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Detection of Depth and Location of Crack in a Beam by Vibration Measurement and its Comparative Validation in ANN and GA

#1M.S. Mhaske,#2 S.N. Shelke

1mayuri.mhaske18@gmail.com

2drsnshelke@gmail.com

#12Department of Mechanical Engineering, Savitribai Phule Pune University.
Sir Visvesvaraya Institute of Technology, Chincholi, Nashik

ABSTRACT

The presence of a crack is hazardous problem in the performance of many structures and it affects many of the vibration parameters like Natural frequency and mode shapes. Crack in a structure changes the dynamic behaviour of the structure and by examining this change, crack size and location can be identified. Current research has focused on using different modal parameters like natural frequency, mode shape and damping to detect crack in beams. This work concentrates on the parameters like Deflection of a beam, Bending moment and behaviour of stresses. In this work, simulation is carried out by using analysis software ANSYS to find the relation between the change in natural frequencies and mode shapes for the cracked and uncracked beam. It is then verified by the results obtained from ANN controller and Genetic Algorithm. ANN is used to determine crack depth and location along with the directions of propagation and Natural frequencies and relative mode shapes difference as input parameters to calculate the variation and the vibration parameters. The output from ANN controller is relative crack depth and relative crack location. Results from numerical analysis are compared with the Experimental results and they have good resemblance to the results predicted by the ANN controller. Genetic algorithm belongs to the larger class of evolutionary algorithms which generate the optimized solution to the problems. It is an iterative process to reach to the final solution. By using this, same results are found and related with the results of ANN. And finally the results are compared to find the most appropriate approach amongst the two methods.

***Keywords*— ANN, Crack, Depth, GA**

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I. INTRODUCTION

Damage detection by using crack analysis in a mechanical or civil structure has been a topic of research for last few decades. For every new researcher, a new method or change in modal parameters is a way to carry out the detection procedure of a crack. Damage is a result of crack and crack changes stiffness of a structure. Due to change in stiffness dynamic response of a system changes.

The dynamic properties of a structure can be determined by Finite Element Method , or by experimental modal analysis. Dynamic characteristics of cracked and uncracked beams are very different. Because of this,faults in materials can be detected, especially in beams. Crack formation due to cycling loads tends to fatigue of the structure and forms discontinuities in the crystal structure of a beam. When a structure suffers from crack, its dynamic properties change. To be specific,crack can cause reduction in stiffness , with a significant reduction in natural frequencies, and increase in modal damping, and a change in the mode shapes.

Cracks in vibrating components can initiate miserable failures. Therefore, there is a need to understand the dynamics of cracked structures [1]. When a structure suffers from damage, its dynamic properties can change. Specifically, crack damage can cause a stiffness reduction, with an intrinsic reduction in natural frequencies, an increase in modal damping, and a change in the mode shapes [2]. From such changes, the crack position and magnitude can be identified. Since the reduction in natural frequencies can be easily observed . In the work by Kam and Lee, the finite elements method has been used to determine the crack locations and magnitudes for a cantilever beam with one crack. Natural frequency of the beam has also been determined and verified experimentally. For the beam with one crack and pinned at the two ends, mathematical expressions were derived [4] to examine the effect of the crack to the natural frequency of beams. Chondros and Dimarogonas [5] conducted a number of experiments with an aluminium cantilever beam with a crack. They proved that the experiments agree with the mathematical formulae. Expressions for bending vibrations of an Euler Bernoulli beam were derived . They studied the effects of the ratio of crack location to the length of the beam and also the ratio of the depth of the crack to the height of the beam. They investigated the variation of the natural frequency of the beam. Rizos et al. [7] developed a method based on the amplitudes at two points in a structure vibrating at one of its natural frequencies and an analytical solution of the dynamic response. Shen and Chu [9] investigated the presence of fatigue cracks by exciting the structures at different frequencies and using a numerical study for the response analysis. Chondros et al. [10] developed a continuous cracked beam vibration theory for the lateral vibration of cracked Euler–Bernoulli beams with single or double edge cracks. This continuous cracked beam vibration theory is used for the prediction of the dynamic response of a simply supported beam with open surface cracks. In this study, dynamic behaviour of an edge cracked concrete beam was analyzed. Effects of crack location and depth on the modal properties of the beam were experimentally investigated to identify the location and depth of the crack. The method was used to excite natural frequencies of the beam.

