ARTICLE IN PRESS CRAS2B:3553

C. R. Mecanique ••• (••••) •••–•••

Contents lists available at ScienceDirect

Comptes Rendus Mecanique

www.sciencedirect.com

Crack identification method in beam-like structures using changes in experimentally measured frequencies and Particle Swarm Optimization

Samir Khatir[a], Kevin Dekemele[a], Mia Loccufier[a], Tawfiq Khatir[b], Magd Abdel Wahab[c,d,e,*]

[a] *Department of Electrical Energy, Metals, Mechanical Constructions, and Systems, Faculty of Engineering and Architecture, Ghent University, Gent, Belgium*
[b] *Institute of Science and Technology, University Center Salhi Ahmed Naama, Algeria*
[c] *Division of Computational Mechanics, Ton Duc Thang University, Ho Chi Minh City, Viet Nam*
[d] *Faculty of Civil Engineering, Ton Duc Thang University, Ho Chi Minh City, Viet Nam*
[e] *Soete Laboratory, Faculty of Engineering and Architecture, Ghent University, Technologiepark Zwijnaarde 903, B-9052 Zwijnaarde, Belgium*

ARTICLE INFO

Article history:
Received 23 June 2017
Accepted 28 November 2017
Available online xxxx

Keywords:
Crack detection
Vibration analysis
Particle swarm optimization
Finite element method
Experimental modal analysis

ABSTRACT

In this paper, a technique is presented for the detection and localization of an open crack in beam-like structures using experimentally measured natural frequencies and the Particle Swarm Optimization (PSO) method. The technique considers the variation in local flexibility near the crack. The natural frequencies of a cracked beam are determined experimentally and numerically using the Finite Element Method (FEM). The optimization algorithm is programmed in MATLAB. The algorithm is used to estimate the location and severity of a crack by minimizing the differences between measured and calculated frequencies. The method is verified using experimentally measured data on a cantilever steel beam. The Fourier transform is adopted to improve the frequency resolution. The results demonstrate the good accuracy of the proposed technique.

1. Introduction

In order to identify the location and depth of a crack in a beam, various experimental studies have been conducted, and several methods were proposed by many authors in recent years [1–8]. Structural Health Monitoring (SHM) using vibration analysis is based on five levels, which are: 1) detection; 2) localization; 3) classification; 4) assessment, and 5) prediction. Many previous works for most of these levels are available in the literature. Beams are essential parts of a structure in various fields of engineering and are considered in mechanical, civil, as well as aerospace engineering. In the vibration-based SHM, it is very critical to extract modal parameters information based on the structural response measurements. The information of a structure provides accuracy and critical data for determining the health of a structure, for which the vibration-based SHM plays an essential role. Doebling et al. [9] presented a review on crack identification, damage detection,

---

[*] Corresponding author.
E-mail addresses: magd.abdelwahab@tdt.edu.vn, magd.abdelwahab@ugent.be (M. Abdel Wahab).

https://doi.org/10.1016/j.crme.2017.11.008

Please cite this article in press as: S. Khatir et al., Crack identification method in beam-like structures using changes in experimentally measured frequencies and Particle Swarm Optimization, C. R. Mecanique (2018), https://doi.org/10.1016/j.crme.2017.11.008

and localization in structures using vibration analysis. The estimation methods were predominately based on the changes in natural frequencies [10–12]. The multiple damage detection in cantilever beam and complex structures using the co-ordinate modal assurance criterion combined with an optimization technique was presented by Khatir et al. [13]. The crack has been modeled as a spring with bilinear stiffness by Ballo [14]. Different detection procedures for damage identification in rotors using damage parameters such as the crack depth and location were identified in [15,16]. Based on changes in natural frequencies, Messina et al. [17] calculated the Damage Location Assurance Criterion (DLAC) to identify single damage, which was later extended to identify multiple damages [18]. Lee [19] proposed a technique for the identification of cracks in a beam using Boundary Element Method (BEM). The detection of a crack in a beam was designed in such a way that the crack was not modeled as a massless rotational spring, and then the problem was solved based on natural frequencies using BEM. Deokar and Wakchaure [20] performed experimental tests for the purpose of crack detection in beam-like structures using natural frequencies.

