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Sound reflection measurements on noise barriers in critical conditions

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ABSTRACT

It is often necessary to check the intrinsic acoustic characteristics of installed noise barriers, like sound reflection and airborne sound insulation, to verify their compliance to design specifications or their quality after some years of life. These characteristics may be measured *in-situ* following CEN/TS 1793-5. These guidelines have been substantially improved in the frame of the European project QUIESST (2009–2012), which is now under consideration by the relevant CEN working groups to produce new European standards. The new method for measuring sound reflection specifies the usage of an electroacoustic sound source and a microphone grid, in order to obtain a set of impulse responses; these are processed by means of improved algorithms to compute the required results. The impulse responses are acquired using MLS (Maximum Length Sequence) or ESS (Exponential Swept-Sine) as test signals. While the acoustical characteristics of a noise barrier obtained using the two signals are generally equivalent, in critical conditions – e.g. excessive background noise or local meteorological variability – some discrepancies may occur. Moreover, different type of background noise (broadband or impulsive) give different effects on the final result, using MLS or ESS test signals. This paper presents a series of experiments designed to put in evidence the differences between Reflection Index measurements performed in the mentioned critical conditions, according to the QUIESST guidelines, done using MLS or ESS signals. The relative advantages and drawbacks are analysed and discussed in detail. Conclusions are drawn on the selection of the best test signal for each situation.

1. Introduction

The *in-situ* measurement method for sound reflection described in CEN/TS 1793-5 [1] was firstly developed in the frame of the ADRIENNE European project (1995–1997), borrowing from the sound reflection method for measuring the sound absorption with MLS (Maximum Length Sequence) signals implemented by Garai some years before [2]. A different source and microphone set up permits to measure also the airborne sound insulation [1,3]. This kind of measurements is used to know the intrinsic acoustic characteristics of an installed noise barrier and to verify their compliance to design specifications after its installation aside of a road or a railroad [4–6]. The same method can be used to check the quality of the installed barriers after some years of life. In the frame of the European project QUIESST (2009–2012) [7], working package 3, the test method has been completely revised, increasing its robustness and obtaining for the first time an objective evaluation of its repeatability and reproducibility [8,9]. However, no explicit guidelines exist about the selection of the test signal used to measure the impulse responses (IRs) required for the computation of the Reflection Index and Sound Insulation Index. Two test signals are mentioned in the QUIESST reports [7]: MLS and ESS (Exponential Swept-Sine), considered equivalent if meeting some general criteria. In fact, the acoustical characteristics of a noise barrier obtained using the two signals are generally equivalent in normal conditions. Instead, in critical environmental conditions – like excessive background noise or time variation of the system under test due to local meteorological instability – some discrepancies may occur between the acoustic characteristics of the same noise barrier in the same conditions obtained using the two mentioned signals. Therefore, it is necessary to investigate the problem more in depth in order to understand how to select of the best test signal for each situation. In the light of this, the paper presents a series of Reflection Index measurements on a real scale noise barrier, following CEN/TS 1793-5 and the QUIESST improved method [7,8]. The experiments are designed to put in evidence the differences between Reflection Index measurements done using MLS or ESS signals in critical conditions. The relative advantages and

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drawbacks are analysed and discussed in detail. Finally, some conclusions are drawn on the selection of the best test signal for each situation. A complete description of the measurement method can be found in Refs. [6–10].

2. Test signals

The test signal type (MLS or ESS) must be chosen to minimize the possible troubles in the impulse response measurements. When applied to *in-situ* barrier characterization, impulse response measurements may be affected mainly by:

- time variance, due to wind and temperature changes during the measurement session;
- distortion of the system (e.g. loudspeaker non-linearity);
- background noise, broadband or impulsive, coming from noise sources in the surrounding of the measurement position or from the measuring equipment itself.

