BRIEF REVIEW ON IN-SITU MEASUREMENT TECHNIQUES OF IMPEDANCE OR ABSORPTION

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ABSTRACT

The paper will present a review on the development of in-situ measurement techniques of sound absorption or the acoustic surface impedance. One of the earliest set-ups to measure the absorption of a material in-situ has been proposed in 1933. In 1934 a method applying short tones to separate the reflected signal from the incident signal in front of a reflecting surface has been tested. Many more methods have been described over the years. Applications of modern MLS-based measurement equipment to deduce the absorption coefficient in-situ were brought up in the early 1990s. A MLS-based procedure similar to an early method has been introduced as subtraction technique and is the basis of draft ENV 1793, part 5. Most of these methods are based on the assumption of plane wave propagation. Other methods relying on spherical wave propagation approach are being reviewed.

INTRODUCTION

Ever since different approaches to measure the acoustic absorption or acoustic surface impedance of a material have been used. According to certain requeirements or applications the quantity to measure has been the impedance or absorption coefficient. As MORSE et al. [1] pointed out the complex quantity impedance is rather used in a scientific context whereas the real quantity absorption is found in practical applications. The impedance might be used to calculate some of the absorption coefficients quoted in the following.

Different measurement concepts lead to many different procedures. Aiming towards various applications each procedure has advantages and disadvantages. The following review of different procedures will be far from complete but has been chosen according with respect to the applicability to measure on spot or in-situ.

At least two procedures for the measurement of absorption are very well know for a long time and are described as international standards. These two will be briefly summarized before some historical approaches in free-field conditions towards the measurement of the impedance or absorption will be quoted. To start the following definitions will be recalled.

DEFINITIONS: IMPEDANCES AND SOUND ABSORPTION COEFFICIENTS

Acoustic Impedance According to DIN 1320 [2] the specific acoustic impedance of a material is defined as the quotient of "the complex amplitudes of sound pressure and particle velocity". One might wonder how the division by an vector (particle velocity) might be mathematically be defined. Some authors [3][4] suggest to work with the specific acoustic admittance instead; then there is no mathematical problem. Relating this specific acoustic impedance to a plane wave will give the definition of the characteristic field impedance Z_0. It is well know that

$$Z_0 = \rho_0 \, c_0$$

with the density ρ_0 of the fluid and the speed of sound c_0. For a spherical wave the characteristic impedance is given by the following expression

$$Z_{o,spherical} = \rho_0 c_0 \frac{ikr}{1+ikr}$$

with the wave number k and the distance r between source and receiver. Only for large values of r compared to the wave length $\lambda = 2\,\pi\,/\,k$ (or $kr >> 1$) this characteristic impedance of a spherical wave will converge to the real and constant value of Z_0. For small values of kr this quantity is complex.

The acoustic behaviour of a boundary between two materials can be described by the change of the characteristic impedances. For porous sound absorbers various models to describe the acoustic properties with wave number and characteristic impedance have been developed, see [4][5][6][7][8]. This leads to the definition of the *normal specific acoustic impedance*, see [3]. This quantity can be theoretically calculated for one or several layers of sound absorbing material [4][5][8]. From a practical point of view this quantity, the *normal specific acoustic impedance* of a surface, is sufficient to describe the acoustic behaviour of a surface. Most of the impedance measurement procedures presented in the following will aim at the value of this quantity that will be referred to as *impedance Z* in the following.

Sound absorption coefficients Since an early discussion on "the sound absorption problem" in 1939 [9] many different definitions of sound absorption coefficients have been introduced. Maybe this lead to a remark by MECHEL about too many sound absorption coefficients (see [4], there p. 275). Quite generally the sound absorption coefficient α can be defined by

$$\alpha = \frac{absorbed\ energy}{incident\ energy}.$$

Plane wave absorption coefficient For a plane wave at normal incidence the formula

$$\alpha_0 = 1 - \left|R_p(Z)\right|^2$$

can easily be deduced, with the plane wave reflection factor $R_p(Z) = (Z - 1) / (Z + 1)$, Z as defined above[4]. For oblique incidence at angle θ this absorption coefficient can be calculated according to

$$\alpha_\theta = 1 - \left|R_p(Z,\theta)\right|^2$$

with $R_p(Z) = (Z \sin\theta - 1) / (Z \sin\theta + 1)$ [4]. For small angles of incidence, e.g. near grazing incidence this description with plane waves is not valid [10].

Statistical absorption coefficient For statistical incidence of plane waves the well absorption coefficient α_{st} can be calculated according to

$$\alpha_{st} = \int_0^{\pi/2} \alpha(\theta) \sin 2\theta \, d\theta \, .$$

For locally reacting absorbers this integral can be solved an corresponding formulae might be found in [4][12][13].

Sabine absorption coefficient In room acoustics the so-called Sabine absorption coefficient is used very often describing the average absorption in a room. Some requirements have to be fulfilled to apply the formula of Sabine [11].

Other absorption coefficients Apart from these absorption coefficients other definitions can be found in literature. EYRING [14], MILLINGTON [15], MORSE ET AL. [1], NOBILE [16], Thomasson [17] and many others have defined absorption coefficients.

MEASUREMENT TECHNIQUES

Standard procedures The traditional method to determine the sound absorption of a material is the standing wave tube. Details of different measurement procedures are described in internationals standards [12][18]. More details may be found in [19]. Another procedure to measure the sound absorption is based on Sabine`s reverberation formula and has been standardized in [20]. This indirect method may result in values for the sound absorption larger than 1. Various inter-laboratory comparisons have been carried out for this method [9][21][22][23].

