or replacement. Also failure of a single machine component in the process industries like petrochemicals or power stations can result into loss of millions of rupees per down time hour.

Also structures and machine components in operational environment are often subjected to various levels of vibration. Excess vibration levels in the machine causes the fatigue failure. The process of fatigue failure starts with initiation of micro crack. Crack reduces strength of machine components considerably and endangers its safety. Most serious failures are occurred by crack growth from a point of stress concentration or from a material defect at the surface of the component. It is believed that fatigue failures occur without any warning, which is dangerous. In order to provide for safe and long lasting operations in the structures, a plan of preventive maintenance in the form of periodic repairs, rehabilitation and sectional replacement is required.

One of the essential requirement for an effective maintenance scheme is the development of an efficient inspection procedure which can provide accurate detection of the degradation and deterioration of the constituted structural components. One of the main degradation mechanisms in case of mechanical structures is the formation of cracks resulting from both environmental effects and external loads. Early detection of the formation of cracks will ensure timely repair or replacement which may in turn, avoid catastropic failures due to unstable crack propagation.

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.

Along with this, due to the large scale and quantity of measurement required to assess a complete inspection of most mechanical systems, it is desirable to have such a procedure that requires minimal setup time and is flexible in application. Thus, there exists a great need in developing an efficient, rapid, accurate and cost effective procedure of crack detection in structures or machine components. The use of vibration monitoring technique satisfies all above requirements. The presence of crack changes the parameters of dynamic system.

These are modal and structural parameters. The modal parameters include modal frequencies, mode shapes and modal damping values. On the other hand, the structural parameters include stiffness or flexibility, mass and damping matrices. Analysis of the changes makes it possible to identify the cracks without disengaging all the system. The technique utilizes one or more of these parameters for crack detection. So what is required is an analytical, numerical and experimental analysis by which one can correlate the modal parameters (like natural frequencies, mode shapes) to crack location and severity. 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.

Here we had taken beam element to carry out vibration analysis, because 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. The dynamics of cracked structural members, especially beams has been the subject of research work. The method adopts weightless torsional spring in the beam element as a mechanical model to represent the local flexibility introduced by a crack in the structure.

The first objective here is to find out the effect of crack on lowest three natural frequencies of beams with different boundary conditions, when the crack depth ratio) and location (R) of a crack is varied along length of beam. To achieve this, numerical analysis is carried out by finite element method (ANSYS 12.0 package). The data of frequencies for intact and cracked beams for different boundary conditions, thus generated is to be used as input to analytical method which will then assess the crack sizes.

The another aim is to perform the experiments on beams with single crack when the crack depth ratio) and location (R) of a crack is varied along length of beam. Again by using this experimental frequency data as a input to analytical method, the cracks in beams are assessed.

