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A Review on Vibration Analysis and Effect of Impact Loading on Cracked Beam

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Abstract-Cracks in vibrating component can initiate catastrophic failures. The presences of cracks change the physical characteristics of a structure which in turn alter its dynamic response characteristics. Therefore there is need to understand dynamics of cracked structures. Crack depth and location are the main parameters for the vibration analysis. So it becomes very important to monitor the changes in the response parameters of the structure to access structural integrity, performance and safety. To examine the effect of the crack to the natural frequency of beams.

Experiment Performed on aluminium beam with different crack location and crack depth.It is found that at first mode there is no appreciable variation in natural frequency.Impact height load is a significant parameter described in this paper. As impact load height increases, stresses also increases in cracked beam as compaired to uncracked beam. Ansys is used for simulation work. It is found that well match of Experimental,Numerical and FEM Results and the presence of crack changes the natural frequency of vibration. The mode shapes also changes considerably due to the presence of crack.

I. Introduction

Many engineering components used in the aeronautical, aerospace and naval construction industries are considered by designers as vibrating structures, operating under a large number of random cyclic stresses. Cracks found in structural elements like beams and columns have different causes. They may be fatigue cracks that take place under service conditions as a result of the limited fatigue strength. They may be also due to mechanical defects, as in the turbine blades of jet engines. In these engines the cracks are caused by sand and small stones sucked from the surface of runway. Another group involves cracks which are inside the material.

II. Objectives

The objective is to carry out vibration analysis on a beam with and without crack. The objective of this study is to analyze the Vibration (Frequency) behaviour of a Cantilever beam using FEM method subjected to a single triangular crack under free vibration.Dynamic characteristics of damaged and undamaged materials are very different. For this reason, material faults can be detected in beams,which are very important construction elements because of their wide spread usage construction and machinery.

III. Methodology

In the present study, vibration analysis is carried out on a Cantilever beam with two open transverse cracks, to study the response characteristics. In first phase local compliance matrices of different degree of freedom have been used model transverse cracks in beam on available expression of stress intensity factors and the associated expressions for strain energy release rates. Suitable boundary condition are used to find out natural frequency and mode shapes. The results obtained numerically and simulation are validated with the results obtained from experimentation. The simulations have done with the help of ANSYS software.

IV. Literature Review

Orhan Sadettin[1] 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 and Papadopoulos[2] have studied the dynamic behaviour of a cracked beam with two transverse surface cracks. Each crack is characterised 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.

Rao, Govardhana (2009)[3] UK in Vibration Analysis of Beam analyze the vibration characteristics of beams. All real physical structures, when subjected to loads or displacements, behave dynamically. The additional inertia forces, from Newton's second law, are equal to the mass times the acceleration. If the loads or displacements are applied very slowly then the inertia forces can be neglected and a static load analysis can be justified. Hence, dynamic analysis is a simple extension of static analysis.

Sonam Lakra And Pradeep Guria[4] , National Institute Of Technology, Rourkela (2011) make the analysis of cracked beams in Vibration analysis of beam with multiple cracks. The present work deals with the free vibration analysis of a cracked beam with multiple transverse cracks using finite element method.

Ranjan K. Behera[5] has presented to model an inclined open edge crack in a cantilever beam and analyse the model using a finite element package, as well as experimental approach. The experiments are carried out using specimens having inclined edge cracks of different depths, positions and crack inclinations to validate the FEA results achieved.

Aniket S. Kamble[6] has presented crack is modelled as a rotational spring and equation for non-dimensional spring stiffness is developed. By evaluating first three natural frequencies using vibration measurements, curves of crack equivalent stiffness are plotted and the intersection of the three curves indicates the crack location and size.

V. Procedure to Designing of Beam

5.1 Mathematical Method

For a cantilever beam subjected to free vibration,and the system is considered as contineous system in which the beam mass is considered as distributed along with the stiffness of the shaft,the equation of motion can be written as (Meirovitch, 1967),

$$\frac{d^2}{dx^2}\left\{EI(x)\frac{d^2Y(x)}{dx^2}\right\} = \omega^2 m(x)\; Y(x) \quad (1.1)$$

Where, E is the modulous of rigidity of beam material, I is the moment of inertia of the beam cross-section, Y(x) is the displacement in Y direction at distance X from fixed end, ω is the circular natural frequency, m is the mass per unit length, m $\rho A(x)$, ρ is the material density, x is the distance measured from the fixed end.

