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Transmissibility of non-linear output frequency response functions with application in detection and location of damage in MDOF structural systems

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ABSTRACT

Transmissibility is a well-known linear system concept that has been widely applied in the diagnosis of damage in various engineering structural systems. However, in engineering practice, structural systems can behave non-linearly due to certain kinds of damage such as, e.g., breathing cracks. In the present study, the concept of transmissibility is extended to the non-linear case by introducing the Transmissibility of Non-linear Output Frequency Response Functions (NOFRFs). The NOFRFs are a concept recently proposed by the authors for the analysis of non-linear systems in the frequency domain. A NOFRF transmissibility-based technique is then developed for the detection and location of both linear and non-linear damage in MDOF structural systems. Numerical simulation results verify the effectiveness of the new technique. Experimental studies on a three-storey building structure demonstrate the potential to apply the developed technique to the detection and location of damage in practical MDOF engineering structures.

1. Introduction

A wealth of methods exists for the detection and location of damage in structural systems. These methods include time and frequency domain techniques, parametric and non-parametric approaches, and empirical and model-based approaches for plates, shells, composites, and other types of structures [1]. The core idea of most of these available techniques is to compare some features evaluated from on-line measured structural responses to the features evaluated from responses measured under the systems' normal working conditions, to assess whether damage has occurred and, if this is the case, where the damage is located.

The frequency-domain transmissibility function is a significant feature that can be applied to detect, locate, and quantify damage in multi-degree of freedom (MDOF) structural systems where structural dynamic sensor arrays can be used to make differential dynamic transmissibility measurements [2]. For MDOF structures, structural damage affects both the system poles and zeros. But, as analyzed in Refs. [2,3], zeros are much more sensitive than poles to localized damage, as zeros depend on the input and output locations whereas poles do not. Transmissibility functions are determined solely by the system zeros, and they are therefore potentially better indicators of localized damage.

The frequency-domain transmissibility function is essentially a linear system concept. It is normally defined as the ratio of the spectra of two different system outputs of interest, and is also equal to the ratio of the system frequency response functions (FRFs) associated with the two outputs. Although, as demonstrated by numerical studies in Ref. [2], this transmissibility concept can sometimes be used for the detection and location of damage in non-linear structural systems, the concept is generally input-dependent for non-linear systems. Consequently, one is generally not able to use the traditional transmissibility function to distinguish the effect of system input from the effect of the change of system properties due to the occurrence of damage in non-linear structural systems.

In structural systems, certain types of damage often manifest themselves as the introduction of a non-linearity into an otherwise linear system [4]. Examples include post-buckled structures (Duffing non-linearity), rattling joints (impacting system with discontinuities), or breathing cracks (bilinear stiffness). Therefore effective techniques are needed which can reliably detect and locate both these types of non-linear damage as well as linear changes due to damage (e.g., a stiffness or mass change, such as with corrosion or loss of an element). Many researchers have addressed different aspects of this important issue using different approaches. These approaches include, for example, mutual

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