Crack Detection in Machine-Structure by Evolutionary Algorithm

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Abstract: *An evolutionary approach for fatigue crack detection in cantilever type of machine structure is investigated in this paper. Fault like fatigue crack detection has received a great attention in recent years. A surface transverse open edge crack is considered for this study. Actual fatigue crack may behave like a non-linear due to opening and closing under vibration. But due to small level of vibrations on structural beams it can be assumed that cracks remain open. To avoid non-linearity, and tackle most practical problems it is assumed that the crack is always open. Vibration parameters obtained from modal analysis as a criterion for crack detection has been extensively used in the last decade due to its simplicity. Most of the works in the application of evolutionary methods for this purpose are limited to numerical examples and small experimental examples only. However an efficient technique is necessary to obtain significant results. The first three natural frequencies were used for the fault detection. The crack parameters are accurately detected using the experimental natural frequencies as an input to genetic algorithm. To investigate the robustness of the proposed method, several experimental cases of cracked beam are considered. It is found that the method is capable of detecting crack in cantilever beam.*

Keywords: *Crack detection, Cantilever beam, Evolutionary method, Genetic Algorithm.*

1. Introduction

Literature on fault detection was focused on the vibration-based method which can be classified into modal-based and signature-based methods. In

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modal based techniques data can be condensed from the actual measured quantities like resonant frequencies, mode shape vectors and quantities derived from these parameters for the crack detection [1, 3, 4, 6].

In signature based methods the vibration signature of cracked machinery structure can be useful for the fault diagnosis. Thus, the development of crack detection methods has received increasing attention in recent years. In order to identify structural damage by vibration monitoring, the study of the changes of the structural dynamic behavior due to cracks is required for developing the detection criterion. [2, 5, 7- 10].

In this paper, an evolutionary method is developed for fault diagnosis of cantilever beam using vibration analysis.

2. Finite Element Analysis

The cracked beam model having a transverse surface edge crack is generated in Ansys(12) software. For a crack depth and crack location 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 through the width and a three-dimensional triangular crack with a 1 mm length on the top surface of the beam and a crack going through the width of the beam model was obtained. A 8-node three-dimensional structural solid element under SOLID 45 having three degrees of freedom was selected to model the beam. The beam was discretized into 11859 elements with 54475 nodes. Cantilever boundary conditions modeled by constraining all degrees of freedoms of the nodes located on the left end of the beam. ANSYS Parametric Design Language (APDL) is a scripting language that is very similar to FORTRAN is used to create 135 cracked beam models by varying the crack depth from 5 mm to 45 mm and crack location from 50 mm to 750 mm. Modal and Harmonic analysis were used to obtain first few natural frequencies of the beam model.

3. Experimental Results

Thirteen beams were considered to obtain the vibration characteristics under different levels of damage. Table 1 gives the physical parameters used in the experiments. The measured vibration data is used in the subsequent section to demonstrate the applicability of the fault detection method developed in this study.

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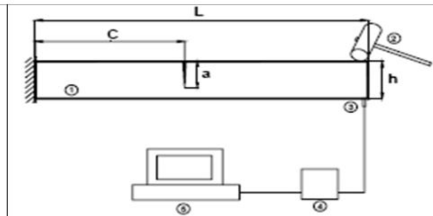
Fig. 1 shows the components in impact modal analysis. Vibration signals were collected for both uncracked and cracked beam conditions. Beam clamped at one end, free at other end with a piezoelectric accelerometer [DYTRAN (USA)-3185 D] with magnetic base, mounted on the flat surface of beam attached. As an input beam was excited by an impact hammer and FRF's were measured for various fault conditions at the end point on the beam to include first three natural frequencies.

Table 1.Parameters used in experiments

Parameters	Values
Beam Length (L)	0.8 m
Beam Width (b)	0.006 m
Beam Height (h)	0.05 m
Modulus of Elasticity (E)	2.068x1011 N/m^2
Density of Beam Material (ρ)	7600.0 kg/m^3
Poisson's Ratio (μ)	0.33



1.Beam 2.Impat Hammer
3.Accelerometer 4.FFTAnalyser
5.Computer terminal

Figure 1. Experimental set up

The sensor was connected to the signal-conditioning unit (SVAN956 FFT analyzer), where the signal goes through a charged amplifier and an analogue-to-digital converter (ADC). The vibration signal in digital form was saved on computer through a USB port for further analyses. The signal was then read from the memory and processed to extract the first few natural frequencies.

