On the determination of transmission loss and facade sound insulation by means of impulse response measurements.

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The research described in the paper reports the determination of transmission loss and facade sound insulation by applying the impulse response method. The work started from the draft ISO/DIS 18233 on the "application of new measurement methods in building and room acoustics". From the measured impulse response it is in fact possible to determine the energy level, corresponding to a steady noise, and the reverberation time through the calculation of the Schroeder integral plot. The required parameters can then be calculated by using the relationship proposed by the ISO 140 series. The experimental measurements were carried out using the technique of exponential Sine Sweep. Some preliminary tests were made using also the MLS and the balloon-bursting techniques. The results obtained were analysed and compared with those produced with the traditional technique.

1. Introduction

The draft ISO/DIS 18233[1] provides for the application of new measurement methods in building and room acoustics; it is a reference guide for the choice of the excitation signal, for the relevant signal processing and for the examination and control of the necessary time-invariance characteristics of the system under examination.
The new standard could be suitable for measuring transmission loss, facade sound insulation, reverberation time and other acoustical parameters.
After the results obtained on the determination of Sound Reduction Index by impulse response measurements of internal partitions [2], in this paper the experimental results for the application of the same method to the facade insulation are described.
The experimental measurements were carried out using the exponential Sine Sweep, MLS signal and balloon-bursting techniques. The obtained results were analysed and compared with those produced with the traditional technique.

2. Airborne Sound Insulation of Facades.

The relations proposed by ISO 140-5[3] for the determination of the Level Difference and the Standardized Level Difference of facades are the following:

$$D_{2m} = L_{1,2m} - L_2 \quad [\text{dB}] \tag{1}$$

$$D_{2m,nT} = L_{1,2m} - L_2 + 10\log\frac{T}{T_0} \quad [\text{dB}] \tag{2}$$

in which:

- $L_{1,2m}$ is the outdoor sound pressure level 2 m in front of the facade [dB];
- L_2 is the sound pressure level in the receiving room [dB];
- T is the Reverberation Time of the receiving room [s];
- T_0= 0,5 [s].

In the present work, other than the traditional technique, the level difference and the reverberation time are calculated also by Schroeder's backward integration of the impulse response, obtained by the following techniques: Exponential Sine Sweep, MLS signal and impulsive signal (balloon-bursting). For the validity of this method, it is necessary to suppose that the system is linear and ensure it is time-invariant during the measurements.
It can be shown [4] that, in a room, the expected decay response $n(t)$ to a stationary white noise excitation switched off at time t=0 is related to the impulse response $h(t)$ by the equation:

$$\langle n^2(t)\rangle = N\int_t^{\infty} h^2(u)du \tag{3}$$

in which N is a constant related to the excitation level.
Consequently the expected energy ‹$n^2(0)$› due to the stationary noise excitation is obtained by integrating the impulse response over the observed time:

$$\langle n^2(0)\rangle = N\int_t^{\infty} h^2(u)du\,; \tag{4}$$

if the logarithmic curve $L(t)$, which is related to ‹$n^2(t)$›, is considered, the corresponding energy level is:

$$L(0) = 10\log_{10}\left[\left\langle n^2(0)\right\rangle\right][dB] \tag{5}$$

and the reverberation time may be computed by evaluating the slope of this curve:

$$T = -60\left(\frac{dL'(t)}{dt}\right)^{-1}[s] \tag{6}$$

in which $L'(t)$ is the linear fit of $L(t)$ function.

If an Exponential Sine Sweep is used as input signal, the impulse response of a room (supposed Linear and Time-Invariant) is expressed as:

$$h(t) = y(t) * f(t) \tag{7}$$

where $y(t)$ is the output signal and $f(t)$ is the inverse filter of the input signal.

The MLS signal has the property that its autocorrelation function yields an impulse signal and the cross-correlation function of a system's response to an MLS with the MLS itself is the system's impulse response

3. Experimental results using the IR measurement techniques and comparison with the traditional technique.

The traditional technique uses a loudspeaker driven by white noise positioned outside with 45° sound incidence angle towards the facade as a sound source, and balloon-bursting to determine the reverberation time of the internal room. The signals are acquired and elaborated by the Sound level meter Brüel & Kjær Type 2260 Investigator. The same instrument is used also to acquire and elaborate the signal level of all the other techniques.

For the IR measurement techniques, the set-up consists of:

- Omnidirectional dodecaedric source Look Line mod. 300 for the emission of Sine Sweep and MLS signals;
- Balloons as impulsive source;
- Brüel & Kjær free field 1/2 inch Microphones (providing the diffuse field correction for the sound pressure levels in the receiving room), with Brüel & Kjær pre-amplifier;
- Adobe Audition® software with Aurora® plug-in to generate and receive the Sine Sweep and MLS signals; the same software was used to record all the balloon bursting signals;
- Audio device type WAMI RACK;
- Dirac® software and post-elaboration software, realized using Matlab® code, to analyze the received signal.

