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Full Length Research Paper

Crack detection of a cantilever beam using kohonen network techniques

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The issue of crack detection and diagnosis has gained wide spread industrial interest. Crack/damage affects the industrial economic growth. Generally damage in a structural element may occur due to normal operations, accidents, deterioration or severe natural events such as earth quake or storms. Damage can be analyzed through visual inspection or by the method of measuring frequency, mode shape and structural damping. Damage detection by visual inspection is a time consuming method and measuring of mode shape as well as structural deflection is difficult rather than measuring frequency. As Non- destructive method for the detection of crack is favorable as compared to destructive methods. So, our analysis has been made on the basis of non-destructive methods with the consideration of natural frequency. Here the crack is transverse surface crack. In the current analysis, methodologies have been developed for damage detection of a cracked cantilever beam using kohonen network. Theoretical analysis has been carried out to calculate the natural frequency with the consideration of mass and stiffness matrices. The data obtained from theoretical analysis has been fed to kohonen competitive learning network. Kohonen network is nothing but a competitive learning network is used here for the detection of crack depth and location. It is processed through a vector quantization algorithm.

Keywords: Damage; vibration; natural frequency; kohonen network.

INTRODUCTION

Damage is one of the important issues in the structural analysis which leads to unexpected failure and affect the economic growth. Prevention of unexpected failure can be predicted by the earlier identification of crack in terms of crack depth and crack location. The most common structural defect 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. Cracks present in vibrating/rotating components could lead to catastrophic failure. They may also occur due to mechanical defects. Another group of cracks are initiated during the manufacturing processes. Generally they are small in sizes. Such small cracks are known to propagate due to fluctuating stress conditions. If these propagating cracks remain undetected and reach their critical size, then a sudden structural failure may occur. Hence it is possible to use natural frequency measurements to detect cracks. Vibration-based methods have been proved a fast and inexpensive means for crack identification. A crack in a structure

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induces a local flexibility which affects the dynamic behavior of the whole structure to a considerable degree. It results in reduction of natural frequencies and changes in mode shapes. An analysis of these changes makes it possible to determine the position and depth of cracks. Most of the researches use in their studies open crack models, i.e. they assume that a crack remains always open during vibration. Therefore, if an always open crack is assumed, the decrease in experimental natural frequencies will lead to an underestimation of the crack depth. (Das et al., 2009) have been performed an analytical studies by on fuzzy inference system for detection of crack location and crack depth of a cracked cantilever beam structure using six input parameters to the fuzzy member ship functions. The six input parameters are percentage deviation of first three natural frequencies and first three mode shapes of the cantilever beam. The two output parameters of the fuzzy inference system are relative crack depth and relative crack location Experimental setup has been developed for verifying the robustness of the developed fuzzy inference system. The developed fuzzy inference system can predict the location and depth of the crack in a close proximity to the real results. Detection of crack location using cracked beam element method for structural analysis has been presented by (Viola et al., 2001). (Parhi et al., 2009) have presented comprehensive review of,no-linear statistical relationship between high dimensional data into simple geometric relationship on a two-dimensional display. It may also be thought to produce some kind of abstraction. These two aspects visualization and abstraction occur in a member of complex engineering task such as process analysis, machine perception, control and communication. (M. Cottrel et al., 2003) have been performed an analytical study on Kohonen Network and suggested methodologies in the domain of dynamic vibration of cracked structures using energy methods, finite element methods, fuzzy inference techniques, neural networks, neuro-fuzzy adaptive techniques and genetic algorithms for identifying the intensity and location of cracks. (T. Kohonen et al., 1996) have been proposed that the Self Organizing Map (SOM) method is a new powerful software tool for the visualization of high dimensional data. They explain that SOM converts complexthat the Kohonen algorithm is a powerful tool for data analysis. In that case they define a specific algorithm which provides a simultaneous classification of the observation and of the modalities. (Vesanto et al., 1999) have been proposed that the Self-Organizing Map (SOM) is a vector quantization method which places the prototype vectors on a regular low- dimensional grid in an ordered fashion. This makes the SOM a powerful visualization tool. Also its performance in terms of computational load is evaluated and compared to a corresponding C program. (Kauppinen et al., 1999) have been proposed a non-segmenting defect detection technique combined with a self-organizing map (SOM) based classifier and user interface. They have tried to avoid the problems with adaptive detection techniques, and to provide an intuitive user interface for classification, helping in training material collection and labeling, and with a possibility of easily adjusting the class boundaries. Many researchers have been used this kohonen network in different area of research but in this paper we have proposed the essential processes as well as the mechanism followed in the Kohonen Network for the detection of crack depth and crack location

