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EXPERIMENTAL DEDUCTION OF EFFECTIVE SURFACE IMPEDANCE

C Nocke & V Mellert

Department of Physics, University of Oldenburg, D-26111 Oldenburg, Germany

1. INTRODUCTION

Complex surface impedance is important for applications in many fields, e.g. outdoor sound propagation, room acoustics or absorber design. This impedance is often determined indirectly by measuring the sound pressure at a given distance in front of a surface assuming plane wave propagation.
This contribution introduces and illustrates a new method for deduction of (effective or apparent) surface impedance from excess attenuation measurements at grazing incidence above arbitrary surfaces. The approach is based on classical theory of wave propagation along an impedance plane. The method has been applied for plane surfaces of different materials in [6]. Laboratory scale measurements of excess attenuation have been carried out and results for surface impedance show good agreement with impedance values from standing wave tube measurements.

2. METHOD OF IMPEDANCE DEDUCTION

Theory. The surface impedance is obtained by a numerical approximation procedure as described in [2, 3, 6]. The method uses theoretical values of the complex spherical wave reflection coefficient given by

$$Q^{\text{theory}}(\mu) = R + (1 - R)F(\sqrt{i}\mu) \text{ with } \mu := \sqrt{(\pi f r_2)/c}\,(\sin\theta + 1/Z).$$

Here μ is the modified numerical distance, f frequency, c velocity of sound, r_2 path length of specularly reflected wave, $R = (Z\sin\theta - 1)/(Z\sin\theta + 1)$ plane wave reflection coefficient for locally reacting materials, θ angle of incidence. The boundary loss F is given by

$$F(\mu) = 1 + i\sqrt{\pi}\mu e^{-\mu^2} \operatorname{erfc}(-i\mu)$$

(see [1]). This μ is closely related to the so-called numerical distance in [1, 8]. The advantage of this definition is that the real part $\operatorname{Re}(\mu)$ is restricted to positive

values (see [8]). μ depends on frequency, geometry and impedance. For any given frequency and geometry Z can be calculated from known μ.
The procedure is based on a comparison of a set of universal values of $Q^{theory}(\mu)$ and measured $Q^{measured}$. The function $|Q^{theory}(\mu) - Q^{measured}|$ is minimised and the corresponding μ taken to derive Z. This minimisation is repeated for each measured frequency. Finally the frequency dependent, complex surface impedance is found.
Fig. 1 shows magnitude of complex F plotted above complex plane representing μ. F can be interpreted as measure of the difference between plane and spherical wave reflection coefficient R and Q. This figure illustrates a possible problem of the impedance deduction routine when applied to large geometries, other impedance values or low frequencies. For one value of $|F(\mu)|$ there is more than one μ-value. This problem of non-uniqueness will be solved with a combination of this method with the method of cubic approximation of F for small $|\mu|$ [3].

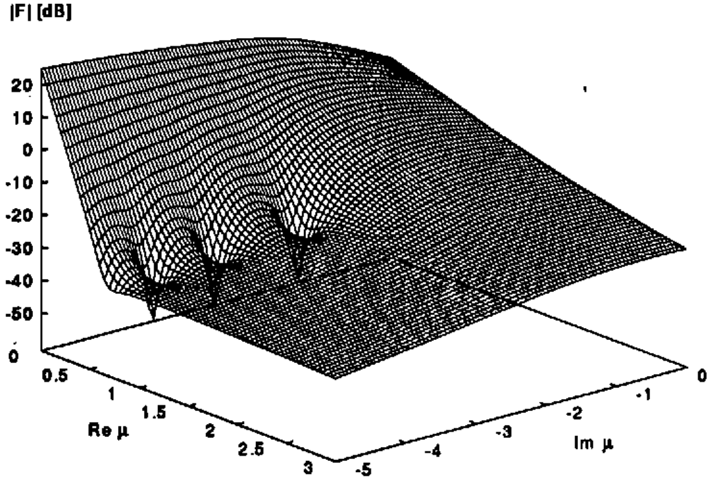


Figure 1: Magnitude of boundary loss factor F in dB re 1 above complex μ-plane. Same discretisation for real and imaginary part, e.g. $\Delta Re(\mu) = \Delta Im(\mu) = 0.04$.

Even for rough, inhomogeneous or wetted surfaces an apparent impedance can be obtained, which incorporates the spatially averaged structure of a corresponding plane surface. Possible optimisations of the minimisation routine itself are being discussed and tested [7].
Example. Fig. 2 shows simulated values of μ and results of two inversions with different step sizes for $Re(\mu)$ and $Im(\mu)$. Not only the magnification of a part of the complex plane shows that a decrease of step size results in an increase

of accuracy for μ. A limit for the decrease of step size is induced by the given measurement accuracy. From μ the impedance Z can easily be calculated.