The IR techniques are realized by measuring simultaneously the inside and outside signals. The microphone positions and the position of the sources are in agreement with the requirements referred to by the classical method.

The first experimental results concerned in a comparison between the traditional technique (Signal Level Differences using white noise excitation signal) and the IR measurement technique that uses a Sine Sweep as test signal (IR level differences) for the evaluation of facade insulation. Figure 1 reports the frequency domain curves showing the Standardized Level Difference $D_{2n,nT}$ and the values of the single number quantities $D'_{2n,nT,w}$ measured according to EN-ISO 717-1 [5].

Figure 2 reports the frequency domain curves showing the Reverberation Time measured with the two different methods: IR analysis obtained by sine sweep test signal, and IR analysis obtained by impulsive signal (Balloon-Bursting) as the traditional technique. In such a comparison it can be seen that the applied techniques for the Reverberation Time are equivalent.

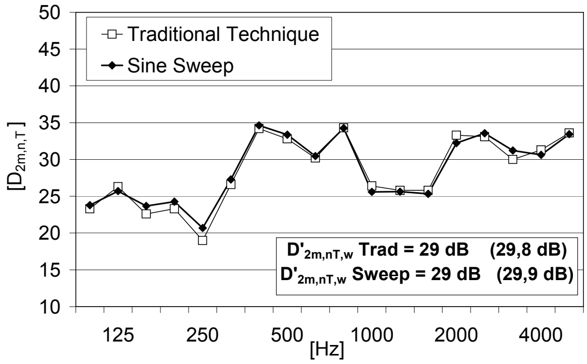

Figure 1: Standardized Level Difference; comparison between Traditional Technique and Sine Sweep

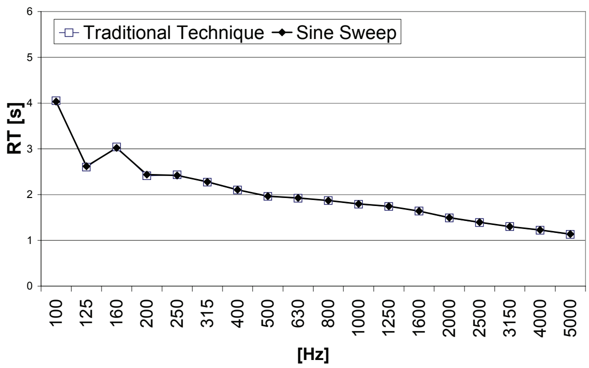

Figure 2: Reverberation Time; comparison between Traditional Technique and Sine Sweep

Figure 3 reports the obtained results concerning a comparison, for a different facade, between the traditional technique and the IR measurement technique using Balloon-bursting as impulsive test signal.

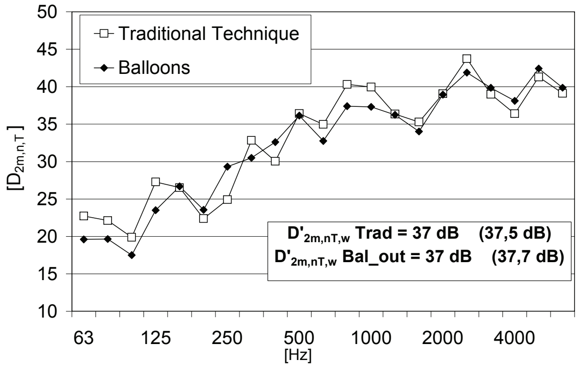

Figure 3: Standardized Level Difference; comparison between Traditional Technique and Balloon-Bursting.

The next results concerned a comparison, for another facade, between the Standardized Level Difference $D_{2n,nT}$ obtained measuring separately the signal level differences (Figure 4) and the IR level differences (Figure 5) using respectively as test signals: White noise (traditional technique), Sine Sweep, MLS signal and Balloon-Bursting.

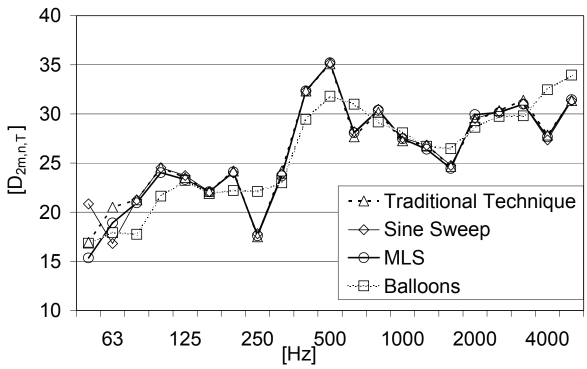

Figure 4: Standardized Level Difference obtained by the signal level differences of various test signals.