Finite element vibration analysis

Finite Element Analysis (FEA) was first developed in 1943 by R. Courant, who utilized the method of numerical analysis and minimization of vibrational calculus to obtain approximate solutions to vibration systems. FEA uses a complex system of points called nodes which make a grid called mesh. This mesh is programmed to contain the material and structural properties which define how the structure will react to certain loading conditions. Nodes are assigned at a certain density throughout the material depending on the anticipated stress levels of a particular area.

Finite element formulation theory

The beam with a transverse edge crack is clamped at left end, free at right end and has uniform structure with a constant rectangular cross-section of 800 mm X 50 mm X 6 mm. The Euler-Bernoulli beam model is assumed for the finite element formulation. The crack in this Finite particular case is assumed to be an open crack and the damping is not being considered in this theory. Both single and double edged crack are considered for the formula.

Governing equation of free vibration

The free bending vibration of an Euler-Bernoulli beam of a constant rectangular cross section is given by the following differential equation as given in:

$$EI\frac{d^4y}{dx^4} - m\omega_i^2 y = 0 \qquad (1)$$

Where 'm' is the mass of the beam per unit length (kg/m), 'ωi' is the natural frequency of the ith mode (rad/sec), E is the modulus of elasticity (N/m2) and I is the moment of inertia (m4). By defining equation is rearranged as a fourth-order differential equation as follows:

$$\frac{d^4y}{dx^4} - \lambda^4 y = 0 \qquad (2)$$

The general solution to equation is

$$y = A\cos\lambda_i x + B\sin\lambda_i x + C\cosh\lambda_i x + D\sinh\lambda_i x \quad (3)$$

Where A, B, C, D are constants and 'λi' is a frequency parameter. Adopting Hermitian shape functions, the stiffness matrix of the two-noded beam element without a crack is obtained using the standard integration based on the variation in flexural rigidity.

The element stiffness matrix of the un cracked beam is given as

$$\left[K^e\right] = \int [B(x)]^T EI[B(x)]dx$$

(4)

$$[B(x)] = \{H_1(x)H_2(x)H_3(x)H_4(x)\} \quad (5)$$

Where $[H_1(x), H_2(x), H_3(x), H_4(x)]$ is the Hermitan shape functions defined as,

$$H_1(x) = 1 - \frac{3x^2}{l^2} + \frac{2x^3}{l^3} \quad (6a)$$

$$H_2(x) = x - \frac{2x^2}{l} + \frac{x^3}{l^2}$$

(6b)

$$H_3(x) = \frac{3x^2}{l^2} - \frac{2x^3}{l^3} \quad (6c)$$

$$H_4(x) = -\frac{x^2}{l} + \frac{x^3}{l^2}$$

(6d)

Assuming the beam rigidity EI is constant and is given by EI_0 within the element, and then the element stiffness is (6)

$$[K^e] = \frac{EI_0}{l^3}\begin{bmatrix} 12 & 6l & -12 & 6l \\ 6l & 4l^2 & -6l & 2l^2 \\ -12 & -6l & 12 & -6l \\ 6l & 2l^2 & -6l & 4l^2 \end{bmatrix}$$

(7)

$$[K_c^e] = [K^e] - [K_c]$$

(8)

