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VIBRATION ANALYSIS OF COMPOSITE BEAM WITH CRACK: A REVIEW

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ABSTRACT

Composite beams and beam like elements are principal constituents of many structures and used widely in high speed machinery, aircraft and light weight structures. Crack is a damage that often occurs on members of structures and may cause serious failure of the structures. The influence of cracks on the characteristics like natural frequencies, modes of vibration of structures has been the subject of many investigations. However, the parametric studies like effect of geometry, crack location and support conditions, volume fraction of fibers, length of the composite material, and boundary conditions of cracked composite material on natural frequencies of composite material. 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. 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 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. In this review studied some theoretical and experimental studies on vibration analysis of composite beam with crack.

Index Terms - Composite material, Finite element analysis,

I. INTRODUCTION

A composite material is a material in which two or more distinct materials are combined together but remain uniquely identifiable in the mixture. In the recent decades, fiber reinforced composite materials are being used more frequently in many different engineering fields. The automobile, aerospace, naval, and civil industries all use composite materials in some way. Composite materials are gaining popularity because of high strength, low weight, resistance to corrosion, impact resistance, and high fatigue strength. Other advantages include ease of fabrication, flexibility in design, and variable material properties to meet almost any application. Composite materials have high strength to weight and stiffness to weight ratios. Hence these materials are important in most of present day applications. There has been an increased interest in modeling epoxy-based Composites with the growth the computer aided design and manufacturing. The key factor in utilizing the strength and uniqueness of laminated composite material is the proper understanding of its structural response under different work load conditions.

II. CRACK DETECTION

Structures that are subject to cyclic stresses in normal service may develop cracks and these cracks will inevitably grow and potentially lead to in-service failure. The reasons for cracks to develop in the first place are many and varied. Components that are working at high cyclic stress levels will simply suffer from cyclic fatigue and fail. In many cases this process is aided by discontinuities at welds or inclusions in the metal (gas or impurities). Rubbing of surfaces will produce stress-corrosion effects and the presence of corrosive agents (water, oxygen, chemicals, etc) can greatly hasten the process.

There are three methods discussed in this study such as using natural frequency, using ANN Using experimental and theoretical studies.

2.1 Using natural frequency

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. Earlier work in this area involved the use of the Frobenius technique for solving the governing deferential equation analytically and then using a semi-numerical approach to obtain the crack location. In this work, they use the finite element approach to solve the same problem. The beam is modeled using beam elements and the inverse problem finding the spring stiffness, given the natural frequency, is shown to be related to the problem of a rank-one modification of an Eigen value problem.[1]

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.[2]

Two approaches were done to detect the crack by using the vibration tests namely; open crack model which depends on change in the parameters of model and the breathing crack model focusing on nonlinear response characteristics .Presented a procedure and suggestion to estimate the damage in structure for cracked cantilever beam by measuring the first and second harmonic amplitude. The study approximated by finite term polynomial series and response amplitude under harmonic excitation. A numerical simulation for two different damage levels used to illustrate the method. It was an accurate estimation provided for the damage through the study, even when the crack size was very small.[3]

The experimental work successfully detected small scale damage under forced harmonic excitation. The dynamic analyses by using the finite element model of the steel-free bridge deck were performed to investigate the implications of using random forced vibrations. It was found that the likelihood of successful damage localization based on the severity of the damage, the number of trials used to obtain the average mode shape, the location of damage relative to the nearest sensor, the distance between the damage and the support, and the magnitude of measurement errors. A method that depends on the repeatability of measured mode shapes was proposed to calculate the probability of successful damage detection and localization.

2.2 Using ANN

The method of multiple cracks detection in moving parts or beams by monitoring the natural frequency and prediction of crack location and depth using Artificial Neural Networks (ANN). Determination of crack properties like depth and location is vital in the fault diagnosis of rotating machine equipments. For the theoretical analysis, Finite Element Method (FEM) is used wherein the natural frequency of beam is calculated whereas the experimentation is performed using Fast Fourier Transform (FFT) analyzer. In experimentation, simply supported beam with single crack and cantilever beam with two cracks are considered. The experimental results are validated with the results of FEM (ANSYSTM) software. This formulation can be extended for various boundary conditions as well as varying cross sectional areas. The database obtained by FEM is used for prediction of crack location and depth using Artificial Neural Network (ANN). To investigate the validity of the proposed method, some predictions by ANN are compared with the results given by FEM. It is found that the method is capable of predicting the crack location and depth for single as well as two cracks. This work may be useful for improving online conditioning and monitoring of machine components and integrity assessment of the structures.[4]

The detection, location and sizing of transverse cracks in a composite beam, by combining damage features of Lamb wave and vibration based techniques in artificial neural network (ANN) environment, using numerical finite element model, is discussed. Four damage features, time of flight (TOF) and amplitude ratio, which are Lamb wave based features and first and second natural frequencies, which are vibration based features were used as input to ANN. The output of ANN was crack location and depth. It was demonstrated that through the simultaneous employment of features from the two modalities in an ANN environment, the sizing could be done more effectively.[5]

