ARTICLE IN PRESS

Precision Engineering xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Precision Engineering

journal homepage: www.elsevier.com/locate/precision

A generally modified cuckoo optimization algorithm for crack detection in cantilever Euler-Bernoulli beams

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A R T I C L E I N F O

Keywords:
Crack detection
Euler-Bernoulli beam
COA
MCOA
GMCOA
ABC
PSO
Taguchi design of experiments
Modal analysis

A B S T R A C T

In this research, a new and Generally Modified Cuckoo Optimization Algorithm (GMCOA) for solving the problem of detecting and estimating open-edge cracks in cantilever Euler-Bernoulli beams is proposed. This method is generated via applying general changes to Cuckoo Optimization Algorithm (COA) and improving its performance. The performance of this algorithm is investigated by performing simulation tests on a cantilever beam. Frequency response equations of a cracked beam is modelled using Euler-Bernoulli beam method and Hamilton's principle and its results are verified via modal tests on a sample beam. Tuning parameters of this optimization procedure is determined using Taguchi design of experiments method. An objective function consisting of the difference between measured and calculated first to fourth bending natural frequencies of the cracked beam is considered for optimization. Analyzing and comparing the results obtained using this method and the results of previous researches shows a better performance for this method. This method, in addition to estimating crack depth and location more accurately than other methods, achieves this accuracy with lower number of Function Evaluations (FEs). By using this number of FEs, other methods have not found crack location and depth more accurately than this method.

1. Introduction

An important and common factor manifesting safety risk in proper performance of an engineered structure is a structural defect called crack. Considering this structural defect in crucial elements such as beams is very important, due to their ability to withstand various loads in many engineering structures during their life time period [1]. Therefore, prior to its propagation and destruction of the structure, a crack should be identified and repaired. It is known that existence of defects in the form of cracks in vital elements such as beams changes their natural frequencies and mode shapes [2]. Today, by non-destructive vibration methods such as modal analysis, frequency data of a defected structure is easily measured, and then crack parameters are identified and measured using various numerical methods.

To identify any defect, two different approaches, including direct and inverse methods, are used. In the first approach, usually a mathematical model is obtained to determine the structure behavior and evaluate the relationship between natural frequencies and mode shapes with parameters of damage or cracks [3]. Many researches may be noted in this field. Nahvi and Jabbari [4] detected crack dimensions in a cantilever beam. Qian et al. [5] obtained stiffness matrix of a beam with an open-edge crack by integrating stress intensity factor. Dimangouros and Papadopolus [6] determined local stiffness matrix at crack location for analysis of changes of natural frequencies and mode shapes. Orhan [7] analyzed free and forced vibrations for a cantilever beam with one and two edge cracks. Numerically, Zheng et al. [8] obtained natural frequencies and mode shapes of a cracked beam using finite element method (FEM) and considered stiffness matrix of an intact beam. Rios et al. [9] modelled the mentioned crack by a torsion spring in order to determine location and depth of the crack created in a cantilever beam. Behzad et al. [10] found location and depth of a created crack by modeling a weightless torsion spring in crack location in a cantilever beam and utilizing a vibration-based algorithm.

Among many researches performed in recent decades to detect crack, reverse methods and algorithms using non-destructive tests have a significant status. In these methods natural frequencies of intact and faulty structures are used to determine existence or absence of cracks, and also to estimate the location and depth of any existing crack.

With increasing developments and particularly speeds in computers, many researchers determine location and depth of cracks with the help of reverse methods, using numerical methods or versatile and efficient optimization algorithms. Most of these methods are population-based ones and inspired by natural behavior of living beings. If "detection of cracks in a structure" is considered as an optimization problem, different parameters of crack such as depth and location may be considered as optimization variables and a proper combination of natural

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https://doi.org/10.1016/j.precisioneng.2017.12.010
Received 18 February 2017; Received in revised form 15 December 2017; Accepted 20 December 2017
0141-6359/

Please cite this article as: Moezi, S.A., Precision Engineering (2017), https://doi.org/10.1016/j.precisioneng.2017.12.010

frequencies of the existing structure be considered as cost functions as well [11].

Researches considering crack detection as an optimization problem include Rubio et al. in 2015 [12] who estimated crack in a long rod using a new optimization method, Sahoo and Maity [13] who estimated parameters of a crack using an algorithm based on neural networks and genetic optimization method and considering changes in natural frequencies and strain, Baghmisheh et al. [14] who estimated depth and location of cracks using genetic optimization method, and Khaji and Mehrjoo [15] who detected size and location of a crack created on a beam-like structure using inverse method procedure via genetic algorithm.

