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Normal response function method for mass and stiffness matrix updating using complex FRFs

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ABSTRACT

Quite often a structural dynamic finite element model is required to be updated so as to accurately predict the dynamic characteristics like natural frequencies and the mode shapes. Since in many situations undamped natural frequencies and mode shapes need to be predicted, it has generally been the practice in these situations to seek updating of only mass and stiffness matrix so as to obtain a reliable prediction model. Updating using frequency response functions (FRFs) has been one of the widely used approaches for updating, including updating of mass and stiffness matrices. However, the problem with FRF based methods, for updating mass and stiffness matrices, is that these methods are based on use of complex FRFs. Use of complex FRFs to update mass and stiffness matrices is not theoretically correct as complex FRFs are not only affected by these two matrices but also by the damping matrix. Therefore, in situations where updating of only mass and stiffness matrices using FRFs is required, the use of complex FRFs based updating formulation is not fully justified and would lead to inaccurate updated models. This paper addresses this difficulty and proposes an improved FRF based finite element model updating procedure using the concept of normal FRFs. The proposed method is a modified version of the existing response function method that is based on the complex FRFs.

The effectiveness of the proposed method is validated through a numerical study of a simple but representative beam structure. The effect of coordinate incompleteness and robustness of method under presence of noise is investigated. The results of updating obtained by the improved method are compared with the existing response function method. The performance of the two approaches is compared for cases of light, medium and heavily damped structures. It is found that the proposed improved method is effective in updating of mass and stiffness matrices in all the cases of complete and incomplete data and with all levels and types of damping.

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1. Introduction

Accurate mathematical models of engineering structures are needed in order to predict their dynamic characteristics accurately. Mathematical models can be derived analytically such as by the finite element method [1] or experimentally by modal testing [2]. A mathematical model derived analytically, at times, has been found to be inaccurate especially in the case of complex structures due to difficulties in the modeling of joints, boundary conditions and damping and lack of

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Nomenclature

M_A	analytical mass matrix
M_X	experimental mass matrix
K_A	analytical stiffness matrix
K_X	experimental stiffness matrix
C	viscous damping matrix
D	structural damping matrix
Z_A	analytical Dynamic stiffness matrix
Z_X	experimental dynamic stiffness matrix
S	sensitivity matrix
DOFs	degrees of freedom
TDOF	translational degree of freedom
RFM	response function method
u	fractional correction factors to the updating parameters
subscript 'X'	experimental
subscript 'A'	analytical
RDOF	rotational degree of freedom
FRFs	frequency response functions
α^N	normal frequency response functions
α^C	complex frequency response functions
α_R^C	real part of complex FRFs
α_I^C	imaginary part of complex FRFs
$x(\omega)$	displacement vector
$f(\omega)$	force vector
NRFM	normal response function method
p	vector of physical parameters to be updated
nu	number of updating parameters
Superscript 'N'	normal
Superscript 'c'	refers to damped system

knowledge of exact material properties. The experimental approach to extract a model is faced with the problems due to limited number of measured coordinates and limited frequency range. While on the one hand a finite element based analytical model has the advantage of being complete and precise, the experimental data on the other hand are generally considered more accurate given the availability of reliable data acquisition and measuring equipment. This has led to the development of technology of model updating that aims at reducing the inaccuracies present in an analytical model in the light of measured dynamic test data while allowing to simultaneously retaining a more detailed representation provided by a finite element model. Model updating thus can be viewed as an attempt to combine the best aspects of the two approaches. Model Updating has attracted great interest not only in scientific community but in many sectors of industry, mainly, because of its capability of improving the quality of prediction data derived from Finite element (FE) models. Updating of the FE model parameters is an essential step towards establishing a reliable FE model for an existing structure. A successfully updated FE model enables the analysis of the structural performance under a variety of user-defined loading conditions. The identification of the structural parameters from an FE model updating procedure also allows for an effective diagnosis and assessment of the structural health and condition.

Updating of the structural dynamic finite element models has been an active area of research for the last two decades and several approaches have been proposed as shown in the surveys by Imregun and Visser [3], Mottershead and Friswell [4] and in the text by Friswell and Mottershead [5]. Model updating essentially is an inverse problem as it attempts to identify certain unknown or uncertain model parameters from the knowledge of the test data [6]. Model updating methods can be broadly classified into direct methods, which are essentially non-iterative ones, and the iterative methods. A significant number of methods, which were among the first to emerge, belonged to the direct category. Of such methods the one proposed by Baruch and Bar-Itzhack [7] assumes that the mass matrix is correct while the measured eigenvectors are updated by minimizing the weighted Euclidean norm of the difference between the measured and the analytical eigenvectors subjected to the orthogonality constraints. The updated eigenvectors are then used to update the stiffness matrix. There have been other publications, like by Berman and Nagy [8] and Baruch [9], in which one of the three quantities, namely the measured modal data, the analytical mass matrix or the analytical stiffness matrix, is taken as a reference and the remaining quantities are updated. These methods though yielding updated matrices that reproduce measured modal data exactly, suffer from the drawbacks that the structural connectivity is generally not maintained and the suggested corrections are not physically meaningful. Kabe [10] proposed to include an additional constraint to ensure connectivity, while Lim [11] used sub-matrix scaling factors that automatically guarantee structural connectivity. The error matrix method proposed by Sidhu and Ewins [12] is an another direct technique that aims at estimating the error in mass and stiffness matrices. Iterative methods are based on minimizing an objective function that is generally a non-linear function of selected updating parameters. Iterative updating methods, which include eigensensitivity methods and frequency response function (FRF) based methods, have become dominant since 1990s due to the fact that these methods can preserve physical connectivity.

The use of eigendata sensitivity for analytical model updating in an iterative framework was first proposed by Collins et al. [13]. This method of Collins is quite popular due to the freedom it allows in the choice of the updating parameters and the applicability of the method even with incomplete data. Chen and Garba [14] used matrix perturbation technique for recomputation of eigen-solution and evaluation of eigendata sensitivities. The effect of including second order sensitivities was studied by Kim and Anderson [15]. Lin et al. [16] proposed to employ both the analytical and the experimental modal data for evaluating sensitivity coefficients with the objective of improving convergence and widening the applicability of the method to cases where there is a higher error magnitude. Modak et al. [17] proposed an updating method based on constrained optimization with constraints on the MAC values. The FRF methods [18–22] use measured

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