Mechanical Systems and Signal Processing 33 (2012) 69–82

Contents lists available at SciVerse ScienceDirect

Mechanical Systems and Signal Processing

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

# A method for damping matrix identification using frequency response data

S. Pradhan, S.V. Modak *

*Department of Mechanical Engineering, Indian Institute of Technology, Delhi, Hauz Khas, New Delhi 110016, India*

ARTICLE INFO

*Article history:*
Received 22 March 2012
Received in revised form
3 July 2012
Accepted 4 July 2012
Available online 14 August 2012

*Keywords:*
Damping
Frequency response
Damping matrix updating
Damping identification
Normal FRFs
Finite element model updating

ABSTRACT

Accurate modeling of damping in structures is of great importance for vibration response analysis and control. This paper addresses the issue of identification of damping matrix of a structure by posing it as a finite element damping matrix updating problem. Many of the current updating approaches, dealing with updating of damping matrix, perform simultaneous updating of mass, stiffness and damping matrices. However, such a strategy is faced with numerical problems in practical implementation, since the magnitude of stiffness and mass matrix elements is generally much more than that of the damping matrix elements causing difficulties in accurate identification of the damping matrix. Some other approaches divide the process of updating of the mass and stiffness matrix and the damping matrix into two stages, but their application is restricted to structures with low levels of damping. This paper addresses these issues by developing an updating formulation that seeks to separate updating of the damping matrix from that of updating of the stiffness and the mass matrix. The proposed damping matrix updating method utilizes the concept of normal frequency response functions (FRFs) available in the literature. The method is formulated so as to reduce the difference between the complex FRFs, which can be measured in practice, and the normal FRFs, whose estimates can be obtained from the measured complex FRFs. The effectiveness of the proposed method is demonstrated through a numerical study on a simple but representative beam structure. The issue of coordinate incompleteness and robustness of the method under presence of noise is investigated. It is found that the proposed method is effective in the accurate identification of the damping matrix in cases of complete, incomplete and noisy data and is not limited by the level of damping in the structure.

© 2012 Elsevier Ltd. All rights reserved.

## 1. Introduction

The identification of damping in structural systems and machines is important for predicting vibration levels, transient responses, transmissibility, decay rate or other characteristics that are influenced by energy dissipation characteristics. There are two distinct issues related with damping identification: identification/knowledge of the correct damping mechanism/mechanisms and identification of the spatial distribution of the damping over the structure. Various damping models such as viscous (Rayleigh [1]), hysteretic (Bert [2]), viscoelastic (Christensen [3], Lakes [4]), friction (Berger [5]), micro-slip (Osinski [6]), air damping (Nashif et al. [7], Jones [8]) and non-viscous damping models based on fractional

* Corresponding author. Tel.: +91 11 26596336; fax: +91 11 26582053.
*E-mail addresses:* svmodak@mech.iitd.ac.in, svmodak@hotmail.com (S.V. Modak).

0888-3270/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ymssp.2012.07.002

**Nomenclature**

| | |
|---|---|
| $M_A$ | analytical mass matrix |
| $M_X$ | simulated experimental mass matrix |
| $K_A$ | analytical stiffness matrix |
| $K_X$ | simulated experimental stiffness matrix |
| $C$ | viscous damping matrix |
| $D$ | structural damping matrix |
| DSM | dynamic stiffness matrix |
| $Z_A$ | analytical DSM |
| $Z_X$ | simulated experimental DSM |
| DOFs | degrees of freedom |
| TDOF | translational degree of freedom |
| RDOF | rotational degree of freedom |
| FRFs | frequency response functions |
| $x(\omega)$ | displacement vector |
| $f(\omega)$ | force vector |
| $\alpha^N$ | normal FRF matrix |
| $\alpha^C$ | complex FRF matrix |
| $\alpha^C_R$ | real part of complex FRF matrix |
| $\alpha^C_I$ | imaginary part of complex FRF matrix |
| $Z^C$ | complex DSM |
| $Z^N$ | normal DSM |
| $\Delta Z^C$ | change in complex DSM |
| $\Delta Z^N$ | change in normal DSM |
| $\overline{Z}$ | part of DSM due to damping |
| $\Delta\overline{Z}$ | change in $\overline{Z}$ |
| $\beta$ | vector of physical parameters to be updated |

derivatives (Bagley and Torvik [9], Torvik and Bagley [10], Gaul et al. [11], Maia et al. [12]) have been proposed. Models that are based on the past history of motion via convolution integrals over some kernel functions offer a most general way to model damping for a linear analysis (Woodhouse [13]). Viscous and hysteretic damping models are often used in vibration and modal analysis due to the relative simplicity they offer in mathematical analysis. Once damping mechanism is chosen, the next step is to identify spatial distribution of damping over the structure.