Here,

$\left[K_c^e\right]=$ Stiffness matrix of the cracked element

$\left[K^e\right]=$ Element stiffness matrix

$\left[K_c\right]=$ Reduction in stiffness matrix due to the crack

According to Peng et al. [10], the matrix [Kc] is

$$[K_c] = \begin{bmatrix} K_{11} & K_{12} & -K_{11} & K_{14} \\ K_{12} & K_{22} & -K_{12} & K_{24} \\ -K_{11} & -K_{12} & K_{11} & -K_{14} \\ K_{14} & K_{24} & -K_{14} & K_{44} \end{bmatrix}$$

(9) Where,

$$K_{11} = \frac{12E(I_0 - I_c)}{L^4}\left[\frac{2l_c^3}{L^2} + 3l_c\left(\frac{2L_1}{L^2} - 1\right)^2\right]$$

(10a)

$$K_{14} = \frac{12E(I_0 - I_c)}{L^3}\left[\frac{l_c^3}{L^2} + l_c\left(2 - \frac{5L_1}{L} + \frac{6L_1^2}{L^2}\right)^2\right] \quad (10b)$$

$$K_{12} = \frac{12E(I_0 - I_c)}{L^3}\left[\frac{l_c^3}{L^2} + l_c\left(2 - \frac{7L_1}{L} + \frac{6L_1^2}{L^2}\right)^2\right] \quad (10c)$$

$$K_{24} = \frac{12E(I_0 - I_c)}{L^2}\left[\frac{3l_c^3}{L^2} + 2l_c\left(2 - \frac{9L_1}{L} + \frac{9L_1^2}{L^2}\right)^2\right]$$

(10d)

$$K_{22} = \frac{12E(I_0 - I_c)}{L^3}\left[\frac{3l_c^3}{L^2} + 2l_c\left(\frac{3L_1}{L} - 2\right)^2\right] \quad (10e)$$

$$K_{44} = \frac{12E(I_0 - I_c)}{L^2}\left[\frac{3l_c^3}{L^2} + 2l_c\left(\frac{3L_1}{L} - 1\right)\right]$$

(10f)

Here,

Ic=1.5W

L=total length of the beam

L1=distance between the left node and crack

$I_0 = \frac{BW^3}{12} =$ Moment of inertia of the beam cross section

$I_c = \frac{B(W-a)^3}{12} =$ Moment of inertia of the beam with crack.

It is supposed that the crack does not affect the mass distribution of the beam. Therefore, the consistent mass matrix of the beam element can be formulated directly as

$$\left[M^e\right] = \int_0^1 \rho A[H(x)]^T \left[H(x)\right]dx \quad (11)$$

$$\left[M^e\right] = \frac{\rho Al}{420}\begin{bmatrix} 156 & 22l & 54 & -13l \\ 22l & 4l^2 & 13l & -3l^2 \\ 54 & 13l & 156 & -22l \\ -13l & -3l^2 & -22l & 4l^2 \end{bmatrix} \quad (12)$$

