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Vibration source description in substructuring: A theoretical depiction

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A B S T R A C T

Analyzing the propagation of vibrational excitations from a source substructure to receiving components is an important issue in many high-tech engineering applications. Two equivalent and mutually dual methods to characterize a vibration source consist in determining either the force on its blocked interface or the vibration of its interface left free. Those source properties, together with information on the impedance (or admittance) of the system, allow predicting the coupled dynamic response of an assembly even though the detailed excitation origin in the source is not known. Despite the fact that the methods were already described more than fifty years ago, applying them in practical engineering problems remains challenging. The purpose of the present paper is to outline the blocked force and free velocity methods in a unified way, starting from the general notions of primal and dual assembly of impedances and admittances. An application example is shortly discussed.

1. Introduction

In many engineering applications it is required to analyze how the vibrations are transmitted between components. Such investigations are performed for instance in automotive engineering to evaluate the different noise and vibration paths leading to the overall nuisance in the interior of a car (see for instance [1,2]). In such problems Transfer Path Analysis (TPA) is often used in order to understand the contribution of different components to the global noise and vibration levels. In TPA approaches one tries to estimate the interface forces and the dynamics they create in neighboring components, enabling the engineer to decide which component to modify or which vibration source to reduce in order to reach the desired design goals. The basic theory of TPA based on correlation analysis can for instance be found in [3].

TPA is a very valuable troubleshooting tool allowing to spot the origin of problems, but has usually one major drawback: the vibration paths obtained in a TPA are valid only for the measured assembly. If a component or an interface is modified,

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Nomenclature

dofs	degrees of freedom
$\mathbf{u}$	dynamic response in frequency domain (displacements, velocities or accelerations)
i, c	partition pertaining to internal and connecting dofs
$\mathbf{Y}$	admittance matrix (receptance, mobility or accelerance)
$\mathbf{Z}$	impedance matrix
$\mathbf{f}$	applied forces
$\mathbf{g}_c$	interface forces
$\boldsymbol{\delta}_c$	interface gap
$\boldsymbol{\delta}_{c,free}$	equivalent interface gap obtained from free interface
$\mathbf{f}_{c,blocked}$	equivalent interface force obtained from blocked interface
$\star^A$, $\star^B$	pertaining to a structure named A, B
$\star_{ij}$	pertaining to a matrix partition ij

classical TPA approaches cannot predict the dynamical behavior of the new assembly since in that case the interface forces and vibration transmission are changing according to the overall interaction between components. To predict the dynamics of the system in a modified situation one needs to properly characterize the excitation sources and to be able to construct the dynamic response of the new assembly. That is where substructuring approaches come in. In substructuring analysis, the system is modeled by the intrinsic dynamics of its components. For instance in the methods described as Frequency Based Substructuring (or FBS, see for instance [4] for an overview) the admittances or impedances of subcomponents, obtained through measured or numerical modeling, are assembled in order to build the overall dynamic model of an assembly. Those methods will not be discussed in detail in this paper. The purpose of this paper is primarily to clarify the concepts needed to characterize the excitation sources.

In practice two types of source subsystems can be considered:

1. *Subsystems of which the interfaces need to be fixed*: Consider the excitation generated by bearings and gears within a gearbox in a car. When engineering a car for comfort, it is of great importance to understand how these vibrations are transmitted to the rest of the car. Due to the rotation of its components, the attachments of the gear box need to be fixed to operate the drive-train. So, in this case, the vibration source must be characterized as forces felt on the interface when the attachment points are (in the ideal case) rigidly fixed (see Fig. 1(a)).
2. *Subsystems for which the vibration level is characterized from the free interface*: Consider now the vibration of a factory floor on which a high-precision machine needs to be installed. Predicting the vibration levels transmitted to the machine is essential in order to guarantee its proper functioning. In this case, it is not practical to measure the interface forces of the floor when it is rigidly constrained, but it is much easier to measure the level of accelerations of its interface when it is left completely free (see Fig. 1(b)).

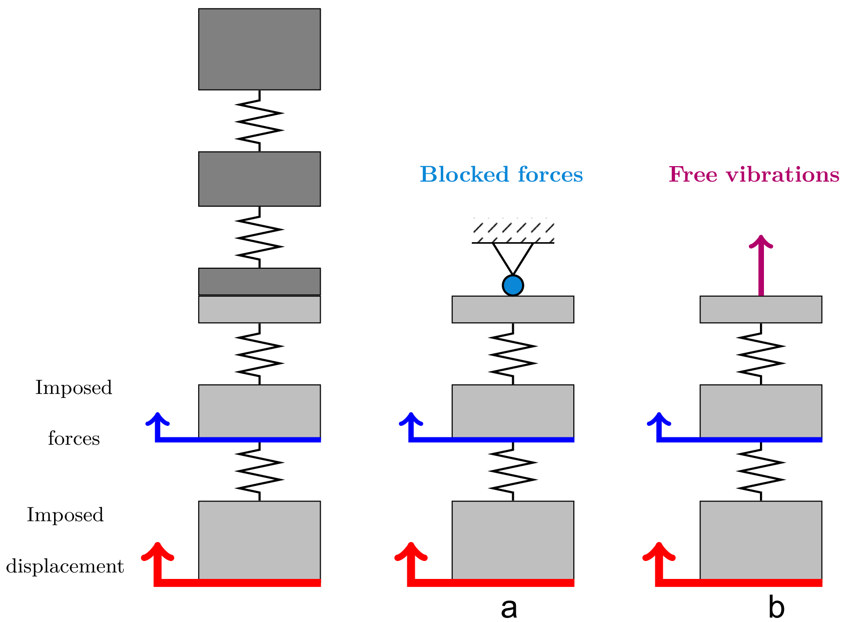

Fig. 1. Coupled dynamics of an assembly of two substructures. The excitation of the lower substructure can be characterized either (a) by the force necessary to fix its interface (blocked force) or (b) by the vibration of its interface when left free.