2.3 Using experimental and theoretical studies

The natural frequency-based method can also be used to detect the location of an unknown crack. The possibility of representing a crack with straight front, normal to the axis, and part through-the thickness In a straight pipe containing fluid under pressure, by a spring for simulating its transverse free vibration has been examined experimentally.[6]

Vibration parameters have been evaluated using various boundary conditions of beam. The beam subjected to different boundary conditions has a principal effect on dynamic characteristics of composite beam. The current work presents the evaluation of changes in natural frequencies and corresponding mode shapes curvature for different boundary conditions by varying crack positions and crack depth. The numerical results were found in good agreement with experimental and analytical results. The study concludes that structure with crack can be diagnosed by using vibration signatures and it help to monitoring the health of beam type structures. [7].

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III. VIBRATION ANALYSIS

Vibration analysis allows the user to evaluate the condition of equipment and avoid failures. Maintenance personnel can minimize unplanned downtime by scheduling needed repairs during normal maintenance shutdowns. In the past, vibration analysis required dialing an instrument through the full spectrum to identify frequencies at which vibration was prominent. The operator then compared the peak frequencies with the operating speed and consulted a chart for likely causes. One advantage of that method was that the operator gradually developed a sense of how equipment vibrates and why certain problems occur at the same multiples of the rotating speed. The latest generation of vibration analyzers has more capabilities and automated functions than their predecessors had. Many units display the full vibration spectrum of three axes simultaneously--providing a snapshot of what is going on with a particular machine. But despite such capabilities, not even the most sophisticated equipment successfully predicts developing problems unless the operator understands and applies the basics of vibration analysis

In present study, two method have been studied viz. vibration analysis using Euler-Bernoulis Beam Theory and Vibration Analysis using FEA. In this paper used simple method for detection of multiple edge cracks In Euler–Bernoulli beams having two different types of cracks is presented based on energy equations. Each crack Is modeled as a mass less rotational spring using Linear Elastic Fracture Mechanics (LEFM) theory, and a relationship among natural frequencies, crack locations and stiffness of equivalent springs is demonstrated .In the procedure, for detection of m cracks in a beam,3m equations and natural frequencies of healthy and cracked beam in two different directions are needed as input to the algorithm.[8]

The analysis is based on energy method and representation of a crack by a rotational spring and Theoretical prediction of 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. The maximum error in predicting location of cracks decreases with an increase in the number of cracks. It is less than 10% and 20% for two and three cracks respectively. The maximum error in predicting the crack size is less than 12% and 30% respectively for the two cases. [9]

Beams of variable depth offer scope for a selective distribution of stiffness and weight. Sometimes, beams are composed of a variable materials and uniform depth segments. The study of the vibration analysis of such beams is very important, although not much attention has been focused on theoretical analysis so far. The lack of study is all the greater in the case of such beams with a crack; this has motivated the present study. The absence of any solution to the related inverse problem has been an additional factor for the motivation. [10]

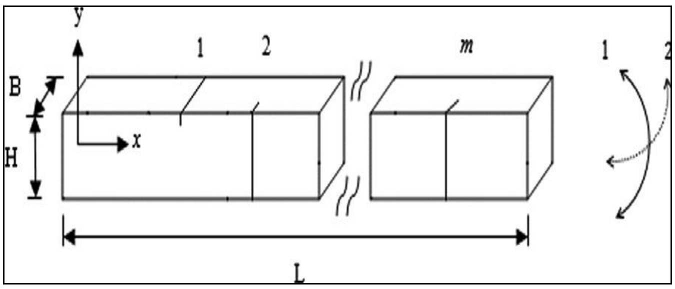

Fig.2.1 A multiple-cracked beam having two different types of crack

Proposed to solve the inverse problem, i.e., crack identification in beams. As shown in Fig. 1, for the vibration of beam in direction 1 (or in plane x–y), the first crack is an edge crack along the beam's width and the second edge crack is along the beam's height. [11]

3.1 Vibration analysis using Euler-Bernoulli beam theory

Based on exact closed-form expressions for the vibration modes of the Euler–Bernoulli beam in the presence of multiple concentrated cracks are presented. The proposed expressions are provided explicitly as functions of four integration constants only, to be determined by the standard boundary conditions. The enforcement of the boundary conditions leads to explicit expressions of the natural frequency equations. Besides the evaluation of the natural frequencies, neither computational work nor recurrence expressions for the vibration modes are required. The Eigen-mode governing equation is formulated over the entire domain of the beam without enforcement of any continuity conditions, which are already accounted for in the adopted flexural stiffness model. The vibration modes of beams with different numbers of cracks under different boundary conditions have been analyzed by means of the proposed closed-form expressions in order to show their efficiency. [5]

Natural frequencies used to measure and estimate the un-cracked mode shapes. The cracks modeled as rotational springs and reveal a relationship amongst natural frequencies, crack locations and depths. Numerical examples for a two-step cantilever beam were presented to illustrate one, two and three cracks to authenticate the method as shown in fig.2.1.