II. EXPERIMENTATION

When damage or crack occurs in a beam,it modifies the vibration characteristics of uncracked beam, such as natural frequencies, mode shape, and modal damping ratios. The characteristics of the uncracked beams are often referred to as initial values in crack detection, which can be identified with modal tests. In comparison with the initial values, any deviation of the structural parameters measured during the service life reflects possible damage and may be used to identify the severity and location of crack . Among various parameters, the natural frequency has been widely used as a representive parameter of damage occurring in a beam. since it can be simply identified from modal tests with sufficient accuracy. If crack occurs in a structure, degradation of stiffness values takes place and the natural frequencies of the structure gets reduced.

The instruments used for experimental analysis *i.e.*, measurement of natural frequencies are Fast Fourier Transform (FFT) analyzer, accelerometer, impact hammer and related accessories. The piezoelectric, miniature type unidirectional accelerometer is used to capture the frequency response functions. The accelerometer is mounted on the beam using mounting clips. The accelerometer is mounted near the crack to capture the correct signal. The impact hammer is used to excite the beam whose frequency response function has to be captured. For every test, the location of impact of impact hammer is kept constant. The beam is tapped gently with the impact hammer. The experiments are performed on mild steel cantilever beam having single crack and one without crack .Depth and location of a crack is varied along the dimensions of the beam.The properties of mild steel are, Young's modulus (E) 2.0 e11 N/m2, density (ρ) 7950 N/m3 and Poisson's ratio 0.3. Specimen beams under consideration have rectangular cross section area.

the cross sectional area is

0.025 x 0.010 m,

L = 0.25m

Crack depth is represented in terms of (a/h) ratio

Where,

a = depth of crack and

h = height of beam

and crack location is represented in terms of (e) where e is ratio of location of crack at distance L1 from the support to the length of the beam L.

The FFT Analyzer is a tool developed for vibration measurement. It uses impulse execution & either frequency domain analysis or time domain analysis to give the model Parameter from the response measurement in real time.

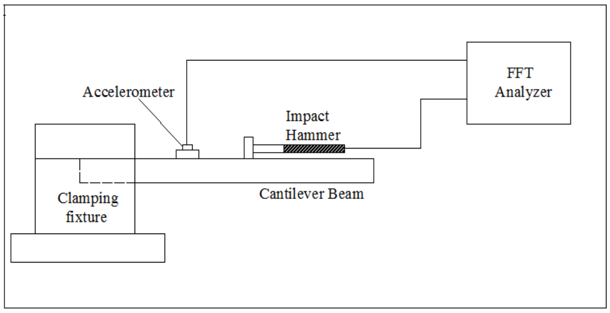

Fig.1 Experimental set up

The variable parameters considered for the experimentation are 1) depth of a crack & 2)location of a crack from fixed end of a beam.

For a crack at 25mm, 50mm, 100mm from fixed end of a beam, depth is varied in order to obtain number of natural frequencies and change in natural frequencies which is further useful to obtain network in ANN and population of GA.

Following are the observations of experimentation. The readings listed below are selected set of readings.

TABLE I
EXPERIMENTAL OBSERVATION OF NATURAL FREQUENCY

Sr. No	Location of Crack from Support L_1 (mm)	Depth of Crack a (mm)	Ratio (a/h)	E = L_1/L	Natural Frequency F_1 (Hz)	Natural Frequency F_2 (Hz)
1	25	2	0.2	0.1	446.21	2301.68
		3	0.3		458.23	2359.34
		5	0.5		496.27	2364.12
2	50	2	0.2	0.2	587.19	2370.93
		3	0.3		621.31	2389.24
		5	0.5		637.14	2408.51

3	100	2	0.2	0.4	658.96	2413.63
		3	0.3		677.33	2456.98
		5	0.5		697.67	2487.53

From the readings obtained after experimentation, a parameter is to be defined or selected for comparison of results and its validation. And the parameter is ratio of frequencies. It is the ratio of frequency of a cracked beam to the frequency of uncracked beam. For this ratio a beam without crack is initially checked for first two natural frequencies in hertz. The values obtained for first two natural frequencies are719.61 & 2489.51 respectively.

TABLE II
RESULTING FREQUENCY RATIO

Sr. No	Location of Crack from Support L_1 (mm)	Depth of Crack a (mm)	Frequency Ratio F_C/F_1	Frequency Ratio F_C/F_2
1	25	2	0.62	0.92
		3	0.64	0.95
		5	0.69	0.95
2	50	2	0.81	0.95
		3	0.86	0.96
		5	0.89	0.97
3	100	2	0.92	0.97
		3	0.94	0.99
		5	0.97	0.99