In this regard, the output level of the power amplifier during the measurement must be carefully selected. In fact, an excessively low level will decrease the signal to noise ratio (SNR) of the measurement and will increase the influence of time variance on the recovered impulse response; an excessively high output level will cause non-linearity of the loudspeaker and possibly other elements of the measurement chain. Considering all the above, the most used test signals are MLS and ESS, well known for their reliability even in presence of a non-negligible background noise. On the other hand, MLS and ESS, have different behaviours in relation to their noise rejecting properties and their capability to withstand some degree of distortion and time variance. Consequently the Reflection Index values coming from impulse responses measured in the same conditions using the two signals may show differences in case of critical measurement conditions (when the system under test doesn't comply the hypothesis of linear and time invariant system).

The use of a MLS (Maximum Length Sequence) signal for measuring impulse responses is well established [11–13]. The sine sweep signal is also widely used [14]. In particular, the ESS (Exponential Sine Sweep) signal [18] has gained considerable interest since Farina introduced it in 2000 [15] and refined it in 2007 [16]. If compared to MLS, it reveals both advantages and drawbacks. The main advantage of the ESS method is the separation of the linear part of the measured impulse response of the system from most part of the harmonic distortion, even if recent studies have shown that some amount of odd orders distortion still remains, as Torras et al. [17] formally proved in 2011. The separation of the most part of distortion from the linear part allows having a much better signal to noise ratio (SNR) than with MLS, because the impulse response is free from the spurious peaks distributed on the time axis typically caused by distortion when using MLS. On the contrary, using ESS, the impulse response is recovered by means of an aperiodic linear convolution, avoiding the time-aliasing problem of MLS. Moreover, the use of an ESS measurement signal allows to describe easily the nonlinearities of the measured system by means of the Volterra model [21] and its simplified implementation (diagonal Volterra model). The crest factor of about 3 dB of the ESS can be exploited performing high power measurements in (steady) noisy conditions. Typically, in similar conditions the ESS has a dynamic range of about 15 dB higher than MLS.

Whereas stationary background noise can be somehow rejected and compensated in different ways for both MLS and ESS methods [20], impulsive noises can contaminate the data sampled using an ESS signal, causing spurious effects on the deconvolved impulse response in form of a frequency decreasing sweep [14,16]. Farina in Ref. [16] proposed a possible workaround for correcting a measurement corrupted by an impulsive noise, consisting in the rejection of the portion of the corrupted sampled ESS through a narrow-band filter, tuning the filter itself at the same frequency of the ESS at the very instant the disturbance occurs. However this procedure can be applied only if the sampled ESS is available and not when a measurement system gives in output directly the deconvolved impulse response. In addition, depending on the kind and duration of the disturbance, the manual correction of the ESS may not be possible.

3. Experimental results

Three series of measurements were executed in order to compare the MLS and ESS signals applied to Reflection Index measurement in critical conditions. The loudspeaker and microphone grid used for the tests are visible in Fig. 1. In a first set of measurements MLS, pink-filtered MLS and ESS signals, in all cases single shot, were employed. The measurements were done at different sound pressure levels and with a powerful fan, switched on or off, placed near the microphones in order to test the resilience of the measurement to time variance and stationary noise. Following the same procedures, a second set of measurements were performed using unfiltered MLS signal, with various average options, and ESS. A third set of measurements were performed in presence of two types of impulsive background noise.

3.1. Single shot measurements

A series of Reflection Index measurements were carried out on the reflective and the absorbing surfaces of the noise barrier. Three signal types were used for this comparison: MLS, pink-filtered MLS and ESS, all of them 256 K samples long. No averages were done on the measurements (it is worth remembering that averaging can improve the MLS performance, while it is useless employing the ESS). A broadband background noise, having an equivalent sound pressure level of about 65 dB, coming from the heating system was present during the measurements. Since the aim of this test was a comparison of different signals in presence of background noise and time variance, measurements at different sound pressure levels and with a powerful fan, switched on or off, placed near the microphones were performed. The first measurement session was done with the fan switched off (air speed nearly 0 m/s) and optimizing the system levels so as to measure a L_{eq} of about 80 dB at the

Fig. 1. Loudspeaker and microphone grid close to the sample noise barrier used for the tests. Reflecting metal sheet on the right; absorptive melamine layer on the left.