4. Genetic Algorithm in Crack Detection

To estimate the location and depth of a crack in a structure using natural frequency information, we use genetic algorithm. The inputs to our crack detection system are three normalized natural frequencies ($\Delta\omega_1, \Delta\omega_2, \Delta\omega_3$). Identification of the crack location and depth is formulated as an optimization problem, and the genetic algorithm is used to find the optimal location and depth by maximizing the objective function which is based on the difference of

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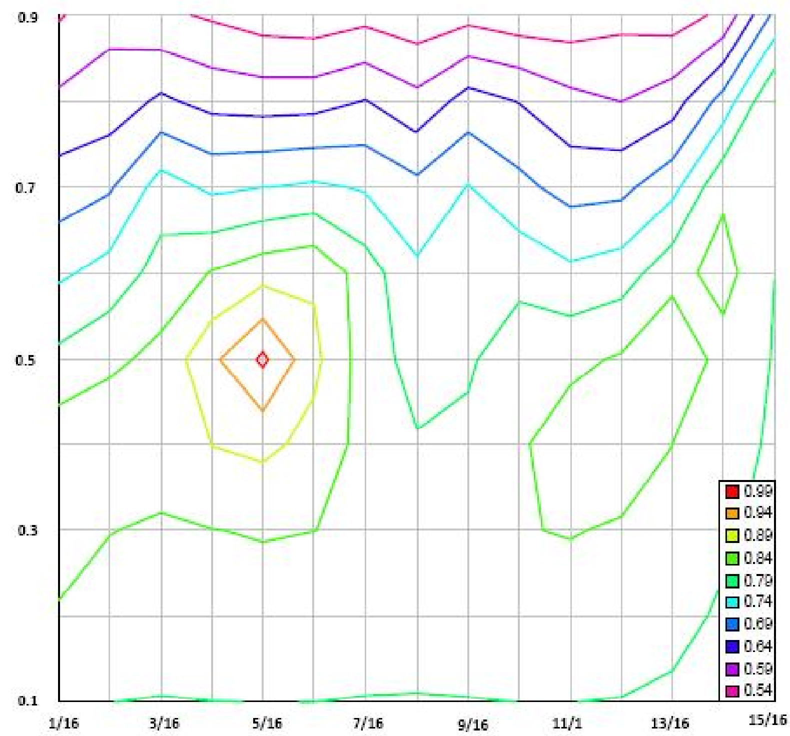

Figure 2. The contours of the objective function as a function of both dimensionless crack location and depth

experimental and simulated frequencies. A contour plot of a fitness value (search space) as a function of crack parameters (location and depth) is shown in Fig. 2 for the beam with crack parameters 0.3125 and 0.5. It shows that fitness value surface has many local maxima and there is a good chance of getting stuck in one of them. The goal is finding the exact parameters for which the fitness function value is one. Conventional optimization techniques have difficulty in finding the global maximum unless the starting point is in the immediate vicinity of it. Fig. 3 shows the flowchart of the method of crack detection using genetic algorithm.

4.1. Genetic Algorithm implementation

Problem encoding: Bit strings used to encode the candidate solution, and the representation of the solution or the approximation for the true crack configuration is a bit string of which each substring represents one parameter. The length of each substring is determined by the solution accuracy and the interval of the solution. In this problem, solution accuracies and the intervals for the crack location and crack depth are set to 0.0625 and 0.01 respectively and total string length of seven bits is used.

Initialization: Initially an individual solution is randomly generated to form an initial population.

Fitness evaluation: Objective function used in the present paper is based on the changes in experimental natural frequencies and simulated natural frequencies. The change in natural frequencies is termed as damage index. The form of objective function is based on the damage index (DI)

$$DI(s) = \sum_{i=1}^{n} \left| \Delta\omega - \Delta\omega_e (f(C/L, a/h)) \right|$$

Where

$$\Delta\omega = \frac{\omega_{cracked} - \omega_{uncracked}}{\omega_{uncracked}}$$ = Normalized simulated frequency,

$$\Delta\omega_e = \frac{\omega_{e\,cracked} - \omega_{uncracked}}{\omega_{uncracked}}$$ = Normalized experimental frequency.

DI values lie in the range 0 to 1, with 0 indicating exact match and 1 indicating no correlation between the patterns of the frequency changes. To convert minimization problem into maximization problem, inverse function is used as a fitness function. The value of s, giving the highest values, determines the predicted damage location and size.