III. ARTIFICIAL NEURAL NETWORK

Artificial Neural Networks (ANN) has emerged as a promising tool for monitoring and classification of fault in machine and equipment. This technique is well prepared for solving inverse variational problems in the context of monitoring and fault detection because of their pattern recognition and interpolation capabilities (Lopes, Jr. et al., 1997). ANN also successfully approach and classify the problems associated with non-linearities, provided they are well represented by input patterns, and also can avoid the complexity introduced by conventional computational methods. It consists of a given set of inputs for which desired outputs are determined by establishing proper and desired relationship between the inputs and there outputs. The mapping between the input and the output is not given but has to be learned and once the mapping is learned or trained the desired outputs can be obtained. It helps to increase the efficiency of design process.Actually the function of the entire neural network is simply the calculation of the outputs of all the neurons considered. The output of a neuron is considered as a function of the weighted sum of the inputs plus a bias. In the given figure only one neuron is considered The inverse problem can be converted into forward technique using tools of Artificial Intelligence like Genetic algorithm, Fuzzy Logic, Artificial Neural Network (ANN). These techniques can be used for prediction of life of components or even optimization to minimize the errors in frequencies determined by numerical simulation and experimental measurement. Genetic algorithms are stochastic search algorithms which are based on the mechanics of nature selection and natural genetics. These are designed to search large, non-linear, discrete and poorly understood search space where expert knowledge is difficult to model and traditional optimization techniques may not give accurate results. In the genetic algorithm, this error is used to evaluate the fitness of each individual in the population. Genetic algorithms have been frequently accepted as optimization methods in various fields and have also been proved as an excellent in solving complicated optimization problem. Thus, Genetic Algorithm can be used to solve inverse problem for the crack detection in a shaft [28]. The Artificial Neural Networks (ANN) in a wide sense belongs to the class of evolutionary computing algorithms that try to simulate natural evolution of information handling [29]. The present paper checks the applicability of this tool to predict the crack location and depth depending upon the input. The input to the ANN is the natural frequency of three or more number of modes and output is crack location and crack depth. In case of single crack the output will be prediction of crack location and crack depth *i.e.,* two parameters whereas for two cracks the output will be prediction of four parameters *i.e.,* two predictions for crack depths and two predictions for crack locations. Amongst the available data, 90% data is used to train the network in ANN whereas 10% of the data is used for validation. The back propagation algorithm is used [30]. The network is trained using the data obtained by FEM. Thereafter, the network predicts the location and depth of crack. The network can predict the crack location and depth for any intermediate input values of natural frequencies. The network decides the predominant input parameter on its own. The iterations are conducted till the average training error and average validating error is minimized [31]. For simply supported beam with single crack, single layer serves the purpose whereas for cantilever beam with two cracks, three layers give close predictions. For cantilever beam with two cracks, three layers are chosen as average training error and average prediction error is minimum in case of three layers. Less error in both is indication of precise prediction of output. During the routine assessment of the health of component or online conditioning and monitoring, if decrease in natural frequency is observed, these frequency values can be given as input in the form of new query to the network. The network predicts the properties of crack. Any number of queries can be run.

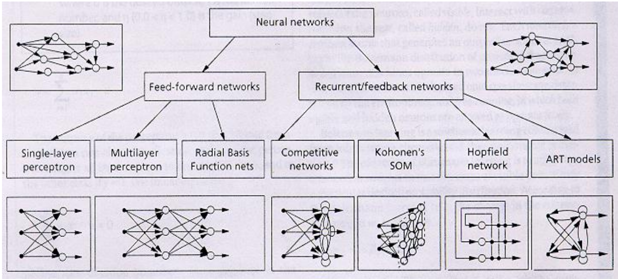

Fig. 2 Schematic network of ANN

According the topology of artificial neural network mentioned in the diagram shown above and the listed procedure, Readings required for the validation are obtained by creating a network in software known as GMDH Shell.

It has given tremendous resemblances of values with the reference values.

TABLE III
RESULTS BY ANN

Sr. No	Location of Crack from Support L_1 (mm)	Ratio a/h	E = L_1/L
1	25	0.19	0.11
		0.31	
		0.53	
2	50	0.18	0.19
		0.31	
		0.52	
3	100	0.21	0.42
		0.33	
		0.51	

It is a computational system inspired by the Structure, Processing Method, and Learning Ability of a biological brain Characteristics of Artificial Neural Networks: A large number of very simple processing neuron-like processing elements, a large number of weighted connections between the elements Distributed representation of knowledge over the connections Knowledge is acquired by network through a learning process.

