ARTICLE IN PRESS

Journal of Sound and Vibration ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Journal of Sound and Vibration

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

Damage detection by a FE model updating method using power spectral density: Numerical and experimental investigation

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ARTICLE INFO

Article history:
Received 6 October 2016
Received in revised form
19 February 2017
Accepted 23 February 2017
Handling Editor: Dr. I. Trendafilova

Keywords:
Power spectral density
Damage detection
Sensitivity-based model updating
Structural vibration
Experimental vibration test

ABSTRACT

This paper investigates the viability of damage detection using power spectral density (PSD) of structural response both numerically and experimentally. The paper establishes a sensitivity based damage detection method to use PSD. The advantages of PSD as a model updating metric are explained and its challenges are addressed. An approximate frequency response function of damaged model is used to redeem the method for the effect of incomplete measurement. The robust solution of the developed sensitivity equation is achieved through a least-squares error minimization scheme, and the challenging issues are discussed. The ability of the method in localizing and quantifying the damage and its robustness against measurement and modeling errors is investigated by a numerical example. Experimental vibration test data of a laboratory concrete beam with various level of distributed damage is used to probe the method in practical conditions. The results show that PSD of response can be used to detect damages in lower frequency ranges with acceptable accuracy.

1. Introduction

Engineering structures of various applications are often constructed for long-term service. However, because of different environmental or operational conditions, damage occurrence is inevitable. If the damages go undetected for long periods, they can lead to sudden, catastrophic structural failure. Therefore, in recent years, great effort has been exerted to detect damages at the earliest possible stage. In this regard, finite element model (FEM) updating is of certain importance for researchers. Significant issues such as measurement error, modeling errors and uncertainty, incompleteness of measurements, derived sensitivity equation, and adopted optimization technique should be addressed. The accuracy of the developed sensitivity equation for selected metrics is the key to the success of an FEM updating method.

Vibration-based tests for damage detection have received increased attention from researchers in the past few decades. The basic premise of these methods is the fact that the changes in stiffness, mass, and damping will lead to changes in structural responses. Dynamic tests are conducted in input-output or output-only conditions. In the first case, the test is performed in controlled conditions in which knowledge of the excitation is required [1]. In the second case, the tests are done using the excitation from ambient resources such as wind, waves, traffic, human activity, etc. [2–4]. Damage detection

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http://dx.doi.org/10.1016/j.jsv.2017.02.052

Please cite this article as: M. Pedram, et al., Damage detection by a FE model updating method using power spectral density: Numerical and experimental investigation, Journal of Sound and Vibration (2017), http://dx.doi.org/10.1016/j.jsv.2017.02.052

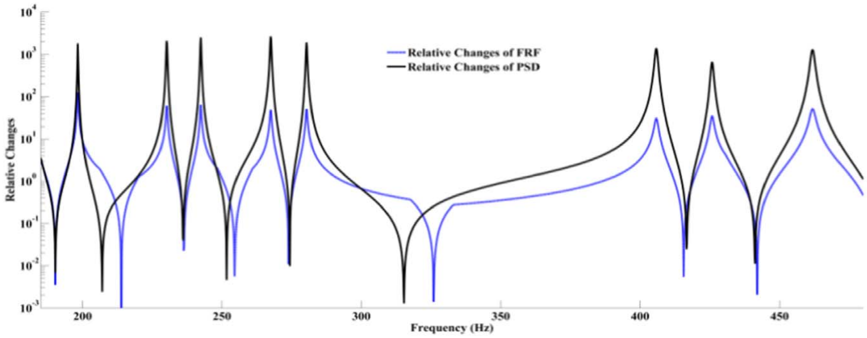

Fig. 1. Relative changes of PSD and FRF for a representative damage case.