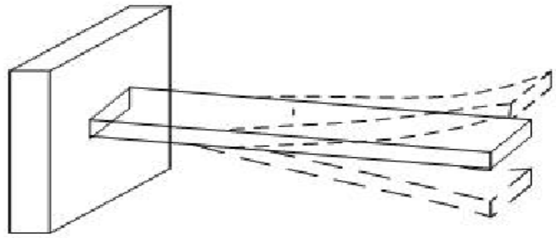

Fig.5.1: The Cantilever beam under free vibration

Fig.5.1 depicts of cantilever beam under the free vibration.

We have the following boundary conditions for a cantilever beam (Fig.5.1)

$$\text{at } x = 0, Y(x) = 0, \frac{dY(x)}{dx} = 0 \qquad (1.2)$$

$$\text{at } x = l, \frac{d^2Y(x)}{dx^2} = 0, \frac{d^3Y(x)}{dx^3} = 0 \qquad (1.3)$$

For a uniform beam under free vibration from equation (1.1), we get

$$\frac{d^4Y(x)}{dx^4} - \beta^4 Y(x) = 0 \qquad (1.4)$$

With $\beta^4 = \frac{\omega^2 m}{EI}$

The mode shapes for a continuous cantilever beam is given as

$$f_n(x) = A_n\{(\sin\beta_n L - \sinh\beta_n L)(\sin\beta_n x - \sinh\beta_n x) + (\cos\beta_n L - \cosh\beta_n L)(\cos\beta_n x - \cosh\beta_n x)\} \qquad (1.5)$$

Where $n = 1,2,3....\infty$ and $\beta_n L = n\pi$

A closed form of the circular natural frequency ω_{nf}, from above equation of motion and boundary conditions can be written as,

$$\omega_{nf} = \alpha_n^2 \sqrt{\frac{EI}{mL^4}} \qquad (1.6)$$

Where $\alpha_n = 1.875, 4.694, 7.885$

So,

First natural frequency, $\omega_{nf(1)} = 1.875^2 \sqrt{\frac{EI}{\rho AL^4}}$ (1.7)

Second natural frequency, $\omega_{nf(2)} = 4.694^2 \sqrt{\frac{EI}{\rho AL^4}}$ (1.8)

Third natural frequency, $\omega_{nf(3)} = 7.855^2 \sqrt{\frac{EI}{\rho AL^4}}$ (1.9)

The natural frequency is related with the circular natural frequency as

$$f_{nf} = \frac{\omega_{nf}}{2\pi} \text{ Hz} \qquad (1.10)$$

Where I, the moment of inertia, b and d are the breadth and width of the beam cross-section,

$$I = \frac{bd^3}{12} \qquad (1.11)$$

5.2. Simulation Method

5.2.1 Model Analysis

Define Materials
- Set preferences. (Structural)
- Define constant material properties.

Model the Geometry
-Follow bottom up modeling and create the geometry

Generate Mesh - Define element type.
-Mesh the area.

Apply Boundary Conditions
-Apply constraints to the model.

Obtain Solution - Specify analysis types and options.
- Solve.

5.2.2 Finite element modeling

The ANSYS finite element program was used for free vibration of the cracked beams. For this purpose, the key points were first created and then line segments were formed. The lines were combined to create an area. Finally, this area was extruded and a three-dimensional V-shaped edge cracked beam model was obtained. We modeled the crack with a 0.005m width on the top surface of the beam and a crack going through the depth of the beam. A 20-node three-dimensional structural solid element under SOLID 95 was selected to model the beam. The beam was discretized into 1028 elements with 2146 nodes. Cantilever boundary conditions can also be modeled by constraining all degrees of freedoms of the nodes located on the left end of the beam. The subspace mode extraction method was used to calculate the natural frequencies of the beam.

5.3. Experimental Analysis

5.3.1 Introduction

Experimental Analysis plays a key role in the research field. For the analysis, the experimental setup is made to determine the natural frequencies and mode shapes to observe the response of cantilever beam with the presence of inclined crack. The experimental setup is discussed in detail in the subsequent sections of this chapter.

5.3.2 Experimental Set up

The PULSE software analysis was used to measure the frequency ranges to which the foundations of various machines are subjected to when the machine is running with no load and full load. Below we present the analysis of frequency measurements for a few cantilever beams measured in structural Engineering lab.