The scope of present work is kept limited to case of beams with single crack. The requirement and potential of the method have provided motivation for the present work.e 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. 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.The defect of the supporting sub grade foundation can be modelled either as degrading sub grade stiffness or increasing damping values. Numerical experiments demonstrate the feasibility of the developed NDT methodology which warrants the next stage of field study.Owolabi et.al.[5]reported an ongoing research on the experimental investigations of the effects of cracks and damages on the integrity of structures, with a view to detect, quantify, and determine their extents and locations. Two sets of aluminium beams were used for this experimental study.Each set consisted of seven beams, the first set had fixed ends, and the second set was simply supported. Cracks were initiated at seven different locations from one end to the other end (along the length of the beam) for each set, with crack depth ratios ranging from 0.1d to 0.7d (d was the beam depth) in steps of 0.1, at each crack location. Measurements of the acceleration frequency responses at seven different points on each beam model were taken using a dual channel frequency analyzer. The damage detection schemes used in this study depended on the measured changes in the first three natural frequencies and the corresponding amplitudes of the measured acceleration frequency response functions.Different researchers have discussed damage detection of vibrating structures in various ways. Chaudhari et al.[8] proposed modelling of transverse vibration of a beam of linearly variable depth and constant thickness in the presence of an open edge crack normal to its axis using the concept of a rotational spring to represent the crack section .B. P. Nandwana And S. K. Maiti they said that, the method based on measurement of natural frequencies is presented for detection of the location and size of a crack in a stepped cantilever beam. The crack is represented as a rotational springs and the method involves obtaining plots of its stiffness with crack location for any three natural modes through the characteristic equation. The point of intersection of the three curves gives the crack location. A method for detection of the location and size of a crack in a stepped cantilever beam has been presented. The details of the method are given. The accuracy of the method is illustrated by a case study involving a two step beam. The method predicts the location of crack quite accurately. The error in prediction of the location is always less. The crack size is also predicted accurately the error is again less. The procedure can easily be adapted for more steps and for a crack located in any of the segments.According to N.T. Khiem. & T.V. Lien, Multi-crack detection for beam by natural frequencies has been formulated in the form of a non-linear optimization problem, then solved by using the MATLAB functions. The spring model of crack is applied to establish the frequency equation based on the dynamic stiffness of multiple cracked beam. The equation is the basic instrument in solving the multi-crack detection of beam. The set of crack parameters to be detected includes not only the crack position and depth, but also the quantity of possible cracks. Numerical result obtained for a cantilever beam with single, two and three cracks scenarios shows, the efficiency and acceptability of the hereby proposed procedure.Abdul Salam Y. Alsabbagh, Osama M. Abuzeid *, Mohammad H. Dado, in their work gave a simplified formula for the stress correction factor in terms of the crack depth to the beam height ratio, f(a/h), is presented. The modified formula is compared to a well-known similar factor in the literature, and shows a good agreement for a/h lower than 0.5. The modified formula is used to examine the lateral vibration of an Euler–Bernoulli beam with a single-edge open crack. This is done through introducing the flexibility scalar. This scalar can be generated from the Irwin's relationship using the modified factor f(a/h). The crack in this case is represented as rotational spring. With the modified model, beam configurations with classical and non-classical support conditions could be studied. The mode shapes for the cracked and the uncracked beam are obtained using this model. They are displayed graphically for selected values of the system parameters; the crack depth ratio a/h, and the crack location ratio s/L. The shift in the mode shape due to the existence of a crack is highlighted. The obtained results showed good agreement with similar published studies.Amit Banerjee*, G. Pohit he proved that, cracks reduce the service life of structures. A crack in a structural member introduces local flexibility that would affect vibration response of the structure. Both the mode shape and frequency change significantly due to the presence of crack. The objective of this paper is to obtain information about the location and depth of transverse open multiple cracks in a rotating cantilever beams. Vibration parameter in the form of mode shape of damaged rotating beam is obtained using finite element simulation. Using fractal dimension of mode shape profile, damage is detected. It is also shown that this method can produce satisfactory results with some limitation based on profile. The dynamic behaviour of beam structure undergoes changes in presence of crack. Using these characteristics of a vibrating beam, a new technique, Fractal Dimension Analysis, has been employed for identification of crack in a rotating cantilever beam. From the results, it is evident that FD analysis can be used for detection of crack location and its depth from the deformation profiles of the rotating mode shapes. The inaccuracy in input signal may produce the noise during data processing leading to misleading or false reporting of damage in beam. It is shown that higher resolution may be employed as possible measures for noise reduction. In some cases, it is better to apply FD on more than one mode for meaningful detection of multiple cracks in a rotating beam.. 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. The crack is modeled as a massless linear spring of infinitesimal length, because the choice of modes of vibration was restricted mainly to axial vibration and the theory has been developed for axial modes. Torsional spring is used in case of modeling of transverse vibration of beam structures. Also in some cases the crack is modeled as a short section with reduced modulus, which requires two parameters for its definition: length and modulus. As it may be shown that the two models are equivalent when the length of the section with reduced modulus is small, the spring model was chosen as it is the simpler of the two.The theory was developed neglecting damping, since only changes in natural frequencies were being considered. Suppose the damage to be located at some unknown axial position x, the value of which is the object of the analysis i.e., the position of the crack. Let the spring representing the damage or crack have stiffness Kx. 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 □ and □ respectively, then the natural frequencies of the cracked bar are such that the following equation is satisfiedThe 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. 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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.

