Vibration Response Prediction on Rubber Mounts with a Hybrid Approach

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Accurate prediction of the vibration response at a point on a complex structure, where the operational behavior cannot be measured directly, is an important engineering problem for design optimization, component selection and condition monitoring. Identifying the exciting forces acting on the structure is a major step in the vibration response prediction (VRP). At the point where direct measurement is impossible or impractical due to physical constraints, a common approach is to identify the exciting forces based on multiplication of an inverted frequency response function (FRF) matrix and a vector of vibration responses measured at the points where the exciting forces are transmitted through. However, in some cases measuring FRFs are almost impossible. In other cases, where measuring is possible, they may be prone to significant errors. Furthermore, the inverted FRF matrix may be ill-conditioned due to the one or few modes that dominate the dynamics of the structure.

In order to improve the force identification step and reduce the experimental challenges, previous studies focused on either conditioning methods or numerical models. However, conditioning methods result in additional measurements, and using only numerical models causes reduced accuracy due to incongruities between the simulation model and the real system. Considering these problems, a hybrid VRP methodology that incorporates the numerical modeling and experimental measurement results is proposed in this study. Creating an accurate numerical model and properly selecting the force identification points are the main requirements of the proposed methodology. A structure coupled with rubber mounts is used to demonstrate the proposed methodology. The numerical model includes hyperelastic and viscoelastic modeling of the rubber to represent the system behavior accurately. The selection of force identification points is based on a metric that is composed of the average condition number of the FRF matrix across the whole frequency of interest. The results show that the proposed hybrid methodology is superior to other alternative methods where predictions are solely based on numerical results or experimental measurements.

1. INTRODUCTION

Mechanical systems are usually composed of various subsystems coupled by several links, such as rubber mounts. Any excitation acting on the system is divided into several internal forces, which propagate throughout the mounts. The structural vibration response at a point of interest, as a result of the exciting forces, is usually of great importance in terms of design optimization, component selection and condition monitoring. For the locations in complex structures where the operational behavior cannot be measured directly, a methodology is required for accurate prediction of the response. A major step of the vibration response prediction (VRP) is to identify the exciting forces acting on the structure. The most evident solution is to measure the forces directly. However, this may not be possible due to the complexity of the structure and the challenges of load cell applications. Consequently, indirect methods have been widely studied in the literature.\textsuperscript{1–20} The following studies are worthwhile to mention here. Verheij\textsuperscript{1} introduced the dynamic stiffness method which seems the most straightforward approach, especially for rubber linked structures. However, accurate complex dynamic stiffness data of the rubber mounts is rarely available, and even if present, it is only valid for a given load condition. Another approach, called the transmissibility method, can be implemented to predict the vibration response at a point of interest.\textsuperscript{2,5} In this method, the forces are replaced by the measured responses at the force identification points, and the propagation paths are represented by the transmissibility. This approach is much simpler and faster, but unconsidered potential cross-coupling between the paths can lead to incorrect predictions.

In the early 1980s, the matrix inversion method was developed.\textsuperscript{6,7} The inverse method basically involves multiplication of a vector of vibration responses with an inverted matrix constituted by the frequency response functions (FRFs). The main drawback of this method is the need of the FRF measurements. However, measuring the FRFs is sometimes not possible, especially for complex structures. Even when it is possible, it is very time consuming and prone to significant errors based on excitation, environment, sensor, structure, and unconsidered sources. The possible sources of the above measurement errors are shown in Fig. (1).\textsuperscript{21–27}

Modal behavior of the structure also influences the accuracy of the matrix inversion method. The FRF matrix includes information about the vibration modes contributing to the response, and the amplitude of the modal contribution depends on the location of the FRF measurements. Accordingly, the condition number of the FRF matrix, which is simply the ratio of the largest singular value to the smallest, varies significantly across the structure at particular frequencies. In the condition that one or few modes dominate the responses of specific points that constitute the FRF matrix, the rows or columns of the FRF matrix may become linearly dependent resulting in high condition numbers. High condition number refers to smaller singular values. In this case, the solution may not be unique, and the FRF matrix can be defined as "almost singular" or "ill-conditioned".\textsuperscript{13,14} By selecting the points where the forces are identified properly, the condition number can be reduced and ill-conditioning can be improved. Therefore, con-