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Prediction Method of Vibration and Noise Regarding Mechanical Systems by Means of Experimental Modeling

N.Ishizuka[1], T.Okada[2], T.Ikeno[2], K.Shiomi[2], M.Okuma[3]

Summary

The accurate modeling of structures is very important for any engineering analysis such as simulation and design optimization of mechanical systems for noise and vibration. It is desired that such a modeling process should not be time-consuming and that the created model must have structural dynamic properties corresponding with the actual ones. But in practice, it is often difficult or even impossible to satisfy the desire by using conventional theoretical methods such as the Finite Element Method (FEM) when we consider actual mechanical systems which consist of many substructures. In this paper, under the assumption that vibration tests can be carried out for actual substructures, we introduce an experimental method for composing the spatial matrix of a whole mechanical system based on the superposition of the substructures' spatial matrices, and for computing prediction analysis about vibration and noise of the whole mechanical system. The substructures' spatial matrices are acquired using an experimental spatial matrix identification method [1][2]. It can make it easy and reliable to make computational models of actual and complex substructures as a database, and can make prediction analysis be carried out smart for the whole systems composed of various combination choices of substructures. The method also works efficiently for structural modification analysis in the case that some of substructures of the whole system are to be modified in the design process. We show a case study using a boat that consists of mainly three substructures, namely a boat hull, an outboard engine and its suspension.

Introduction

The accurate and reliable modeling of structures is most essential for any engineering analysis such as the vibration and acoustic simulation for mechanical design optimization. FEM will be the most popular theoretical method in virtue of today's computer power in aspects of computing speed, gigabit size memory and user friendly software. However, in practice, we often have the difficult or even impossible cases unavailable to accept FEM approach for the analysis of actual and complex mechanical systems because of such structure's complexity, non-linearity and/or some degrees of uncertainty of material properties. Therefore, experiment-

[1]Master Course, Department of Mechanical and Aerospace Engineering, Tokyo Inst. of Tech., Japan

[2]Power Products R&D Center, HONDA R&D Co., Ltd., Japan

[3]Department of Mechanical and Aerospace Engineering,Tokyo Inst. of Tech., 2-12-1-I3-15, O-okayama, Meguro-ku, Tokyo, 152-8552, Japan, E-mail:mokuma@mech.titech.ac.jp

based methods should complement to such theoretical methods as an alternative approach. It can enhance the potential ability of prediction analysis.

In this paper, we show an experiment-based method of vibration and noise prediction analysis by modeling of substructures' dynamics with practical accuracy and rapidity using a experimental spatial matrix identification method. We show a case study using a boat that consists of mainly three substructures, namely a boat hull, an outboard engine and its suspension. It is desired to estimate the vibration and noise quality of "boat system" without test boarding because the system have many different combination choices of main substructural mechanical components such as boat hulls, outboard engines and engine suspensions according to the taste of end-users. Different combinations perform different vibration and noise behaviour. Such a computational prediction method will be very useful that can estimate and demonstrate the vibration and noise quality of any combination of substructural components using speaker and/or vibrator driven by computer as customers wish to change any of the substructures in a business discussion. Experiment-based modeling of substructures is adequate to understand vibration and noise characteristics of such diversified structural systems. Because such substructures are available for vibration testing to get their structural dynamics modeling in advance. The results can be kept and used as database for prediction computation. If we accomplish this method we will be able to make it realize to execute acoustic and vibration simulation of various combinations of substructures in front of customers in a short time. That will help customers find their best choice of a substructure combination. Moreover, the method is useful on technical and business development stages among developers of all substurural components.

The Objective Assembly Structural System

The objective assembly structural system picked up in this study is a boat consisted of an aluminum-made hull, a four-stroke single-cylinder outboard engine whose maximum output power is 5HP and its suspension as shown in figure 1(a). Figure 1(b) shows that the engine is mounted using five rubber mounts to suspension. The suspension is directly connected on the center top part of the transom of the boat hull.

Outline of the Method

The first step of the procedure is to carry out vibration testing for each substructure under the free-free boundary condition. In this case study, we executed hammering test for all substructures, which are softly suspended or mounted to realize a pseudo free-free boundary condition. Vibration of the hull is measured using uni-axial accelerometers with respect to only out-of-plane vibration at 63 measurement points on the transom part of the hull. Vibration of both the outboard engine and the suspension are measured using triaxial accelerometers at 24 mea-

(a) The whole system

(b) The connecting points

Figure 1: The objective structure

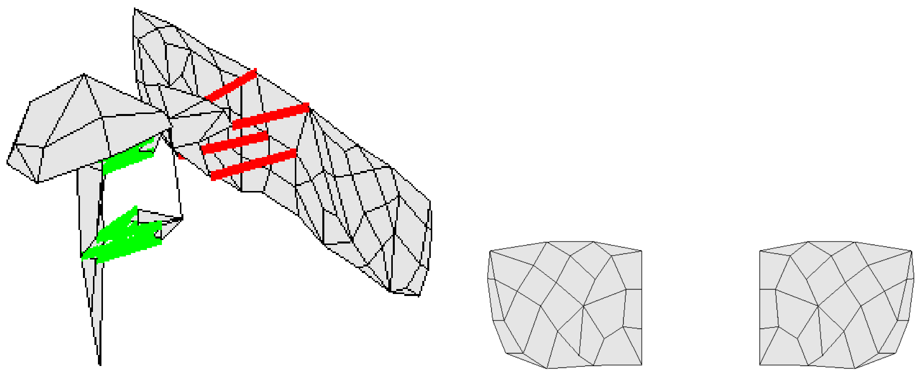
surement points for each. Then, frequency response functions are obtained for all the substructures.

