USE OF RESIDUAL PRESSURE-INTENSITY INDEX FOR EXAMINATION OF THE ACCURACY OF A SURFACE-IMPEDANCE MEASUREMENT SYSTEM

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Introduction

The surface impedance of materials can be determined experimentally in the free field or ***in situ*** by measuring sequentially the transfer function at two locations using a single microphone if the excitation signal can be controlled [1]. However as no experimental system is perfectly linear and repeatable, errors will be introduced. The objective of this work was to verify experimentally the measurement system of surface impedance using the residual pressure-intensity index. The method presented here can be used to examine the stationarity and repeatability of an experimental system.

Expression for residual pressure-intensity index

The biased impedance $\hat{Z}$ can be expressed as a function of equivalent phase errors defined in terms of the characteristics of microphones [2] . In the configuration of measurements adopted here, the microphone is oriented parallel to the surface of the material and the measurement is little sensitive to the vent effect in reactive field. The biased impedance $\hat{Z}$ depends only on the equivalent phase error ϕ_e between the signals measured at two positions:

$$\hat{Z} = \frac{Z \pm |Z|^2/K_0}{1 \pm 2\,\mathrm{Re}\{Z\}/K_0}, \quad K_0 = |p_0|^2/2\rho c\,|I_0| \simeq ka/|\phi_e|. \qquad (1)$$

The residual pressure-intensity index is given as

$$L_{K_0} = 10\log K_0 \simeq 10\log ka/|\phi_e| \qquad \text{(dB)}. \qquad (2)$$

As only one channel is used in the impedance measurements, the equivalent phase error here does not include the electronic phase mis-match. However if the repeatability properties of a system are not perfect (non-linear effects for example), equivalent phase error will be introduced. This error can be represented as the difference in phases between two average transfer functions $\bar{H}_1$ and $\bar{H}_2$, which are determined using N time acquisitions without changing the position of the microphone $\phi_e = \mathrm{Arg}\{\bar{H}_1\bar{H}_2^*\} = \bar{\varphi}_1 - \bar{\varphi}_2$, $\bar{\varphi}_1$ and $\bar{\varphi}_2$ are the phases of $\bar{H}_1$ and $\bar{H}_2$ respectively (for $a = 0$). As $\bar{\varphi}_1$ and $\bar{\varphi}_2$ are random variables and have Gaussian distributions, it is natural to determine ϕ_e by calculating the standard deviation of the phase of the transfer function φ. Since the two sets of measurements are independent of each other, $\mathrm{Cov}[\bar{\varphi}_1, \bar{\varphi}_2] = 0$, $\mathrm{Var}[\bar{\varphi}_1 - \bar{\varphi}_2] = 2\sigma^2[\varphi]/N$. The equivalent phase error can be defined statistically from the variance of $\bar{\varphi}_1 - \bar{\varphi}_2$ by $|\phi_e| \approx \sqrt{\frac{2}{N}}\,\sigma[\varphi]$. The standard deviation of the phase of the transfer function is estimated by $\sigma[\varphi] \simeq \sqrt{\frac{1}{M-1}\sum_{m=1}^{M}(\varphi_m - \bar{\varphi})^2}$, where $\bar{\varphi} = \mathrm{Arg}\{\bar{H}\}$ with $\bar{H} = (1/M)\sum_{m=1}^{M} H_m$. The residual pressure-intensity index becomes

$$L_{K_0} \simeq 10\log\sqrt{\frac{N}{2}}\,\frac{ka}{\sigma[\varphi]} \qquad \text{(dB)}. \qquad (3)$$

Eq. (2) shows that the residual pressure-intensity index L_{K0} is dependent on the standard deviation of the phase of the measured transfer function, the separation distance of the microphones, frequency and the number of acquisitions.

Verification of experimental system using L_{K0}

In order to determine experimentally the variance $\sigma^2[\varphi]$ of the phase of the transfer function, a series of transfer functions H_m (m=1,2,3, ... M) were measured using a single microphone at the same position in the sound field. The measurements were done in a semi-reverberant room. The glassfiber sheet was put on the floor of the room. A microphone was placed 10 cm from the surface of the material. A loud-speaker used in the impedance measurement was driven by a determinist broad-band signal. Fig. 1 shows the standard deviation $\sigma[\varphi]$ estimated from 150 measurement samples. It is noted that $\sigma[\varphi] > 50°$ at frequencies $f < 100$ Hz. The measured values L_{K_0} were calculated using $\sigma[\varphi]$ in the case of $a = 10$ cm and $a = 0.5$ cm respectively. The results are presented in Fig. 2, for $N = 32$. It is shown that for $a = 10$ cm, $L_{K0} > 20$ dB at frequency range $300 < f < 20000$ Hz. Hereas when $a = 0.5$ cm $L_{K0} > 20$ dB in the frequency range $2 < f < 20$ kHz.

Conclusion

A technique using pseudo-random sequences and a single microphone for ***in situ*** measurement of the acoustical properties of materials was validated experimentally by measuring the residual pressure-intensity index L_{K0}. This verification allows us to obtain the impedance using a single microphone without phase-mismatch errors as in the two microphone method. It was shown that this technique has frequency-range limitations determined by the distance between the two microphone positions.

References

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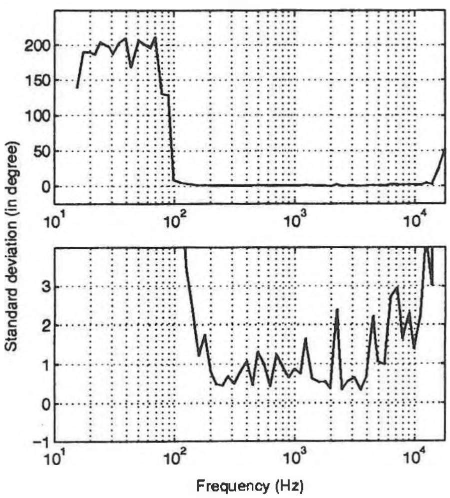

Fig.1 – Standard deviation $\sigma[\varphi]$ (in degree) estimated using 150 experimental samples $H_m(m = 1, 2, 3 \ldots 150)$.

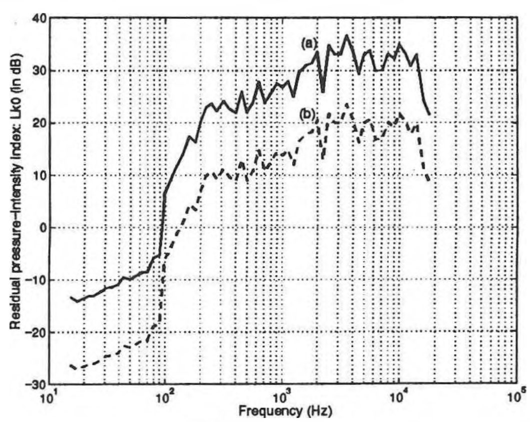

Fig.2 – Variation of L_{K_0} (in dB) with the frequency for two distances between microphones (a) $a = 10$ cm; (b) $a = 0.5$ cm.