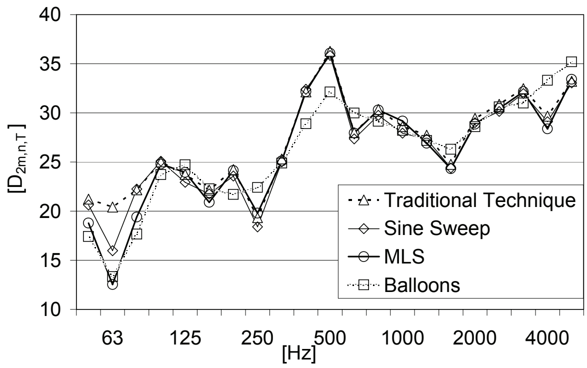

Figure 5: Standardized Level Difference obtained by the IR level differences of various techniques.

In Figure 4, all measurements for obtaining parameter $D_{2m,n,T}$ were made using the Sound level meter, those are: outdoor and receiving room sound pressure levels for each signal type and the RT of the receiving room obtained with the balloon-bursting impulse responses. While, in Figure 5, the sound pressure levels and the internal RT are obtained computing the IR of every different technique, using the audio device, recording and post-processing software.

In the following table are given the values of the single number quantities measured according to EN-ISO 717-1 [5], obtained with the previously described techniques.

Table 1: Values of single number quantities obtained with the different techniques.

Test Signal	$D_{2m,n,Tw}$ [dB]	
	Signal Level Differences	IR Level Differences
Traditional	28,6	
Sine Sweep	28,7	28,8
MLS	28,6	29,1
Balloons	29	29,5

Figures 6, 7 and 8 show a comparison for every single signal, between signal level difference measured by the Sound level meter and level difference calculated from the IRs obtained from the respective technique.

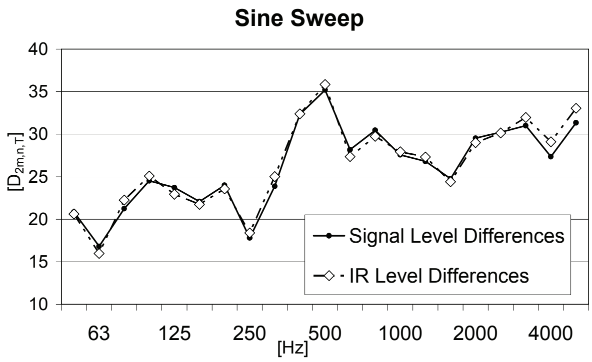

Figure 6: Standardized Level Difference; comparison between signal level difference measurements and IR level difference measurements for Sine Sweep

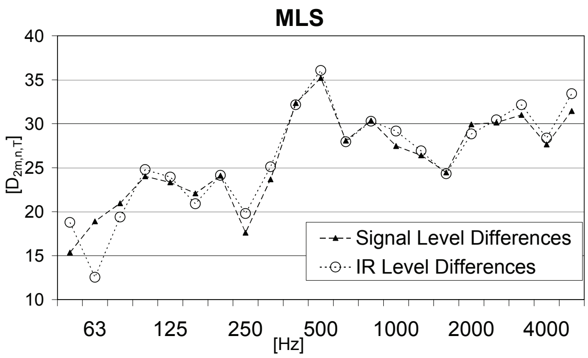

Figure 7: Standardized Level Difference; comparison between signal level difference measurements and IR level difference measurements for MLS signal.

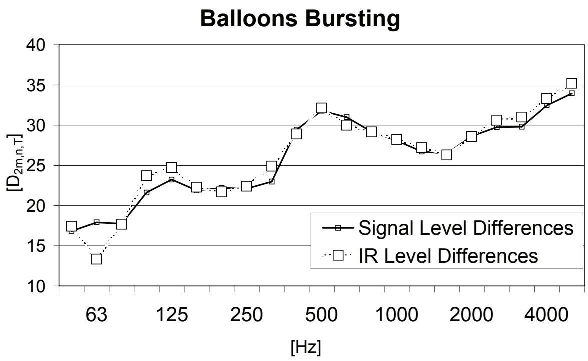

Figure 8: Standardized Level Difference; comparison between signal level difference measurements and IR level difference measurements for Balloon-Bursting.

4. Conclusion

With respect to the traditional method, described by ISO 140-5, the new technique guarantees high accuracy and leads to good repeatability regarding level and reverberation time measurements. Discrepancies between the results obtained with Sine Sweep and MLS techniques are only noticed at low frequencies (below 200 Hz); a suitable explanation could be that IR methods are sensitive to background noise in the receiving room, and also that the dodecaedric source has scarce efficiency at those frequencies.
The Sine Sweep and MLS methods seem to be less sensitive to extraneous noise then the balloon-bursting technique, which presents the same frequency curve but with reduced peak values. The sound power of the balloon bursts has less energy than the dodecaedric source, but this technique has the advantage of being simpler and cheaper to realize than all the other measurement methods.
However, the IR method is limited because of the linearity and time-invariance of the system. Therefore it is not possible to move the microphone in order to obtain spatial averaging of the parameters using the IR measurement techniques as described in the ISO 140-5.

References

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