The second step is to carry out the experimental spatial matrix identification method for each substructure to obtain its computation model about the dynamic characteristics in the form of the set of spatial matrices, namely the set of mass matrix, viscous damping matrix and stiffness matrix. Then, the database about all substructures becomes ready to use for the prediction analysis of the whole assembled system. Note that the essential input-data are frequency response functions and the coordinates of the measurement points for the experimental spatial matrix identification method. Refer to [1] and [2] for details about the algorithm used in the method.

Once the database is ready to be used, the prediction analysis of the whole assembly system can be carried out very fast and very simply. Because the spatial matrices of the whole assembly system can be made just by superposing the spatial matrices of the substructures, and its degrees of freedom is generally small enough for today's personal computer to deal without any problem. For elastic connection parts between two or more substructures can be represented in the computational model by superposing appropriate pseudo spring constants onto the stiffness matrix of the whole assembly system. For example, elastic connection between a freedom each in two substructures' stiffness matrices $\mathbf{K}_1$ and $\mathbf{K}_2$ can be simply represented by

$$\mathbf{K} = \begin{bmatrix} \mathbf{K}_1 & \mathbf{O} \\ \mathbf{O} & \mathbf{K}_2 \end{bmatrix} + \begin{bmatrix} 0 & \cdots & 0 & \cdots & 0 \\ \vdots & k & \vdots & -k & \vdots \\ \vdots & -k & \vdots & k & \vdots \\ 0 & \cdots & 0 & \cdots & 0 \end{bmatrix}. \tag{1}$$

Figure 2(a) is the schematic to show the computational model of the whole assembly system, which consists of a boat hull, a suspension, five rubber mounts and an outboard engine. The each rubber mount is modeled using three translational springs in parallel. The connection between the hull and the suspension is also modeled using pseudo springs that equivalently represent the local elastic characteristics of the connecting points.



(a) the whole model (b) the attached panel model

Figure 2: The Schematics of computational model

Case Study

In order to demonstrate the validity and practicability of the presented prediction method, we carry out two case studies about the objective assembly structural system.

The first case study is a very simple one but it is a good one to demonstrate the validity of the method. The vibration characteristics of the transom part of the boat hull is modeled in the form of the spatial matrices having 63 degrees of freedom based on 63 measurement points. The locations of the measurement points are schematized as if FEM mesh modeling about the transom part in figure 2(a). For this case study, the attachment panel as shown in figure 2(b) is prepared, and its vibration characteristic is also modeled in the form of spatial matrices using hammering test and the identification method [1]. Then, by just superposing the two sets of spatial matrices, prediction analysis of vibration characteristics of the boat hull attached the panel is carried out. The computational result is compared with experimental one.

The second case study is a prediction analysis of the whole assembly system shown in figure 2(a). Firstly, a hammering test is carried out. Secondly, a firing test is executed and measured vibration responses and noises due to actual firing under a steady-state operation, i.e., a constant engine speed. The position nor the magnitude of the real exciting force due to firing is unknown in the strict sense. It will be impossible to identify the real exciting force that must be distributed type of force. Then, the equivalent exciting force is identified for the prediction analysis. Under the assumption that the vibration behaviour of the firing engine can be approximated as a linear-time invariant system, the exciting force **f** generated in engines under steady-state operation can be expressed as

$$\mathbf{f}(\omega) = \mathbf{H}(\omega)^{+}\xi(\omega) \tag{2}$$

in the frequency domain [3] where $\xi(\omega)$ is the vector that consists of vibration response at measurement points of the engine , $\mathbf{H}(\omega)$ is the matrix that consists of FRFs obtained by hammering test in advance, and the superscription $^{+}$ means the generalized inversion.

The estimated equivalent force can be used for the prediction analysis. The presented method computes the vibration response of the whole assembly system due to the equivalent force. Once the vibration response is obtained , acoustic level at a point of interest and acoustic power radiated from any part of the whole assembly system can be easily computed using the BEM, such as acoustic level of noise radiated from only the transom part and from only the surface of the engine excluding the extension part to its screw. In acoustic experiment, it is impossible to distinguish the acoustic directly radiated from the outboard engine and from the surface vibration of the boat hull, etc. So, comparing the computational prediction results about such some different case predictions with experimental result, we can investigate the dominant noise source of each noticeable noise spectrums. The result of the investigation is presented.

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