Mechanical Systems and Signal Processing 117 (2019) 723–737

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

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

In-situ sub-structure decoupling of resiliently coupled assemblies

J.W.R. Meggitt *, A.T. Moorhouse

Acoustics Research Centre, University of Salford, Greater Manchester M5 4WT, United Kingdom

A R T I C L E   I N F O

Article history:
Received 30 August 2017
Received in revised form 16 July 2018
Accepted 21 July 2018
Available online 23 August 2018

Keywords:
In-situ
Measurement
Experimental
Free-interface
Decoupling
FRF
Sub-structure
Structural
Characterisation

A B S T R A C T

The context of this paper is the increasing need for vibro-acoustic simulation across many sectors. A procedure is derived for decoupling the components of resiliently mounted assemblies. An independent characterisation of the components is obtained such that they can be mathematically recombined with other elements to form virtual assemblies or Virtual Acoustic Prototypes. Unlike standard decoupling procedures, the proposed approach does not require the assembly to be physically decoupled at any stage. It is argued that this offers significant advantages in terms of convenience and, importantly, representativeness. The boundary conditions within a physically coupled assembly are realistic by definition, which may not be the case for physically decoupled components. The procedure is validated numerically using a lumped parameter model and demonstrated experimentally through several case studies.

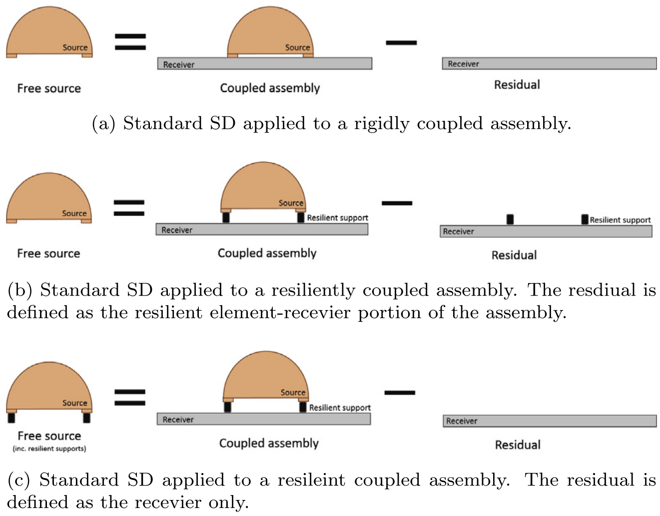
1. Introduction

A drive towards leaner engineering has seen the use of physical prototypes become a limiting factor in both the development of new products, and the continual development of existing products. As such, alternative prototyping methods are of interest. For the assessment of vibro-acoustic performance the aptly named 'virtual acoustic prototype' (VAP) offers a convenient alternative [1]. A robust and experimentally focused VAP is built on the foundation of dynamic sub-structuring (DS) [2], where structural components are coupled together mathematically through the application of continuity and equilibrium constraints [3]. DS techniques allow for the convenient interchange and/or modification of components within a 'virtual' assembly, and offer a multitude of advantages within product development. However, a fundamental requirement in the application of any DS methodology is that each structural component is independently characterised, for example, by their free-interface frequency response function (FRF) matrices. It is only with an independent characterisation that structural components can be coupled together in a physically representative manner. Such a characterisation is the focus of this paper.

The free-interface dynamics of a structural component are typically approximated through 'free' suspension. Whilst a suitable approximation is obtained from mid to high frequencies, the low frequency dynamics are often influenced by the presence of resilient supports [4]. Consequently, the acquired FRFs are unsuitable for use within DS.

* Corresponding author.
E-mail address: j.w.r.meggitt1@salford.ac.uk (J.W.R. Meggitt).

https://doi.org/10.1016/j.ymssp.2018.07.045
0888-3270/



(a) Standard SD applied to a rigidly coupled assembly.

(b) Standard SD applied to a resiliently coupled assembly. The resdiual is defined as the resilient element-recevier portion of the assembly.

(c) Standard SD applied to a resileint coupled assembly. The residual is defined as the recevier only.

Fig. 1. Diagrammatic representations of standard SD procedures applied to rigidly and resiliently coupled assemblies.

In the search for an alternative approach, standard DS procedures have been reformulated and used, instead, to decouple structures and return their free-interface dynamics [5–7]. Whilst this approach, referred to as sub-structure decoupling (SD), provides an independent characterisation, its implementation requires a priori knowledge of a *residual* sub-structure, from which the *target* sub-structure is decoupled. This knowledge is required in the form of the residual's free-interface FRF matrix. Once known, the residual is decoupled from the assembly, leaving behind the free-interface dynamics of the target sub-structure. This standard SD procedure is illustrated diagrammatically in Fig. 1a.

Whilst SD procedures have gained popularity within the structural dynamic community, they are undeniably inconvenient to implement as they require the dismantling of the assembly beforehand (so as to characterise the residual sub-structure). Furthermore, their application to resiliently coupled assemblies is unclear. This may be illustrated by considering the independent characterisation of a resiliently coupled source sub-structure. Following the standard SD procedure, the residual is taken as either; the receiver sub-structure alone, or as the coupled resilient element-receiver portion of the assembly. These are shown diagrammaticality in Figs. 1b and 1c, respectively. In each case there exist clear practical issues. In the former (Fig. 1b), the residual's free interface dynamics are not readily available from measurement[1], whilst in the latter (Fig. 1c), the source is defined such that it includes the resilient supports. Moreover, the argument remains; with standard SD procedures, once dismantled, the residual sub-structure is no longer under a representative mounting condition. As such, its free-interface dynamics are placed into question.

Clearly, an ideal SD methodology would require only measurements to be made on the assembly in its coupled state, thus avoiding the need for it to be dismantled. The development of such an 'in situ' approach is the main concern of this paper.

Whilst the proposed in situ SD procedure is restricted to resiliently coupled assemblies[2], it potentially offers a convenient and independent characterisation of source, receiver *and* coupling elements simultaneously. Like standard SD, the in situ decoupling is based on the mathematical removal of a residual sub-structure from the coupled assembly. Unlike standard SD however, the residual here is defined as the resilient supports that couple source and receiver (see Fig. 2). Through the independent and in situ characterisation of this residual, the decoupling of source and receiver sub-structures may be achieved without dismantling the assembly.

The in situ decoupling of resiliently coupled assemblies has previously been investigated by Zhen et al. [8,9], Pavic and Elliot [10,11], Wang et al. [12], Keermaekers et al. [13], Liao et al. [14], and Wang et al. [15]. Zhen et al. [8,9] appear to be the first to derive a set of sub-structure decoupling relations. These were later generalised in [12] for more than 2 sub-structures. More recently Wang et al. [15] extended the derivation of Keermaekers et al. [13] such that DoFs remote to the coupling interface may be included in the decoupling procedure. A capability which is recognised in the present work.

In the derivation of their respective formulae, the aforementioned authors assume spring-like coupling elements (i.e. a conservation of force across the element) and present formulas for the free-interface sub-structure FRFs. The SD procedure presented herein is based on this same assumption (conservation of force across the element), and may therefore be consid-

[1] This would require the measurement of point and transfer mobilities between the free-interfaces of the resilient supports. With the source removed the coupling elements would no longer be under a representative mounting condition. Furthermore, there would likely be little room to perform the required measurements.

[2] It should be noted that the coupling element need not be all that resilient. The SD procedure is more generally restricted to spring-like coupling elements.