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Linear contact interface parameter identification using dynamic characteristic equation

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ABSTRACT

The stiffness characteristics of the contact interfaces in joints or boundary conditions have a great effect on dynamic response of assembled structures. Predictive analytical/numerical modeling of mechanical structures is not possible without representing the contact interfaces accurately. Because of the complex mechanisms involved, contact interfaces introduce difficulties both in modeling the inherent dynamics and identification of the model parameters. In this paper an identification approach employing the dynamic characteristic equation is proposed for linear interface parameters. The proposed method is applicable to both analytical and numerical problems. The accuracy of the proposed method is investigated by simulation results of a beam with elastic boundary support and experimental results of a bolted lap-joint.

1. Introduction

Joints are widely used in mechanical structure either to connect two components together or to restrict a component to the boundary. In either application, the contact interface of the joint introduces local stiffness to the containing structure which is of great importance in structural dynamics. Including the interface stiffness characteristics precisely in structural models requires adopting an appropriate joint model and employing an appropriate identification approach. Because of the complex mechanisms involved, both modeling and identification of the parameters of the contact interfaces of joints are challenging tasks and have attracted numerous considerations by researchers in the literature.

Zero thickness and thin layer interface elements have been widely used for representing normal and tangential stiffness of the contact interfaces [1–4]. Without considering a thickness for contact interface, in zero thickness elements, a constitutive relation with constant stiffness values for normal and tangential directions is considered [5]. In thin layer elements the contact interface is modeled with finite thickness elements similar in formulation to the brick element [6]. The lumped spring and the generic joint models being usually used to model contact interfaces can be respectively categorized as zero thickness and thin layer interface elements. The cross coupling effects between different DOFs at the joint interface can be considered easily by using the generic joint models. The concept of generic elements was first introduced by Gladwell and Ahmadian [7]. They proposed the use of eigenvalues and eigenvectors to formulate the FE model of an element. The concept has been used for modeling different joints in structures since then. Ratcliffe and Lieven [8], Wang et al. [9],

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Law et al. [10], Titurus et al. [11,12] and Ahmadian and Jalali [13] used generic joint element in modeling and identification of joints in structures.

In identification of the contact interface parameters the model-based techniques which usually employ the FE or analytical modeling results and experimental observations from a test structure have been widely used in literature. The model-based techniques are categorized into direct methods and penalty methods. In direct methods the joint parameters are identified by directly employing structural dynamic equations – either in the form of characteristic or mechanical impedance equations. Wang and Chen [14], Wang and Sus [15] and Ahmadian et al. [16] employed the modal parameters, i.e. natural frequencies, damping ratios and mode shapes, and identified the contact interface parameters of boundary conditions and joints by solving characteristic equation. Li [17] introduced a reduced order characteristic polynomial and identified the stiffness characteristics of an elastic boundary-support.

Direct using of the measured frequency response functions (FRFs) can be considered as an alternative to use modal parameters which are usually extracted from FRFs. The advantages of FRF based approaches over modal based approaches in joint parameter identification were discussed by Nobari [18]. Hong and Lee [19] proposed a hybrid method which employs the experimentally measured and numerically simulated FRFs and identifies the structural joint parameters. Hwang [20] identified the joint parameters by employing the FRFs of a structure with joint and the FRFs of a structure without joint. Tsai and Chou [21] implemented the substructure synthesis method and the measured FRFs and identified the joint parameters. Wang and Liou [22] and Yang et al. [23] improved the method proposed by Tsai and Chou [21] by avoiding the inversion of matrices and eliminating the need of FRFs at the joint locations. Tol and Ozguven [24] measured the FRFs of substructures and assembled structure and identified the joint parameters by FRF decoupling.

The other methods for joint parameter identification termed as penalty methods are based on the minimizing the discrepancies between experimentally measured and analytically/numerically obtained results. This error is related to the corrections to the joint parameters through a sensitivity matrix and a set of linear equations is formed. The joint parameters are then identified by considering some initial values and updating them in successive iterations. Yang and Park [25] dealt with the problem of joint parameter identification by using incomplete measured FRFs.

Aruda and Santos [26] employed a maximum a posterior (MAP) approach and identified the mechanical joint parameters by using measured FRFs. Mottershead et al. [27] considered model updating of mechanical joints by using eigen-sensitivity approach. By examining the effect of joint stiffness and joint geometric parameters, they concluded that the modal data are more sensitive to the geometric parameters.

In this paper a new approach for characterization of linear parameters of contact interfaces in joints or boundary conditions is proposed. The proposed method is based on two features: minimizing the residue of system characteristic equations and decomposing the system stiffness matrix. The reduced order characteristic equation has been used in the past by Ahmadian et al. [16] and Li [17] to identify the stiffness parameters of boundary conditions. In the current study the exact – and not the reduced order – characteristic equation is used and a new approach in solution of resultant equations is presented. This is achieved by factorizing the determinant in characteristic equation as will be described in next section. Also, the proposed method is applicable to identify both joints and boundary conditions parameters. The generic element concept introduced by Gladwell and Ahmadian [7] and used by Ahmadian and Jalali [13] is based on decomposing the element stiffness matrix using its eigenvalues and eigenvectors matrices. In this paper decomposition of the stiffness matrix is used in characteristic equation and a new identification approach is proposed.

The remaining of this paper is arranged as follows: the joint identification approach is described in the next section. Then, identification of boundary condition parameters of a constrained beam using simulation results and joint parameter identification of a bolted structure by employing experimental data are considered in two next sections. Finally, conclusions are drawn and references are presented.

2. Joint identification approach

The equation governing the natural frequencies of an un-damped system, i.e. the so-called characteristic equation, is obtained by calculating the following determinant,

$$|\mathbf{D}(\omega)| = 0 \tag{1}$$

By solving the characteristic equation the natural frequencies of the system are obtained. It is worth mentioning that although $\mathbf{D}(\omega)$ leads to the characteristic equation as is described in Eq. (1), this matrix has different physical meaning for discrete and continuous systems. For discrete systems, $\mathbf{D}(\omega)$ is the dynamic stiffness matrix, i.e. $\mathbf{D}(\omega) = \mathbf{K} - \omega^2\mathbf{M}$, which relates the force and displacement variables of the system. $\mathbf{M}$ and $\mathbf{K}$ are the system mass and stiffness matrices respectively. For continuous systems, $\mathbf{D}(\omega)$ is a matrix containing the boundary condition relations and compatibility equations.

For structures containing joints, $\mathbf{D}(\omega)$ can be divided into two sub-matrices as,

$$\mathbf{D}(\omega) = \left(\mathbf{K} + \mathbf{K}_j\right) - \omega^2\mathbf{M} = \overline{\mathbf{D}}(\omega) + \mathbf{K}_J \tag{2}$$

where $\overline{\mathbf{D}}(\omega)$ is the dynamic stiffness matrix of the structure without the joints and $\mathbf{K}_J$ is the stiffness matrix corresponding to the joints. The joint stiffness matrix $\mathbf{K}_J$ usually contains unknown parameters and needs to be identified when modeling physical structures. The aim of this paper is to introduce an identification scheme for the unknown parameters of $\mathbf{K}_J$.