methods by model updating are inverse problems that rely on optimization techniques to reach a global optimum [4,5]. In this regard, a sensitivity-based FEM updating scheme contributes to localization and quantification of damage. The selection of metrics for model updating is the other influential issue. Until now, FEM updating, using modal data such as natural frequency [6–8], mode shape [9–11], mode shape curvature [12–14], and modal strain energy [15–17] has been greatly noticed by researchers. Modal data (natural frequencies and mode shapes) are inherent structural properties and render great information about structural condition. Using modal data for sensitivity based model updating, leads to better convergence in presence of measurement noise when more vibrating modes are considered. On the other hand, the accuracy of parameter estimation attenuates when the data from fewer lower modes is accessible. In such situations, the frequency domain data are more admissible, because they provide data from more frequency points. Availability of data from more frequency points is necessary for robust model updating and solution uniqueness by setting an over-determined equation [18]. Furthermore, the frequency domain indices exhibit significant changes with change of structural parameters [19]. Pradhan and Modak [20], Rahmatalla et al. [21] and Yang et al. [22] used frequency response function (FRF) for model updating. Ghafory-Ashtiany and Ghasemi [23] used full measured structural response in frequency domain for model updating by minimizing a force residual.

There are certain advantages for using PSD for model updating [24]. Pedram et al. [25] proposed model updating using PSD of strain data (SPSD). Since the quality of predicted parameters and robustness of method depended to excitation location and measurement elements, spectral strain energy [26] (SSE) was used to solve this issue. PSD is a second-order function of transfer function, and it is also a highly sensitive and implicitly nonlinear function of structural parameters. Hence, it is expected to be more sensitive to the changes of structural parameters as compared with FRF [27,28]. The PSD matrix includes auto spectral density (ASD) and cross spectral density (CSD) components, which provide large amounts of data. For a highly sensitive structural response such as PSD, the derivation of the sensitivity equation is a paramount issue for successful model updating. Li et al. [29] used the forward finite difference method for calculation of the sensitivity equation of power spectral density transmissibility (PSDT). Despite the simplicity of the calculation, the quality of the sensitivity equation highly depends on the assumed increments for change in structural parameter. It is worth noting here that the idea of PSDT was originally proposed by Yan and Ren [30]. Zheng et al. [28] derived the sensitivity of PSD implicitly using the sensitivity of FRF. Yan and Ren [31] proved the merits of a closed-form sensitivity equation for model updating and damage detection. However, because of measurement incompleteness, the derivation of such a sensitivity relation is quite impractical. And using data expansion or model reduction for dealing with data incompleteness is not a totally efficient

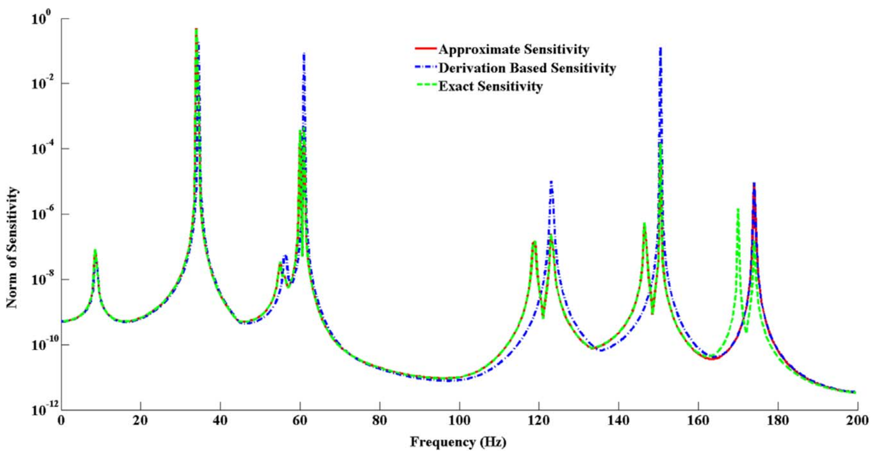

Fig. 2. Norm of sensitivity matrices for exact, approximated and derivation based formula.

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