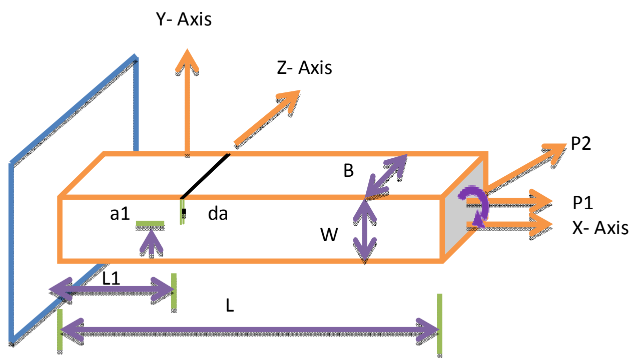

Fig.1. Geometry of the Cracked Cantilever Beam

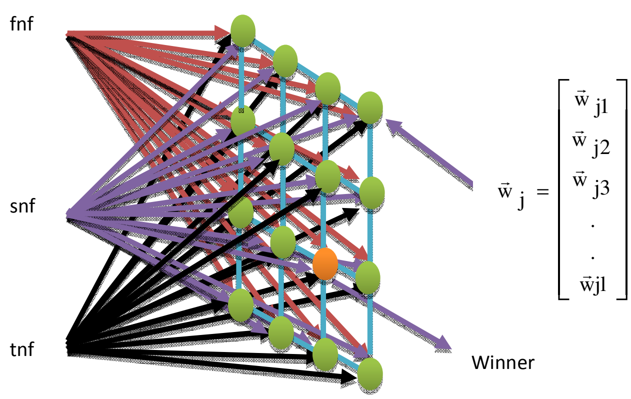

Fig 2. Architecture of Kohonen Network

Table 1. Input data and results for genetic controller

S/N	Relative first natural frquency	Relative second natural frequency	Relative third natural frequency	Relative crack depth	Relative crack location	Kohonen technique relative crack depth	Kohonen technique relative crack location
1	0.87	0.914	0.985	0.212	0.145	0.216	0.139
2	0.878	0.945	0.992	0.297	0.254	0.307	0.265
3	0.885	0.969	0.995	0.267	0.228	0.273	0.23
4	0.904	0.973	0.974	0.252	0.232	0.257	0.229
5	0.915	0.981	0.979	0.229	0.272	0.226	0.267
6	0.936	0.991	0.955	0.198	0.305	0.208	0.302
7	0.947	0.995	0.969	0.217	0.395	0.21	0.391
8	0.918	0.929	0.974	0.265	0.378	0.263	0.388
9	0.932	0.955	0.995	0.159	0.21	0.162	0.212
10	0.976	0.98	0.929	0.165	0.248	0.161	0.252

The natural frequency then can be calculated from the relation.

$$[-\omega^2[M]+[K]]\{q\}=0$$
(13)

Where,
q=displacement vector of the beam

Kohonen network technique

The training of the Kohonen Network is done by a specific algorithm. The goal is to obtain a map where two points, which are nearby in the input space are also closed in the map. The algorithm of kohonen network is processed through various mechanisms as explained

below: $\vec{x} = [x_1, x_2, ..., x_m]^T$ Where, $\vec{x}$ is the input vector, m= Dimensional Input.
(14)

$\vec{w}_j = [w_{j1}, w_{j2}, ..., w_j]^T$, j=1, 2, 3...l, l= Number of output neurons.

(15)

$[\vec{w}_j]$ = Weight Vector

Every output is connected to all input. There will be $m \times l$ number of arrays. We have to determine the best match between $\vec{x}$ and $\vec{w}_j$. Compute $\vec{w}_j^T \vec{x}$ for j=1, 2 …l.

Winning neuron= arg maximize $(\vec{w}_j^T \vec{x})$, we have to minimize the Euclidian distance $(\|\vec{x} - \vec{w}_j\|)$

$\Rightarrow$ Winner neuron

$= \arg_j \max(\vec{w}_j^T \vec{x}) = \arg_i \min(\|\vec{x} - \vec{w}_j\|)$ (16)

Update $\vec{w}_j(t+1) = \vec{w}_j(t) + \eta(t) h_{j,i}(t)(\vec{x} - \vec{w}_j(t))$

$$h_{j,i}(\vec{x}) = \exp\left(\frac{-d^2_{j,i}}{2\sigma^2(t)}\right)$$

(17) Where,

$$\eta(t) = \eta_0 \exp\left(-\frac{t}{\tau_2}\right)$$

DISCUSSION AND CONCLUSION

Early detection of damage in beam type structural elements is very essential to avoid a major failure or accident. For non-destructive testing of cracked cantilever beam, vibration based methods make a good approach. Vibration based methods use the fact that due to the presence of the crack, there is a change in the flexibility which affects the natural of the structural element.

The natural frequencies of the cracked cantilever beam at different locations with different depths are derived using Finite element analysis. Then these frequencies are trained in the kohonen competitive algorithm. The results of the kohonen analysis are given in the TABLE I.

Comparing the results of FEM and the above proposed algorithm; it has been found that, they are in good agreement with each other. Using the methodology crack location and crack depth can be found efficiently.

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