The problem on crack is the basic problem of science of resistance of materials. Considering the crack as a significant form of such damage, its modeling is an important step in studying the behavior of damaged structures. Knowing the effect of crack on stiffness, the beam or shaft can be modeled using either Euler-Bernoulli or Timoshenko beam theories. The beam boundary conditions are used along with the crack compatibility relations to derive the characteristic equation relating the natural frequency, the crack depth and location with the other beam properties. [12]

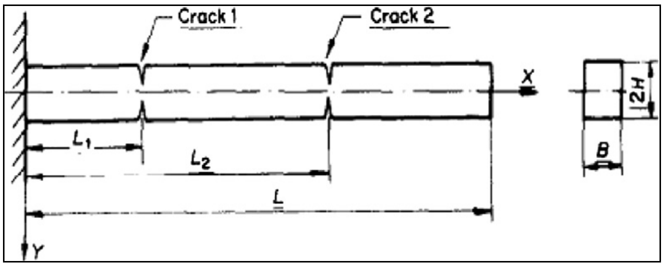

Fig. 2. Schematic diagram of a beam with two cracks.

Proposed modeling method to transverse vibration and solved the differential equation of Euler–Bernoulli for two slender beams, with and without crack. Each beam content two segments: one segment was uniform in depth and the second with a linearly variable depth. A rotational spring was considered for crack section in cracked beam. The inverse method employed was to detect the damage according to the size and location of crack. Natural frequency was used as input. The accuracy of the proposed method was illustrated by a number of numerical examples. The results improved the error in prediction of crack location and crack size as (<3%) and (25%), respectively. [13]

The method is based on the approach given by Hu and Liang [J. Franklin Inst. 330 (5) (1993) 841] transverse vibration modeling through transfer matrix method and representation of a crack by rotational spring. The beam is virtually divided into a number of segments, which can be decided by the analyst, and each of them is considered to be associated with a damage parameter. The procedure gives a linear relationship explicitly between the changes in natural frequencies of the beam and the damage parameters. These parameters are determined from the knowledge of changes in the natural frequencies.[14] The method is approximate, but it can handle segmented beams, any boundary conditions, intermediate spring or rigid supports, etc. It eliminates the need for any symbolic computation which is envisaged by Hu and Liang [J. Franklin Inst. 330 (5) (1993) 841] to obtain mode shapes of the corresponding uncracked beams. The proposed method gives a clear insight into the whole analysis.

Shaft beams based on compliance approach in the presence of a planar open edge crack in an arbitrary angular orientation with a reference direction. The compliance coefficients to account for the local flexibility due to the crack for both the beams have been obtained through the concept to strain energy releaserate and crack tip stress field given in terms of the stress intensity factors .The type of disturbance in stress–strain field that a continuous cracked beam theory can accommodate is not within the scope of the model. The compliance matrices for the Timoshenko (short) and Euler–Bernoulli (long) beams respectively are of size 6_6 and 3_3, and they consist of only 9 and 4 nonzero coefficients.[15].

3.2 Vibrations analysis using FEA

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. A number of analytical, numerical and experimental techniques are available for the study of damage identification in beams.

Developed a damage detection method in a composite cantilever beam with a double edge crack has been studied using finite element method. The vibration-based damage detection methods are based on the fact that changes of physical properties (stiffness, mass and damping) due to damage will manifest themselves as changes in the structural modal parameters (natural frequencies, mode shapes and modal damping). The task is then to monitor the selected indicators derived from modal parameters to distinguish between undamaged and damaged states. In the present study, vibration analysis is carried out on a cantilever beam with two open transverse cracks, to study the response characteristics and damage identification is based on the damage index method. [16].

IV. CONCLUSION

The important element in the research of vibration analysis for real engineering applications is a Composite beam. The composite material has high strength also it should be more flexible in machineries and construction structures to be capable of withstanding high levels of stress and strain. An important factor in the evaluation of the safety of the investigated structure and to detect faults and defects in a structure, a non-destructive technique was adopted and reviewed in this paper. This technique used widely in Structural Health Monitoring (SHM) in order to acquire analytical solutions of natural frequencies and dynamic deflections. Based on the changes in dynamic properties such as the stiffness which could lead to changes in:

i. The mode shape a,
ii. Reduction in frequencies, and
iii. Increase in damping,

The location and the magnitude of the crack can be determined. The vibration analyses for composite beam with crack were illustrated analytically, theoretically and experimentally; with the beams having various properties and dimensions

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