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Sound source measurement by using a passive sound insulation and a statistical approach

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ABSTRACT

This paper describes a measurement technique developed by the authors that allows carrying out acoustic measurements inside noisy environments reducing background noise effects. The proposed method is based on the integration of a traditional passive noise insulation system with a statistical approach. The latter is applied to signals picked up by usual sensors (microphones and accelerometers) equipping the passive sound insulation system. The statistical approach allows improving of the sound insulation given only by the passive sound insulation system at low frequency. The developed measurement technique has been validated by means of numerical simulations and measurements carried out inside a real noisy environment. For the case-studies here reported, an average improvement of about 10 dB has been obtained in a frequency range up to about 250 Hz. Considerations on the lower sound pressure level that can be measured by applying the proposed method and the measurement error related to its application are reported as well.

1. Introduction

Unusual noises might be an indication of defective products and/or possible future failures of the manufactured product [1,2].

Generally, in situ noise-based product quality control procedures are preferred to ones implying the availability of a controlled acoustic environment. However, these procedures need the measurement of the noise emitted by the industrial product without any effect of other extraneous noise. A possible solution to reduce background noise effects can be a box with suitable passive noise insulation, enclosing the sound source being tested.

An in-depth analysis of the vibro-acoustic interaction between air-cavity and its boundaries is required to reduce the noise transmitted inside a cavity. These issues have been widely treated in the past. Preliminary studies on a coupled rectangular air-cavity system were conducted by Dowell and Voss [3] and Pretlove [4] to understand the dynamic behaviour of a flexible panel backed by an acoustic cavity with rigid walls. By using the modal coupling theorem, Pope [5] studied the sound transmission into small rectangular and cylindrical air-cavities. Pan and Bies [6] analysed the sound decay into a coupled rectangular air-cavity system while Tanaka et al. [7] recently derived explicitly the eigenpairs formulation for it. These studies allow to predict the sound transmission into small cavities taking into account the effects of interaction

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between the inside sound field and cavity boundaries. All cited studies consider a single vibrating wall and they need the exact knowledge of the boundary conditions. In real cases, instead, all walls vibrate when exposed to an external sound field and it can be difficult to assign boundary conditions. An active control system can also be used to reduce background noise effects in an air-cavity. Starting by the preliminary study of Lyon [8], Pan and Bies [9] studied an active control system by using force actuators to reduce the noise transmitted through a panel into a cavity, while Snyder and Hansen [10] dealt with the problem of feedforward active systems by using the modal coupling theory. Hill et al. [11] showed that the noise transmitted through the walls of a rectangular cavity can be described by a generalized acoustic function and the sound transmission control is independent on vibration characteristics of the radiating structure. A wider presentation of the issues concerning with the active noise control in cavities can be found in a previous study [12].

However an active noise control system is a complex hardware which, in addition to data processing system and signal acquisition sensors, involves the use of additional sound sources or force actuators. The latter must be properly located and must be fed by suitable signals.

In general, as reported by Fahy [13], the sound pressure inside a cavity can be considered as a superposition of the direct sound pressure field due to an internal acoustic source and the sound pressure field imposed by boundary conditions. When inside the box there is no sound source, the internal sound field is induced by the vibration of the box walls, which in turn depends on the external sound field. When inside the box there is a sound source, the internal sound field depends on both the internal sound source and the vibration of the box walls. The fluid medium in the cavity, loading the walls with its weight, may have a significant effect on the vibration of the enclosing structure. Therefore, the problem of the dynamical behaviour of the box walls has to be simultaneously solved with the sound field inside the box, resulting in a coupled complex equation system. Nevertheless, if the internal fluid is air, the sound field inside a large cavity does not affect the dynamic behaviour of the box thick-walls.

However, at low frequencies, passive noise insulation requires heavy and tightly sealed devices, hard to be installed on an existing production line.

In this scenario, the authors have developed a procedure for improving, at low frequency, the measurement of the Sound Pressure Level (SPL) of noise emitted by manufacturing products working inside industrial noisy environments by using a statistical approach.

It is worth noting that the aim of the procedure is not to completely characterize the acoustic behaviour of an industrial product, as the latter depends on the environment enclosing the tested industrial product [14–16]. This application addresses mainly to industrial control quality processes for which a comparison between noise measurements emitted by the considered industrial product and by the reference one is usually required.

The proposed method is based on an apparatus consisting of a box containing the manufacturing product, a microphone located inside it (internal microphone), an array of microphones located outside the box (external microphones) and some accelerometers.

Generally, the internal microphone measures both the noise emitted by the industrial product and the noise due to the industrial environment crossing through box walls. Instead, given the low-noise level due to the industrial products, the box walls can acoustically isolate the microphones placed outside the enclosure from the noise emitted by the sound source. In this way, the sound signal picked up by each external microphone is only due to the external background noise.

The proposed method is not based on feedback or feedforward active noise control; no control sound source or force actuators is used. Furthermore it describes the sound transmission through cavity walls by using a statistical approach, taking into account the effective boundary conditions of the cavity walls. The signal picked up by the internal microphone is then modified during a post-processing phase to obtain the sound signal due only to the internal sound source. It is also shown that the results are affected by a statistical error that can be predicted with a given probability level.

The paper has been organized in 4 Sections in addition to Section 1. In Section 2, the vibro-acoustic and statistic basics in cavities are reported. Fundamentals of the proposed statistical approach, and considerations on the measurement error related to the suggested method, are analyzed as well. Sections 3 and 4 deal respectively with numerical simulations and in-situ measurements performed to check the validity of the proposed statistical approach. Finally, Section 5 reports main results and hints for future works.

2. Theoretical background of the statistical approach

2.1. Basics of vibro-acoustics in cavity

The statistical approach starts by the classical vibro-acoustic problem of a closed air-box exposed to an external sound pressure field. If the box walls are thick enough and their density is greater than one of the air, the modal coupling theorem allows describing of the displacement of the box walls due to a distributed sound pressure field on the cavity surface S [5,10] as follows:

$$v(x) = j\omega \int_S G_s(x/x^{'})(p_e\left(x^{'}\right) - p_{int}(x^{'}))\mathrm{d}x^{'} \tag{1}$$

where ω is the angular frequency, $p_e\left(x^{'}\right)$ and $p_{int}\left(x^{'}\right)$ are the external and the internal sound pressure, respectively, x and x' are vectors defining the receiver and source positions on the box surface S. $G_s(x/x')$ represents the Green function of the