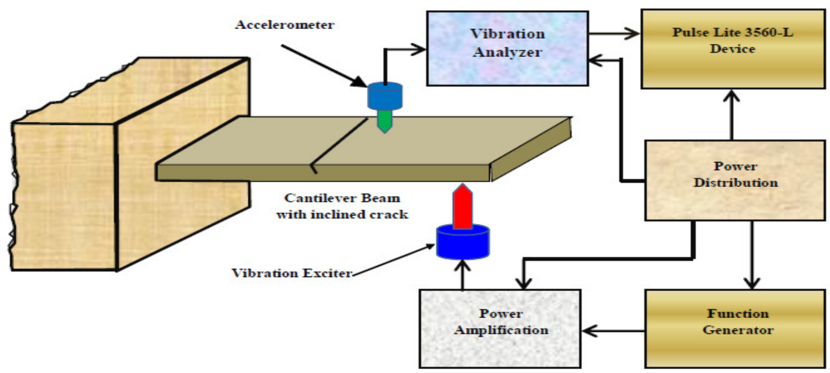

Fig.5.3.2.1. Schematic Block Diagram of Experimental set-up

5.3.3 Equipments Required

Vibration Analyser,Power Distribution Vibration Indicator (Pulse Lab Shop Sotware) Accelerometer, Power Amplifier,Function Generator Vibration Exciter, Test Specimen Beam,Model hammer

5.3.4 Experimental procedure and Programm

Fig. 5.3.4.1 Complete view of the experimental setup

Setup and Procedure (FFT analyzer)

1.Aluminium beam of required length 80cm was cut from a bulk available beam.
2.By the use of screw gauge the depth and width of beam section were measured.
3.10 cm length of beam was properly inserted to the concrete inside the mould and compacted using vibrator.
4.The connections of the FFT analyzer, laptop, transducers, and model hammer along with the requisite power connections were made.
5.The accelerometer - 4507 type was fixed by beeswax to the cantilever beam at one of the nodal points.
6.The 2302-5 modal hammers were kept ready to strike the beam at the singular points.
7.Then at each point the modal hammer was struck once and the amplitude Vs frequency graph was obtained from graphical user interface.
8.The FFT analyzer and the accelerometer are the interface to convert the time domain response to frequency domain. Hence the frequency response spectrumH1 (response, force) was obtained.
9.By moving the cursor to the peaks of the FFT graph (m/s2/N),the cursor values and the resonant frequencies were recorded.
10.At the time of the striking with modal hammer to the singular point precautions were taken whether the striking should have been perpendicular to the aluminium beam surface.
11.The above procedure is repeated for all the nodal points.
12.The values (i.e.,natural frequencies and resonant frequencies) obtained from the FRF spectrums were compared with respect to the FEM analysis.

Table No.5.3 Beam specification

Software used	FFT analyzer and accessories, pulse lab shop version 9.0
Parameter	Frequency
Length of cantilever	0.8 m
Section dimentions	0.05 × 0.01m2

Boundary conditions	One end fixed and another free
Material	Aluminium
Mass density	2713kg/m3
Elastic modulus	0.724×10^{11} N/m2
Poison's ratio	0.334

VI. Effects of Dynamic Impact Loading on Cracked Beam

It is required that structures must safely work during its service life. But, damages initiate a breakdown period on the structures. Cracks are among the most encountered damage types in the structures. Cracks in a structure may be hazardous due to static or dynamic loadings, so that crack detection plays an important role for structural health monitoring applications.Cracks may be caused by fatigue under service conditions as a result of the limited fatigue strength. They may also occur due to mechanical defects.

Most of researchers studied the effect of single crack on the dynamics of structures. However in actual practice structural members such as beams are highly susceptible to transverse cross-sectional cracks due to fatigue. Therefore to attempt has been made to investigate the dynamic behaviour of basic structures with crack systematically.

VII. Conclusion

The presence of crack in structure member introduces local flexibilities which can be computed and used in structural analysis. Analytical computational method can be used for solving the frequency of equation of elastic beam with cracks. It is shown that the natural frequency changes substantially due to the presence of cracks. The changes depending upon the location and size of cracks. When the crack positions are constant i.e. at particular crack location, the natural frequencies of a cracked beam are inversely proportional to the crack depth.

It has been observed that the change in frequencies is not only a function of crack depth, and crack location, but also of the mode number. When the position of the crack is at that point where amplitude of vibration is zero there is no change in natural frequency in spite of change in crack depth. Natural frequency changes drastically when crack is on that point where amplitude of vibration is maximum.

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