Different optimization algorithms have been utilized by researchers to detect cracks. Rong and shun [16] determined parameters of a crack created in a beam with different boundary conditions (BCs) by a genetic-simulated annealing hybrid algorithm. Moradi et al. [11] obtained location and depth of an open-edge crack in a cantilever beam using Bee Algorithm (BA). Baghmisheh et al. in 2012 [17] identified location and depth of a crack in a cantilever beam using PSO-Nelder-Mead hybrid method. They compared their proposed method with other methods such as neural networks and Genetic-Nelder-Mead hybrid method, and showed that their results are more accurate than other methods. Moezi et al. in 2015 [18] estimated location and depth of a crack created in a cantilever beam using Modified Cuckoo Optimization Algorithm (MCOA) with a very high accuracy. They compared results of their proposed method with the results of Cuckoo Optimization Algorithm (COA) and genetic-Nelder-Mead hybrid algorithm, and showed that their results were far more accurate.

Reviewing trends and results in the mentioned researches where various optimization techniques were used to detect cracks in different structures, following remarks may be derived:

- In many studies, location and depth of cracks estimated by proposed methods are not sufficiently accurate. General reasons may be weakness of proposed methods or not accurately tuning the parameters of utilized optimization algorithms [11–16].
- In some studies, although accuracy of the proposed methods is almost enough, numerical calculations performed (i.e., number of Function Evaluations (FEs)) are too lengthy. This leads to a time-consuming optimization process that is not economically efficient [17–18].

One of the most powerful and relatively new optimization methods that has been used to solve optimization problems in many studies [18–21] is called Cuckoo Optimization Algorithm (COA). COA is an evolutionary and population-based optimization algorithm, the main idea of which is inspired from life and reproduction of a unique bird named Cuckoo. As stated in the survey, Moezi et al. [18] estimated location and depth of crack using a modified version of this method with a high accuracy. One of the disadvantages of their research was the relatively large amount of numerical calculations in achieving the optimal solution.

The aim of this study is to change and improve COA, and to present a new Generally Modified Cuckoo Optimization Algorithm (GMCOA) for solving optimization problems in detecting an open-edge crack in cantilever Euler-Bernoulli beams. In addition to the accuracy in identifying parameters of estimated crack, the proposed method may significantly reduce the amount of calculations in implementing optimization algorithm (i.e., number of FEs). In this research, some modifications and changes have been applied to COA in order to improve its performance, which are listed as:

- Appropriate allocation of eggs to each mature cuckoo corresponding to its fitness value
- Changing and modifying egg laying radius (ELR) of a cuckoo depending on its fitness value and number of optimization iterations, in order to increase accuracy and improve final answer for the optimization problem
- Changing population distribution of cuckoos in order to achieve better points using a lower number of population in search space during optimization iterations

In this study Taguchi design of experiments method is used to tune parameters of GMCOA. This method has a higher accuracy than trial and error method or random selection used in many previous studies [11–21], and also tunes parameters of the optimization algorithm in a shorter time.

In this study, using GMCOA and minimization of proper cost function, parameters of crack created in beam is estimated. The cost function is based on the difference between measured and calculated four bending natural frequencies of cantilever Euler-Bernoulli beams. The created crack is modelled by a torsion spring, the stiffness of which depends on crack depth and beam height. Frequency response equations for the cracked beam are developed by Euler-Bernoulli beam method and Hamilton's principle. Results of the proposed method, the tuning parameters of which are obtained by Taguchi method, are compared with results of COA, MCOA, Artificial Bee Colony (ABC) [22], Particle Swarm Optimization (PSO) [23] and previous researches [3,11,14,16–18,24] performed in this field. Moreover, results are validated using modal test experiments on a cantilever beam with specific dimensions.

2. The cracked beam model

In this study, a cantilever beam having a length L, height h, width b and a transverse open-edge crack of depth d_c is considered (Fig. 1a). To calculate natural frequencies of the cracked cantilever beam, it is divided into two uniform sections joined by a torsion spring (Fig. 1b). Stiffness of the spring is calculated based on crack depth and geometrical and physical characteristics of the beam. Any change in the crack depth affects the beam natural frequencies. Coefficient of the spring (K_θ) is calculated using the following relationship [25]:

$$K_\theta = \frac{EI}{6(1-\nu^2)h} \times \frac{1}{J} \tag{1}$$

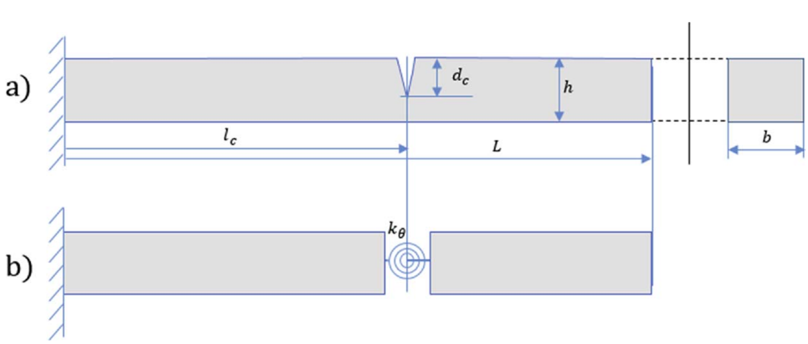

Fig. 1. Schematics of a cracked beam.