Mechanical Systems and Signal Processing 95 (2017) 380–396

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Replacement of unobservable coupling DoFs in substructure decoupling

Walter D'Ambrogio [a], Annalisa Fregolent [b,*]

[a] *Dipartimento di Ingegneria Industriale e dell'Informazione e di Economia, Università dell'Aquila, Via G. Gronchi, 18, I-67100 L'Aquila, AQ, Italy*
[b] *Dipartimento di Ingegneria Meccanica e Aerospaziale, Università di Roma La Sapienza, Via Eudossiana, 18, I-00184 Roma, Italy*

ARTICLE INFO

Article history:
Received 25 November 2016
Received in revised form 21 March 2017
Accepted 24 March 2017
Available online 6 April 2017

Keywords:
Optimal DoF selection
Substructure decoupling
Rotational DoFs
Mixed interface
Experimental dynamic substructuring

ABSTRACT

In this paper, suitable criteria are sought for an optimal replacement of unobservable coupling DoFs when performing substructure decoupling, that is the identification of a dynamic model of a substructure embedded in a known structure. The need arises since coupling DoFs are often difficult to observe, either because they cannot be easily accessed or because they include rotational DoFs. The substitution must be carried out both to preserve the information that would be lost when some coupling DoFs are not taken into account, and to avoid or minimize ill-conditioning problems.

As shown in previous papers, coupling DoFs can be effectively replaced by internal DoFs for the sake of substructure decoupling. Furthermore, criteria for an appropriate selection of the internal DoFs used to replace unobservable coupling DoFs are sketched, which involve either the Frequency Response Function (FRF) or the transmissibility between internal and coupling DoFs.

Here, previously introduced FRF and transmissibility criteria are combined with the condition number of the interface flexibility matrix to develop a procedure to optimally replace some coupling DoFs with a subset of internal DoFs. The procedure is tested using both simulated and experimental data of a tree structure (known structure), made by a cantilever beam with two offset short arms, coupled to another beam (structure to be identified).

1. Introduction

The objective of this paper is to define and test suitable criteria for an optimal replacement of unobservable coupling DoFs when performing substructure decoupling [1,2]. Substructure decoupling can be defined as the identification of the dynamic model of a substructure embedded in a structure known from experiments (assembled structure) and connected to the remaining part of the structure (residual substructure) through a set of coupling DoFs. The degrees of freedom of the assembled structure not belonging to the couplings are defined as internal DoFs.

The need of replacing some coupling DoFs arises since they are often difficult to observe, either because they cannot be easily accessed or because they include rotational DoFs. The substitution must be carried out both to preserve the information that would be lost when some coupling DoFs are not taken into account, and to avoid or minimize ill-conditioning problems [2]. Also in the transmission simulator method [3], a well conditioned mode shape matrix ensures the effectiveness of

* Corresponding author.
E-mail addresses: walter.dambrogio@univaq.it (W. D'Ambrogio), annalisa.fregolent@uniroma1.it (A. Fregolent).

http://dx.doi.org/10.1016/j.ymssp.2017.03.038

such fixture. Coupling DoFs can be efficiently replaced by internal DoFs when dealing with substructure decoupling, as shown in [4,5].

Substructure decoupling is a need for subsystems that cannot be measured separately, but only when coupled to their neighboring substructure(s), such as fixtures needed for testing [6,7]. Decoupling represents a special case of experimental dynamic substructuring, since the model of the assembled system derives from experimental tests. In Frequency Based Substructuring, Frequency Response Functions (FRFs) are preferred to modal parameters to avoid modal truncation problems. A general framework for dynamic substructuring is provided in [8]. Some experimental issues arising in frequency based substructuring are reported in [9].

Another well known issue in experimental dynamic substructuring is related to rotational DoFs: rotational FRFs are quite difficult to be obtained experimentally, both from translational FRFs [10] and by measuring directly the rotational responses [11,12]. To obtain rotational FRFs around two axes from translational FRFs, the equivalent multi-point connection (EMPC) was proposed in [13,14]. Subsequently, it was extended to triaxial environment in [15,16]. However, whilst rotational FRFs are needed when coupling together different subsystems, they are not essential in substructure decoupling (see again [4,5]). In fact, the actions exchanged through the connecting DoFs, and specifically through rotational DoFs, are already embedded in each FRF of the assembled system.

To achieve decoupling, a negative structure with a dynamic stiffness opposite to that of the residual substructure is added to the coupled system, and appropriate compatibility and equilibrium conditions are enforced at interface DoFs. Interface DoFs may include coupling DoFs only (standard interface), additional internal DoFs of the residual subsystem (extended interface), subsets of coupling DoFs and internal DoFs of the residual subsystem (mixed interface), or a subset of internal DoFs of the residual subsystem only (pseudo interface). The use of a mixed or pseudo interface amounts to replace some coupling DoFs (e.g. rotational DoFs) with a subset of internal DoFs.

In previous papers [17,18], criteria for an appropriate selection of the internal DoFs used to replace unobservable coupling DoFs are sketched, which involve either the Frequency Response Function (FRF) or the transmissibility between internal and coupling DoFs. These criteria allow to rank the effectiveness of using any internal DoF instead of a given coupling DoF.

Here, previously introduced FRF and transmissibility criteria are combined with the condition number of the interface flexibility matrix to develop a procedure to optimally replace some coupling DoFs with a subset of internal DoFs. The procedure is tested using both simulated and experimental data of a tree structure (known structure), made by a cantilever beam with two offset short arms, coupled to another beam (structure to be identified). In Section 2, the substructure decoupling problem is recalled by highlighting the role of the so called disconnection forces. In Section 3, criteria for an optimal replacement of unobservable coupling DoFs with internal DoFs are presented and discussed. In Section 4, the devised criteria are applied to show that they lead to optimal decoupling results.

2. Direct decoupling: disconnection force intensities

Substructure decoupling consists in the identification of a dynamic model of a structural subsystem, starting from an experimental dynamic model (e.g. FRFs) of the assembled system RU and from a dynamic model of a known portion of it (the so-called residual subsystem R). The unknown substructure U (N_U DoFs) is joined to the residual substructure R (N_R DoFs) by n_c coupling DoFs through which constraint forces (and moments) are exchanged (see Fig. 1). The degrees of freedom of the assembled structure (N_{RU} DoFs) can be partitioned into coupling DoFs (c), internal DoFs of substructure U (u) and internal DoFs of substructure R (r).

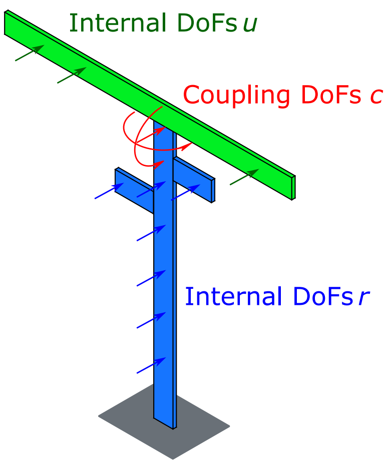

Fig. 1. Assembled system RU, with the unknown subsystem U (green) and the residual subsystem R (blue). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)