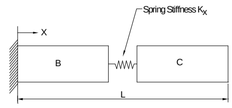


Figure 2.1 Structure with spring representation of damage

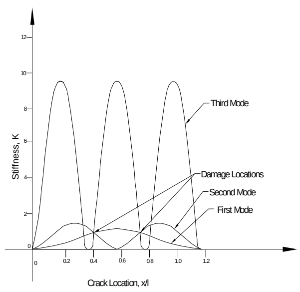


Figure 2.2 Damage Location in a Straight bar

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:

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

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

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:

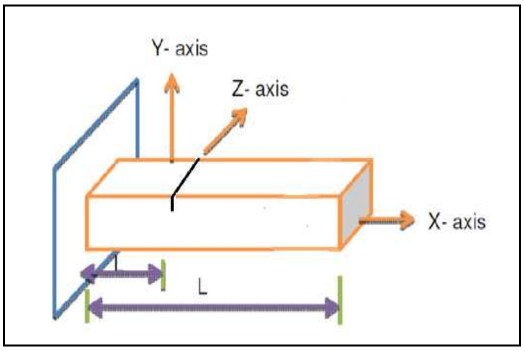
The lateral vibrations of beam in XY plane is often modeled by Euler-Bernoulli beam. The beam equation for such vibration is as derived in section 3.2.1

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

Where

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

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



$$\mathrm{d}^4U_1/\mathrm{d}\beta^4 + \lambda_1^4 U_1 = 0, \qquad 0 \leqslant \beta \leqslant e/L,$$

$$\mathrm{d}^4U_2/\mathrm{d}\beta^4 + \lambda_1^4 U_2 = 0, \qquad e/L \leqslant \beta \leqslant \beta_1, \qquad \beta_1 = L_1/L,$$

$$\mathrm{d}^4U_3/\mathrm{d}\beta^4 + \lambda_2^4 U_3 = 0, \qquad \beta_1 \leqslant \beta \leqslant \beta_2, \qquad \beta_2 = L_2/L,$$

$$\mathrm{d}^4U_4/\mathrm{d}\beta^4 + \lambda_3^4 U_4 = 0, \qquad \beta_2 \leqslant \beta \leqslant 1,$$

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

$$\begin{vmatrix}
1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 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\lambda_3 & \sinh\lambda_3 & -\cos\lambda_3 & -\sin\lambda_3 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \sinh\lambda_3 & \cosh\lambda_3 & \sin\lambda_3 & -\cos\lambda_3 \\
0 & 0 & 0 & 0 & \cosh\alpha_1 & \sinh\alpha_1 & \cos\alpha_1 & \sin\alpha_1 & -\cosh\alpha_2 & -\sinh\alpha_2 & -\cos\alpha_2 & -\sin\alpha_2 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \sinh\alpha_1 & \cosh\alpha_1 & -\sin\alpha_1 & \cos\alpha_1 & -F_1\sinh\alpha_1 & -F_1\cosh\alpha_2 & F_1\sin\alpha_2 & -F_1\cos\alpha_2 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \cosh\alpha_1 & \sinh\alpha_1 & -\cos\alpha_1 & -\sin\alpha_1 & -G_1\cosh\alpha_2 & -G_1\sinh\alpha_2 & G_1\cos\alpha_2 & G_1\sin\alpha_2 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \sinh\alpha_1 & \cosh\alpha_1 & \sin\alpha_1 & -\cos\alpha_1 & -H_1\sinh\alpha_2 & -H_1\cosh\alpha_2 & -H_1\sin\alpha_2 & H_1\cos\alpha_2 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 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 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \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 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \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 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \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 \\
\cosh\alpha & \sinh\alpha & \cos\alpha & \sin\alpha & -\cosh\alpha & -\sinh\alpha & -\cos\alpha & -\sin\alpha & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\cosh\alpha & \sinh\alpha & -\cos\alpha & -\sin\alpha & -\cosh\alpha & -\sinh\alpha & \cos\alpha & \sin\alpha & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\sinh\alpha & \cosh\alpha & \sin\alpha & -\cos\alpha & -\sinh\alpha & -\cosh\alpha & -\sin\alpha & \cos\alpha & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\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 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{vmatrix} = 0, \quad (18)$$

4. Mode*ling Of Stepped Cantilever Beam* Solid Modelling 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.

5. 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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