The above technique is called the response-based approach since the response data are directly related to damage [3, 21]. This approach is therefore fast and inexpensive. Another method known as the model-based approach [22] has been proposed to detect damage based on updating certain parameters to get perfect agreement between the experimental measured modal parameters and an initial finite element model. For damage detection in a beam using Genetic Algorithm (GA) and vibration data, three objective functions were used by Khatir et al. [23]. Khatir et al. [24] presented a new damage detection and quantification technique based on the changes in vibration parameters using BAT and PSO algorithms to detect single and multiple-damage positions and the rate of damage in structural elements. The simplest method in a Finite Element (FE) model is to use a reduced stiffness to simulate a small crack [25–27]. Cam et. al. [28] presented a technique for damage detection, in which the vibrations as result of impact shocks were analyzed. Friswell and Penny [29] have presented different approaches to model cracks, and showed that for SHM using low frequencies produced good results.

This paper is divided into five main sections. After the introduction section, the damage detection algorithm is presented in the second section. Numerical examples of a 1-D cantilever beam and of a 2-D frame structure are illustrated in section 3. In section 4, experimental validation using a laboratory steel beam is presented. Finally, the paper is concluded with some remarks in section 5.

2. PSO algorithm

Khatir et al. [30] presented a new approach for detecting and locating single damage based on the FEM and the Proper Orthogonal Decomposition method with Radial Basis Function (POD–RBF) coupled with Genetic Algorithm (GA) and PSO algorithm. The results of both algorithms showed that PSO could be used to detect damage with height accuracy. The PSO method was based on swarm intelligence and has been used widely in recent years. It was developed based on a variety of versions that could handle the majority of optimization problems [31,32]. In this study, we used PSO for damage detection in 1-D and 2-D structures. The swarm is modeled as a number of individual particles chosen based on the problem description for a global optimum. The particles communicate with their neighbors over the progress made so far and adjust their moving velocity according to the information given. First, a population of candidate solutions is created randomly, each of which is considered to be a particle moving through the multidimensional design space in search of the position of a global optimum. The particle can be characterized by its physical position in the space and its velocity vector, while it has the ability to remember two important pieces of information, namely; a) the best position has passed so far or a personal best (P_best) and b) the best position that any other particle of the swarm has passed so far or a global best (G_best). The acceleration coefficients of PSO, c_1 and c_2, represent the degrees of confidence in the best solution found by the individual particles. The updated equations for the speed and position of a particle are:

$$\left\{v^i(t+1)\right\} = w\left\{v^i(t)\right\} + c_1\{r_1\} \times \left(\left\{x^{\mathrm{Pb},j}\right\} - \left\{x^j(t)\right\}\right) + c_2\{r_2\} \times \left(\left\{x^{\mathrm{Gb}}\right\} - \left\{x^j(t)\right\}\right) \tag{1}$$

$$\left\{x^i(t+1)\right\} = \left\{x^i(t)\right\} + v^i(t+1) \tag{2}$$

where w is an inertia weight parameter, $\{x^{\mathrm{Pb},j}\}$ is a vector of the personal best location found by the particle j until current iteration, $\{x^{\mathrm{Gb}}\}$ is a vector of the global best location found by the entire swarm up to the current iteration, $\{v^i(t)\}$ is the velocity vector of particle j at time t, $\{x^j(t)\}$ is the position vector of particle j at time t, and r_1, r_2 are vectors containing random numbers with uniform distribution in the interval $[0, 1]$.

The fitness of each particle shows the quality of each solution and is evaluated by an objective function. In every iteration, the speed of the particle is updated in a stochastic way. In this paper, we use PSO as an inverse problem for detecting and locating damage using measured and calculated natural frequencies. The objective function (OF) is presented in the following form:

$$\mathrm{OF} = \sum_{i}^{n} \left(\left(\omega_i^{\mathrm{r}} - \omega_i^{\mathrm{c}}\right)^2 / \left(\omega_i^{\mathrm{r}}\right)^2 \right) \tag{3}$$

where, n is the number of modes, ω_i^{r} are the frequencies calculated by PSO–FEM, and ω_i^{c} are the experimentally measured frequencies.

Please cite this article in press as: S. Khatir et al., Crack identification method in beam-like structures using changes in experimentally measured frequencies and Particle Swarm Optimization, C. R. Mecanique (2018), https://doi.org/10.1016/j.crme.2017.11.008