Fitness function = $f(s) = \dfrac{1}{1 + DI(s)}$

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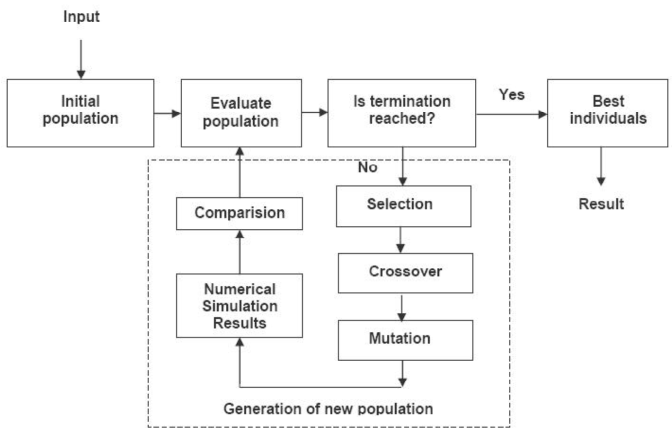

Figure 3. Evolutionary method

4.2 Genetic operators

Following genetic operators were applied in genetic algorithm.

Selection: The classical 'roulette wheel' method is implemented as a selection criterion.

Crossover: Crossover with a probability of (P_c) was implemented by choosing a point in the selected pair *of strings and exchanging the substrings defined by the cross over site.*

Mutation: The role of the 'mutation' operation is to introduce new genetic materials (genes) to the chromosomes. With a probability of (P_m); an elite strategy was used thus preventing the inadvertent loss of useful genetic material in earlier phases of evolution.

Termination: This generation process is repeated until a termination condition has been reached. In the present study fixed number of generations (200) reached was used as a termination criterion.

5. Results

Performance analysis of condition monitoring technique was done with different GA variable tested at a time to optimize values. The studied parameters includes population size, cross over and mutation probabilities and number of generations. In GA there is no general theory about selecting genetic parameters. To improve performance of GA a through study on the performance of GA using different strategies is presented. Results show that the proposed procedure leads to improvement in the performance of the estimates. To evaluate the effect of different input parameters on GA performance thirteen experimental damage scenarios are considered.

As most typical values of the genetic algorithm parameters could be considered as follows:

- Mutation Probability (Pm) – 0.04, 0.05, 0.06 and 0.07;
- Cross over Probability (Pc) – 0.4, 0.5, 0.6 and 0.8;
- Population Size – 10, 15, 20, 25 and 30;
- Number of generations – 200

In Table 2 the best results are marked in dark background. The results showed that with every step of the tuning procedure the problem decision was achieved for less and less iterations. The final result was an increase in the decision accuracy.

Table 2 Performance improvement of GA parameters

Genetic Parameters		Objective Function	Generations
Population Size	10	0.9944	143
	15	0.9944	19
	20	0.9944	2
	25	0.9944	12
	30	0.9944	7
Pc = 0.6 Pm = 0.05			
Cross over Probability	0.4	0.9944	6
	0.5	0.9944	14
	0.6	0.9944	2
	0.8	0.9944	1
Population Size = 20 Pm = 0.05			
Mutation Probability	0.04	0.9944	19
	0.05	0.9944	1
	0.06	0.9944	5
	0.07	0.9944	2
Population Size = 20 Pc = 0.8			

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During GA parameters tuning the parameters optimized were as below:

- Mutation Probability (Pm) – 0.05;
- Cross over Probability (Pc) – 0.8;
- Population Size –20;
- Number of generations – 200;
- Objective function – 0.9944

6. Conclusion

A crack detection method presented in this paper allows successful estimation of crack parameters in cracked cantilever beam. This procedure is based on a stochastic method using evolutionary approach. The non-gradient nature of genetic algorithm has been exploited to handle problems of the initialization solution and the degree of correlation between parameters. Genetic algorithm method has been adopted in the present investigation to predict the identification and localization of the crack with the help of natural frequencies in the cracked cantilever beam and found to be very efficient. The input parameters used in this method are first three natural frequencies of the beam. The outputs are crack depth and crack location. The aim of this study was to establish a novel fault diagnosis and condition monitoring method using genetic algorithm, open through cracks were considered. Based on the same method work can be extended for non-through and micro crack conditions.

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