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Model updating of damped structures using FRF data

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Abstract

Due to the important contribution of damping on structural vibration, model updating of damped structures becomes significant and remains an issue in most model updating methods developed to date. In this paper, the frequency response function(FRF) method, which is one of the most frequently referenced model updating methods, has been further developed to identify damping matrices of structural systems, as well as mass and stiffness matrices. In order to overcome the problem of complexity of measured FRF and modal data, complex updating formulations using FRF data to identify damping coefficients have been established for the cases of proportional damping and general non-proportional damping. To demonstrate the effectiveness of the proposed complex FRF updating method, numerical simulations based on the GARTEUR structure with structural damping have been presented. The updated results have shown that the complex FRF updating method can be used to derive accurate updated mass and stiffness modelling errors and system damping matrices.

Keywords: Model updating; Damped structure; FRF; Damping; Complex; Sensitivity

1. Introduction

In engineering practice, accurate mathematical models representing the dynamic characteristics of various engineering structures have been required for structural design and analysis. However, current finite element analysis (FEA) cannot provide sufficiently accurate finite element (FE) models, which are in good agreement with the measured results. As a way to improve FE models, model updating procedure has been introduced and widely used to correct analytical FE models using experimental test data.

In the past 30 years a large number of model updating methods have been developed as discussed in the literature surveys carried out by Mottershead and Friswell [1,2]. In early 1980s, Lagrange multiplier methods were introduced by Baruch [3] and Berman [4]. These methods usually assumed that either the mass matrix or the stiffness matrix is correct. Then an objective function, with constraints imposed through Lagrange multipliers, is minimised in order to derive updated system matrices. The matrix mixing methods were developed by Caesar [5] and Link et al. [6]. This approach sought to combine experimental modal data with

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analytical ones to construct the inverses of the mass and stiffness matrices. Error matrix methods [7], on the other hand, estimated the error mass and stiffness matrices, based on the assumption that these errors are small in Euclidean sense as compared with the analytical mass and stiffness matrices themselves. These early methods are direct and computationally efficient. However, physical meanings of the updated system matrices are often not preserved and this raises the question on its validity.

Iterative updating methods, which include eigensensitivity methods and frequency response function (FRF) methods, have become dominant since 1990s due to the fact that these methods can preserve physical connectivity. In eigensensitivity based methods [8,9], parameters of FE model are updated iteratively using pseudo-inverse of the sensitivity matrix, which is calculated using analytical modal data. However, non-unique solutions emerge due to the under-determined or ill-conditioned nature of the sensitivity matrix. On the other hand, the FRF methods [10,11] used measured FRF data directly to optimise a penalty function, which is defined in terms of the different types of error functions. Lin and Ewins [12,13] presented an iterative FRF method in which the physical difference between the measured and analytical receptances was written as a linear function of the parameters to be updated. This method is able to produce highly accurate updated system matrices through iteration since the FRF sensitivity matrix involved is formulated directly without approximation when measured coordinate data are complete and accurately when measured coordinate data are incomplete.

In recent years, several novel methods have also been tried and applied to the practice of model updating. Neural networks [14] can quickly achieve accurate updated model once they have been trained. However, updated results are dependent on the training cases used. Genetic algorithm [15] is effective due to its capability of finding the global minimum for optimisation problems. However, the execution of Genetic algorithm is computationally intensive since the method uses stochastic search for optimal parameters. Taguchi method [16] was applied to model updating by optimising a carefully defined objective function. The merit of this method is that the updated results are robust against various noises since parameters are so updated that the signal to noise (SN) ratio is maximised.

2. Difficulties in model updating of damped structures

Usually, due to the complex mechanism of damping, parameterisation of damping model is more difficult than parameterisation of mass and stiffness models, the different method of which were summarised in [2]. One possible way is to identify damping model using experimental test data, which has attracted more research interests, especially for non-proportional damping model. Since usually natural frequencies and mode shapes of a general damped system are complex, damping matrix cannot be simultaneously diagonalisable with mass and stiffness matrices and the identification of physical damping matrix is also not available. Some researchers have studied how to decouple the equation of motion of a non-proportionally damped system and obtain non-proportional damping matrix. Rayleigh [17] considered approximate methods to determine complex eigensolutions using first-order perturbation theory by assuming the small elements of general damping matrix. The main idea is that complex modes of a system are close to modes of the corresponding undamped system and the mode shape can be expressed as a linear combination of undamped mode shapes. Then complex modes can be used to decouple the equation of motion approximately combined with real modes meanwhile the first-order approximate expression of complex natural frequencies and mode shapes can be obtained. Based on the former research results, Woodhouse [18] discussed two kinds of linear damping models: the familiar dissipation-matrix model and the general linear model and presented simple expressions for complex modal data and transfer functions. Following their idea, Adhikari and Woodhouse [19] presented a first-order perturbation method to obtain a full viscous (non-proportional) damping matrix from complex modal data in the case of the sufficiently light damping. This method constructs the physical damping matrix using the inverse transformation of the modal damping matrix from the decoupling of the damped system. They [20] further developed the first perturbation method for identification of a non-viscous (non-proportional) damping model involving an exponentially decaying relaxation function. The experimentally identified complex modal data together with the system mass matrix are also used to determine the modal damping matrix and the transformation.