IV.GENETIC ALGORITHM

The genetic algorithm is a search technique based on ideas from the science of genetics and the process of natural selection. A simple genetic algorithm consists of three basic operations: reproduction, crossover and mutation. The algorithm starts with a randomly generated initial population. Members of this population are usually binary strings (called chromosomes). Particular elements of the chromosomes are called the genes. In these strings values of a variable or variables are coded, which can be a solution to the examined problem in the search space. These variables are then used to evaluate the corresponding fitness value, which is the objective function. In the next step the chromosomes are selected for reproduction. Selected processes can be realised in many ways (Goldberg, 1989), nevertheless the number of selected members is a function of their fitness. Thus, the individuals with a higher fitness will receive more copies. In order to minimise premature convergence of the initial populations special scaling methods are applied (Goldberg, 1989). One of the most widely applied methods is the linear scaling proposed by Bagley (1967). After reproduction the process of crossover is realised. There are many ways of implementing this idea (Goldberg, 1989). Generally, crossover with one or many crossover points can be used. The crossover points are selected randomly, usually using roulette wheel. This way, by exchanging some portions between the selected chromosomes (called parents), two new strings (called children) are created. The final process is mutation. Here, a particular gene in a particular chromosome is randomly changed. It means that *O* is changed to 1, and vice versa. The process of mutation in nature is very rare and, for this reason, in a genetic algorithm the probability of mutation in a chromosome is kept on a very low level.

There are four evolutionary elements in GA:

1. *Selection* of parent individuals or strings can be achieved by a “wheel of fortune” process, where a string’s probability of selection is proportional to its performance against the total performance of all strings.
2. *Crossover* takes pairs of mating partners, and exchanges segments between the two, based on a randomly chosen common crossover point along both strings.

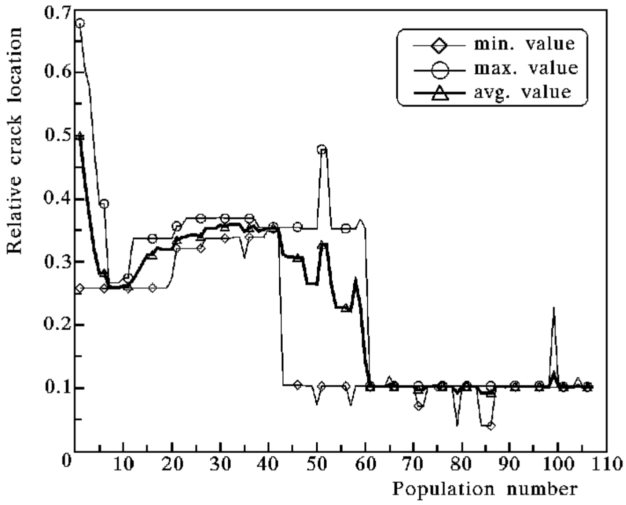

Fig.3 Graph representing Relative Crack Location by Population of GA

3. *Mutation:* with a small probability each bit is flipped. This eliminates premature convergence on a sub-optimal solution by introducing new bit values into a population of solutions.
4. *Encoding* is the way in which the artificial agent’s contingent behaviour is mapped from the individual’s structure to its behaviour. As well as the decision of whether to use binary or decimal digits, or perhaps

Floating-point numbers, there is also the way in which the model is encoded.

So, the values of parameters are to be found out by using the procedure enlisted above. And it is supported and verified by a software KEEL and Mat Lab. KEEL is a software tool to assess evolutionary algorithms.

TABLE IV
COMPARISON OF CRACK PROPERTIES BY EXPERIMENTATION, ANN AND GA

S. N.	Location of Crack from Support L_1 (mm)	Ratio a/h (Expt)	Ratio a/h (ANN)	Ratio a/h (GA)	E = L_1/L (Expt)	E = L_1/L (ANN)	E = L_1/L (GA)
1	25	0.2	0.19	0.2	0.1	0.11	0.1
		0.3	0.31	0.31			
		0.5	0.53	0.5			
2	50	0.2	0.18	0.19	0.2	0.19	0.2
		0.3	0.31	0.3			
		0.5	0.52	0.5			
3	100	0.2	0.21	0.2	0.4	0.42	0.41
		0.3	0.33	0.31			
		0.5	0.51	0.5			

V. RESULTS AND CONCLUSION

1. To study crack properties, the variation in natural frequencies is observed.
2. The results of Experimentation, ANN and GA are compared and they are in good agreement.
3. The database obtained is used as input to train the Neural Network. The trained Network can predict crack characteristics like depth and location by giving the natural frequency as input.
4. The predictions of crack location and depth by ANN are verified with the results of Experimentation. The results are in good agreement with error of 1% to 7% for single crack.
5. The error in prediction of crack location by GA is in the range of 1% to 3% where as in case of experimental analysis, it is in the range of 2% to 3%. The variation in the experimental results is due to structural vibrations.
6. The proposed method can be further implemented for crack detection in beams, shafts or rotating machine element.

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