Many of the approaches, that have been proposed, attempt to identify the damping matrix directly from either the measured FRFs or from the modal data extracted from them. If all the eignevalues and the eigenvetors of a structure are known then the damping matrix, as well as the mass and stiffness matrix can be computed using the explicit formulas given by Lancaster [14]. Fritzen [15] extended the instrument variable method for identification of mass, stiffness and damping matrices using vibration test data. This method is considered superior to least square method as it has been shown that it gives unbiased estimates in the presence of noise when equation error is used to formulate the error between the analytical and the experimental data. Mottershead and Foster [16] developed the formulation of instrument variable filter in the continuous frequency domain. Lee and Dobson [17] presented a method for estimating spatial matrices from the FRF data. The matrices obtained are of reduced size as compared to the FE model. A concept of so-called normal FRFs is presented by Chen et al. [18], in which they derive a relationship between the complex FRFs and the normal FRFs, which represent the FRFs in the absence of damping. Chen et al. [19] use these relationships to identify mass, stiffness and damping matrices directly from the complex FRF data. The main idea proposed is to separate the estimation of the damping matrix from that of estimation of mass and stiffness matrix. The effectiveness of this direct identification method is demonstrated on two lumped parameter examples. Adhikari and Woodhouse [20] presented a method to obtain a viscous damping matrix from complex mode shapes and complex natural frequencies. The method is based on a first order perturbation approach assuming that the damping is small. Barbieri et al. [21] proposed a method for identification of damping matrix directly from the experimental estimate of natural frequencies and the damping ratios. The size of the damping matrix obtained is related to the number of measured modes. A review of damping matrix identification from experimental data is presented by Pilkey and Inman [22] and Phani and Woodhouse [23]. Prandina et al. [24] present a study of comparison of three of the approaches to damping matrix identification and the method based on inversion of the measured matrix of receptances is found to be superior.

It is seen that the methods of identification of damping matrix, and mass and stiffness matrices, directly from the experimental data have been demonstrated on discrete and lumped parameter models and simple structures. The application of these methods to damping matrix identification of complex structures places a stringent requirement that experimental measurements should be available at all the degrees of freedom of the structure or the damping matrix. Quite often, in practice, the damping matrix needs to be used along with FE mass and stiffness matrices that typically have much higher order than the number of measurements. Since, it is not practically possible to perform measurements at all the degree of freedoms used in the FE model, the application of direct identification methods to practical problems is not straightforward if the identified damping matrix is intended to be used with FE mass and stiffness matrices.

In view of above, this paper addresses the issue of identification of damping matrix indirectly through FE model updating. Updating of structural dynamic finite element models has been an active area of research for the last three decades and several approaches have been proposed as shown in the surveys by Imregun and Visser [25], Mottershead and Friswell [26] and in the text by Friswell and Mottershead [27]. A large number of methods, a majority of which focus on updating of mass and stiffness matrix, have been proposed and the details of these can be seen from these references. The review of updating methods here would be restricted to only those methods that consider updating of the damping matrix.

Lin and Ewins [28] presented an iterative FRF based method to update mass, stiffness and damping matrices, in which the difference between the measured and analytical FRFs is linearized with respect to the parameters to be updated. Lin et al. [29] presented a mass, stiffness and damping matrix updating method based on sensitivity of eigendata. For lightly damped structures, Brown et al. [30] developed a two stage approach based on complex eigendata sensitivity in which the

Download English Version:

https://daneshyari.com/en/article/6956727

Download Persian Version:

https://daneshyari.com/article/6956727

Daneshyari.com