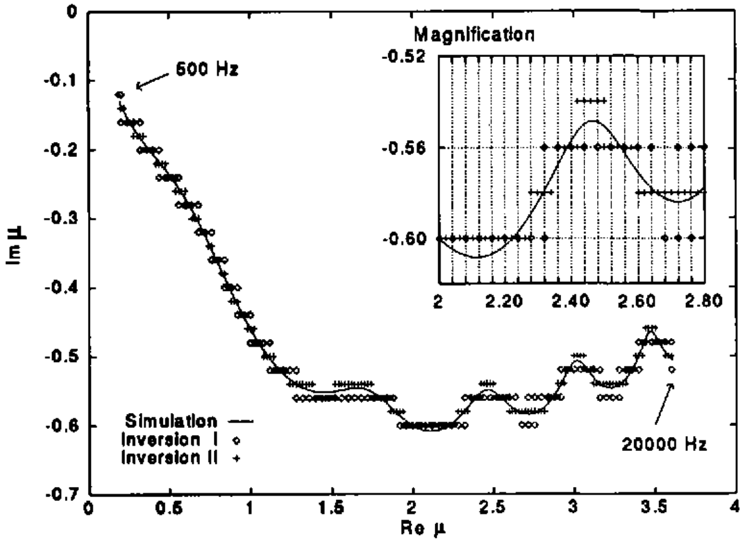


Figure 2: Results for two inversions with different discretisation for μ. Inversion I with $\Delta Re(\mu) = \Delta Im(\mu) = 0.04$ and II with $\Delta Re(\mu) = \Delta Im(\mu) = 0.02$. The simulated values for μ have been calculated using homogenous absorber model and certain layer thickness (see fig. 3). The geometry is similar to one used for the measurements with heights of source and receiver of $h_S = h_R = 2$ cm and a separation of $r = 0.7m$.

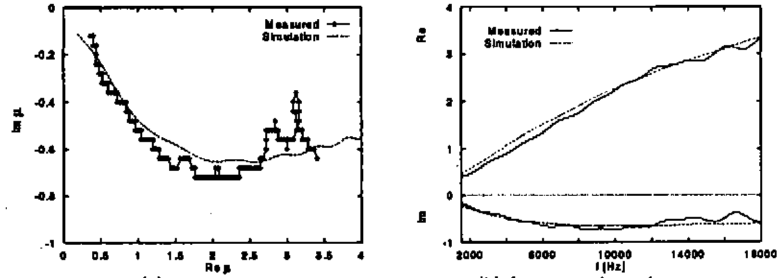
For any given impedance the geometry influences the values of μ. Large geometries result in an increase of real and imaginary part of μ.

3. IMPEDANCE RESULTS FROM MEASUREMENT

Measurements. Scaled measurements of complex excess attenuation are described in [2, 6]. Glass beads and sand are used as model substances for rigid porous absorbents. Using pulses of a spark source allows to use time-windowing to cancel unwanted reflections. The spark emits a broad band pulse with frequencies between 1.5 and 18 kHz

For the glass beads non-acoustically measured parameters (porosity Ω, flow resistivity σ, tortuosity α_∞) are known [4]. These values are used as input for model calculations.

Impedance. To deduce impedance from measured excess attenuation the required range for μ can be estimated using a large area of the complex plane with a coarse grid first. After this estimation the range can be reduced to search with a finer grid size. The following inversions are obtained using a grid size of $\Delta\text{Re}(\mu) = \Delta\text{Im}(\mu) = 0.04$ and an area of $0.0 \leqslant \text{Re}(\mu) \leqslant 4.0$ and $-1.0 \leqslant \text{Im}(\mu) \leqslant 0.0$ for the complex plane.



(a) μ-plane (b) frequency dependence

Figure 3: Measured and calculated values for complex μ. The measurement has been carried out with source and receiver heights $h_S = h_R = 2$ cm and a horizontal separation of $r = 0.7$ m above a plane surface of quartz sand. For the simulation this geometry and the measured layer thickness of $d = 4$ cm was used. Values for wave number and characteristic impedance of the material have been obtained using homogeneous absorber model [5] with parameters porosity $\Omega = 0.3$, flow resistivity $\sigma = 250$ k N s m^{-4} and tortuosity $\alpha_\infty = 1.2$. (a) μ plotted in complex plane. The area shown corresponds to the one used by deduction method. (b) Same data but Re(μ) and Im(μ) plotted against frequency.

4. CONCLUSIONS

A new method of impedance deduction has been introduced. Because classical propagation theory is used certain criteria have to be fulfilled, e.g. the surface has to be locally reacting. If rough or inhomogeneous surfaces are investigated an apparent surface impedance is obtained which is equal to an assumed plane and homogenous surface. For low frequencies the routine could be enhanced by the use of cubic approximation for F. This will solve the problem of non-uniqueness and remains for further investigations.

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