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Response prediction for modified mechanical systems based on in-situ frequency response functions: Theoretical and numerical studies

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ABSTRACT

In this paper, a general method using in-situ frequency response functions (FRFs) is proposed for predicting operational responses of modified mechanical systems. In the method responses of modified mechanical systems can be calculated by using the delta dynamic stiffness matrix, the subsystem FRF matrix and responses of the original system, even though operational forces are unknown. The proposed method is derived theoretically in a general form as well as for six specific scenarios. The six scenarios correspond respectively to: (a) modifications made on the mass; (b) changes made on the stiffness values of the link between a degree-of-freedom (DOF) and the ground; (c) the fully rigid link between a DOF and the ground; (d) changes made on the stiffness values of the link between two DOFs; (e) the null link between two DOFs and (f) the fully rigid link between two DOFs. It is found that for scenarios (a), (b) and (d) the delta dynamic stiffness matrix is required when predicting responses of the modified mechanical system. But for scenarios (c), (e) and (f), no delta dynamic stiffness matrix is required and the new system responses can be calculated solely using the subsystem FRF matrix and responses of the original system. The proposed method is illustrated by a numerical example and validated using data generated by finite element simulations. The work in this paper will be beneficial to solving vibration and noise engineering problems.

1. Introduction

Noise and vibration problems are often encountered in buildings, cars, or airplanes, which is the result of the transmission of vibration generated by excitation sources [1]. The vibrations generated by the sources propagate throughout the mechanical system or building structure, and are radiated into living spaces. The noise and vibration characteristic is one of the key factors to make product design successful. In recent years, a large number of methods have been developed in literature to address these problems [2–6]. Among these methods, TPA has been a valuable engineering tool for analyzing vibration and noise in complex structural systems. A recent review of TPA methods can be found in [7].

In TPA method, the target response at the receiver point is expressed as a sum of contributions due to individual path or source, and each path contribution is considered as the result of the individual load acting on the localized interface.

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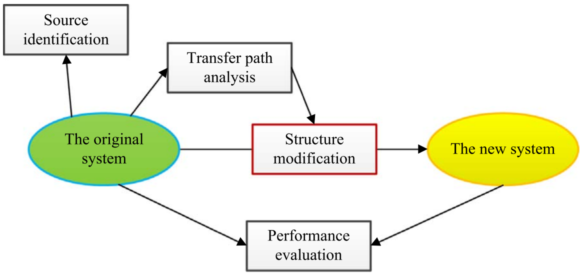

Fig. 1. Noise and vibration analysis processes for a mechanical system.

According to the TPA result, dominant causes can be identified and then solutions are put forward. Finally structural modifications can be made in order to reach the desired goals. Structural modification actions that follow from such an analysis are generally not considered part of the TPA work flow [7]. For existing or already finished products, a common means is the use of TPA results combined with the empirical knowledge for modifying the structure to diminish the vibration or noise level. Usually it does not involve iterative structure optimization, and therefore the structural modifications may be suboptimal. To verify the effectiveness of the structural modification scheme, the performance evaluation is simply conducted on the modified mechanical system. Related analysis processes are shown in Fig. 1.

This paper focuses on the structural modification stage of the above analysis procedure. So far, there are some approaches already reported in literature to address structural modification issues, such as structural modification or reanalysis methods [8–11]. Most research on these methods has been focused on obtaining dynamic characteristics of the modified system based on the determination of the behavior of the original structure and a delta dynamic stiffness matrix [12]. In [13] the problem of assigning natural frequencies to a multi-degree-of-freedom undamped system by an added mass connected by one or more springs was addressed. In references [14,15] the use of transmissibility properties to estimate FRFs on modified structures has been investigated. Among these studies, no study has been devoted to the response prediction of the modified structure for a particular operational condition, since the prediction of operational response may inevitably involve in the determination of operational forces. In [16] relative path measures in a discrete system has been experimentally investigated for several path disconnect schemes. In [17], the response prediction for two path blocking systems (blocking a mass and blocking a link between two masses) using the Global Transmissibility Direct Transmissibility method was discussed. However, in order to obtain the new system direct matrix, the new global transmissibility has to be measured in the new system, which is difficult even impossible to be applied in practice.

In this paper, a general response prediction (GRP) method for a modified mechanical system is developed. It allows for predicting operational responses of the modified mechanical system based on in-situ frequency response functions (FRFs) and operational responses of the original system. Schematic diagram of the GRP method is shown in Fig. 2. The proposed method uses the subsystem FRFs and responses of the original system together with the delta dynamic stiffness matrix to calculate the subsystem responses of the new system. It doesn't require knowing the situation of operational forces. This method is particularly suitable for the structural modification or optimization stage shown in Fig. 1. The GRP method can be used for response prediction and structure optimization design for finite element model, reducing the complexity of the model and shortening the analysis time, when the simulations are time-expensive. For real-life mechanical systems, it can be used for a quick and inexpensive investigation of the approximate effects of several possible modifications on the system for a specific operational condition.

The goals and achievements of this research are as follows:

- To explore relationships between subsystem FRFs of the new and original mechanical systems.
- To derive a general methodology that allows for predicting subsystem responses of the modified system based on

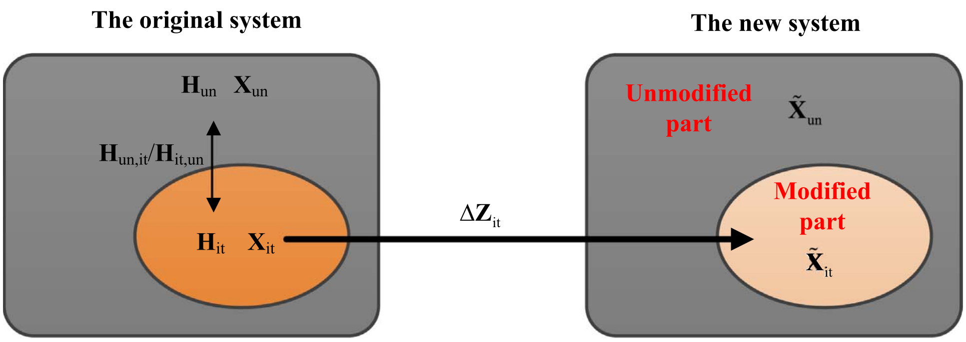

Fig. 2. Schematic diagram of the GRP method.