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Experimental and numerical study of Advanced Transfer Path Analysis applied to a box prototype

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ABSTRACT

Advanced Transfer Path Analysis (ATPA) is a technique that allows the characterisation of vibroacoustic systems not only from the point of view of contributions but also topologically by means of the path concept. Some of the aspects addressed in the current research such as the proper characterisation of the less contributing paths remained not proven. ATPA is applied to a cuboid-shaped box. The simplicity of this vibroacoustic system helps to make a detailed analysis of the ATPA method in a more controlled environment than in situ measurements in trains, wind turbines or other mechanical systems with complex geometry, big dimensions and movement. At the same time, a numerical model (based on finite elements) of the box is developed. The agreement between the experimental measurements and the numerical results is good. The numerical model is used in order to perform tests that cannot be accomplished in practise. The results are helpful in order to verify hypotheses, provide recommendations for the testing procedures and study some aspects of ATPA such as the reconstruction of operational signals by means of direct transfer functions or to quantify and understand which are the transmission mechanisms in the box.

1. Introduction

A major concern when dealing with vibroacoustic systems is to understand how the vibration and noise are transmitted and distributed. A common way to acquire this knowledge is through the path concept. In a network of interconnected nodes we understand that there exists a path between the node i and the node j simply if they are connected. In a vibroacoustic system the nodes are control points, and signals (vibrations or acoustic pressure) are used in order to identify and study the paths. It is not the same a path from i to j as a contribution from i to j. A contribution describes the amount of signal that arrives at j due to an excitation on i. But this signal can be transmitted through any path from i to j (regardless of the existence of a direct path between i and j). So, the contributions are descriptions of the inputs and the outputs while paths are a description of the system topology. One formal definition of 'path' can be found in [1]. More recently, it was shown in [2] that the solution of a mechanical problem can be expressed in terms of paths. This can be used at both numerical modelling and experimental levels. An application example is to characterise the transmission of vibration and noise

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from the engine to the passengers cavity or other parts of a car. It is usually generated at the wheels, engine, exhaust and travels through the chassis, axes and insulating layers to the passenger compartment.

The final goal is always to characterise the response of each subsystem (measured in terms of the acceleration of a vibrating element or the acoustic pressure in a zone of interest) caused by a specific excitation. A large amount of experimental methods have been developed during the past decades [3]. We can distinguish, in a quite general classification: Transfer Path Analysis (TPA [4]) and Advanced TPA (ATPA [5,6] or also Force contribution analysis [7]). The main difference between the methods grouped under the name TPA and the name ATPA is that traditional TPA characterises only the source contributions from the inputs to some receivers. It is done by combining operational signals (measured while the equipment is working) with transfer functions (frequency response functions, FRF) measured on the empty passive structure where the equipment is installed. For example, the transfer functions can be measured on a car chassis prior to the engine installation. This chassis is uncoupled from the engine and passive in the sense that it only acts as transmitter of vibrations that are generated elsewhere. ATPA, as the in situ TPA procedure [8,9], does not require any disassembly of the structure. It characterises furthermore the topology of the mechanical system and thus, the paths and their contribution to any receiver. TPA measures global transfer functions between subsystems while ATPA measures the direct transfer functions. Direct transfer functions provide a more useful information on the system behaviour. Another feature of ATPA is that, contrary to TPA, the measurement of the excitation force is not required which is indeed an advantage. Both ATPA and TPA are adequate if one can act on the exciting forces to control and reduce them. This means that a redesign of the vibroacoustic system acts on the exciting force in order to improve the response in terms of noise emission or vibration levels. However only with ATPA it is possible to quantify the contributions of a passive system (like the interior panels of a train coach or of a vehicle) and with this information decide which part of this system needs to be modified in order to reduce the noise measured in the receiver position (the redesign acts on the system itself).

If the studied system is understood as a black box with n inputs and m outputs interconnected through the box, TPA and ATPA can predict which is the contribution of each input to each output. This means that both methods are able to decompose the output signal into contributions coming from every input signal. However, TPA is unable to describe how the input and outputs are connected. ATPA is able to characterise, in addition, how the input and output signals are connected inside the black box, discover which is the intrinsic structure of the mechanical system, which and how are the paths. For this reason when a detailed analysis of the mechanical system is needed, the use of ATPA is helpful.

1.1. Goals of the research

This work deals with the application of the ATPA method to a simple laboratory prototype. This is a cuboid-shaped box with an air cavity inside. A major control on the laboratory measurements is possible due to the simplicity of the prototype. This allows a more detailed analysis. It also opens some unusual options for the analysis of the method that are not possible in more complex mechanical systems such as a car or a train coach. TPA and ATPA methods have several common limitations in practice such as: difficulty in the access to the desired control points, limit in the number of sensors to be used, large time required to make the installation of the measurement setup, difficulty in the repetition of tests (i.e. time to measure in a building, car or train is often limited), etc. All these drawbacks are non-existent in the box prototype because it is available at the lab, sensors can therefore be placed without problems (the box is lightweight and it can be handled and moved without external machinery).

A numerical model of the box is also developed. The degree of uncertainty of the experiment is more controlled than usual. Consequently a better agreement between the numerical model and the experimental data can be obtained. Once calibrated, the numerical model will allow for a faster execution of virtual experiments, the possibility of doing parametric analyses or a more visual representation of the results. In other words, to analyse and gain understanding of aspects that are very difficult to visualise and control in the laboratory or in situ test such as: automatic identification of the subsystems, optimisation of the sensor position inside each subsystem, combination of more than one sensor per subsystem, study the influence of the excitation type (point force, rain-on-the roof, acoustic wave, etc.) and the spectrum of the excitation.

The application of the ATPA method in a vibroacoustic mechanical system as well as the comparison with a numerical model have not been reported before.

1.2. Contributions of the research

In addition to the application of ATPA to a vibroacoustic problem as the box with cavity inside, the main contributions of the research and results shown here are:

1. To be able to compute any transmission path with ATPA and show that it properly characterises the paths with small contributions (not only the main contributors). This is important because after a redesign oriented to suppress the most contributing paths, these other still remain and are the ones that define the response of the modified system.
2. To verify that two methods of estimation of the direct transfer functions provide equivalent results. One of the methods is used in laboratory and in situ measurements and the other is based on the definition of direct transfer.