Geometrical or in-situ procedures Apart from these two traditional procedures mentioned above various free-field methods for the absorption coefficient and/or the impedance can be found in literature. Common to many of these approaches is the assumption of plane wave propagation or sound rays. Following this they might be named as geometrical procedures, see § 24 in [11].

One of the first suggestions for the measurement of the acoustical properties of a material in free-field conditions has been given by SPANDÖCK [24] in 1934. Short pure tones with 800 Hz and 4000 Hz and a duration of 1/200 s have been applied to record the direct and reflected signal before and after reflection at a surface. The result is the sound absorption of the surface. A similar technique has been described one year earlier by CREMER [25].

An experimental set-up from ENRSTHAUSEN/VON WITTERN for outdoor applications is depicted in Fig. 1, taken from [26].

Abb. 4. Meßanordnung im Freien

Fig. 1: Experimental set-up for outdoor measurements from[26]

INGARD/BOLT [27] described in 1951 a procedure using a standing wave in front of the sample under investigation. In analogy to the standing wave tube the amplitude and phase of the sound pressure has been measured. A comparison between a acoustically hard surface and the sample yields the complex reflection factor R_p. These authors clearly indicate a low frequency limit of this procedure as the assumption of plane waves is not valid at the short distances used for the measurement. For small angles of incidence the sphericity of the wave should also be taken into consideration [28]. ANDO [29] describes a “interference pattern method” similar to this approach.

YUZAWA [30] develeoped a subtraction technique using two microphones with exactly the same distance to the source. One microphone is positioned close the surface, the other further away. Subtraction of both signals delivers the magnitude of the reflection factor R_p.

DAVIES/MULHOLLAND [31] describe a method to determine the impedance from measurements of the complex reflection factor. A comparison of two measurements, one in free-field and the second close to the surface, is carried out. The signal used is a short pulse of 3 ms duration allowing the separation of direct, reflected and other time signal components. A similar approach has been applied by KINTSL [32]. Instead of a loudspeaker a spark source has been applied. The required size of the sample is estimated by a formula also used later on [33][34].

A method to measure the impedance also using two microphones is presented by ALLARD [35][36]. Both microphones are positioned close to the surface. This method is very similar to a procedure only theoretically proposed by KURZE [4] [37]. The measured quantity is the transfer function between both microphones. Form this the impedance is deduced using a full wave description of the sound field in front of an impedance plane as given by NOBILE/HAYEK [38].

WILMS/HEINZ [39] demonstrate the application of maximum length sequences (MLS-) based measuring techniques to obtain the reflection factor in-situ. The basis of this procedure is the recording of impulse responses between a speaker and microphone at normal incidence of sound. The microphone is positioned half the distance between sample surface and speaker. Applying time windowing to the impulse responses extracts the direct and reflected sound. This method is very similar to SPANDÖCKS [24] pulse method. Measured results are shown for a range of 100 Hz to 15000 Hz. No hints are given about sample size and validity of the results at low frequencies.

A very similar method also applying MLS-technique is presented by GARAI [33]. Especially restrictions of the frequency range and the size of the sample are investigated. At low frequencies GARAI shows that there are restrictions of the method. These restrictions are explained because the assumption of plane wave propagation is not valid at low frequencies.

MOMMERTZ [40] finally refines the last two methods and introduces a subtraction technique to deduce the complex reflection factor R_p. Again MLS measuring technique is applied avoiding any special requirements for the measurement environment. Instead of using a fixed positioning of source and receiver as proposed by YUZAWA [30] also time windowing is applied to the recorded impulse responses. Two measurements have to be carried out, one serves as reference and is subtracted from the reflection measurement. For normal incidence of sound a frequency range between 250 Hz and 8000 Hz is employed. For oblique incidence of sound no range of validity is proposed. For small angles of incidence results for the plane wave reflection factor R_p greater than 1 in magnitude are shown. Especially at low frequencies MOMMERTZ proposes that these results should be explained by spherical wave reflection. Several publications related to the development of EN 1793 – 5 [41] refer to MOMMERTZ` subtraction technique, see [42][47].

An improvement of ALLARD`s [35][36] two microphone technique also using MLS technique is presented by LI/HODGSON [44]. Here results with reflections factors R_p above 1 in magnitude are presented below 500 Hz. No further discussion of this result is included.

The application of the spherical wave reflection factor to deduce the impedance is described in [45][46]. Measurements of the so-called excess attenuation function at small angles of

incidence are carried out and the impedance is obtained by a numerical inversion procedure. Different numerical optimizations are presented in [47] [48]. In [49] an experimental setup using MLS measurement technique is applied to measure in rooms. Agreement between different procedures has been shown. As these methods rely on spherical wave reflection measurements a frequency range between 80 Hz and 4000 Hz is possible.
For the measurement of non-locally reacting materials LI ET AL [50] show a theoretical model to calculate the effective impedance of the surface.

SUMMARY

Most of the in-situ measurements quoted above compare results of the in-situ mehod with results from tube measurements. Perfect matching is not achieved by any method. Some of the authors give a lower frequency limit of the method or just show results for certain frequency range without further expliations. Hardly any results below 250 Hz are presented. Only above 500 Hz rough agreement with results from the tube is achieved. Only methods based on spherical wave propagation give reliable results below 500 Hz.
This compilation hopefully gives a small survey on different aspects of in-situ methods. Finally, the authors would like to emphasize that this survey might not complete and welcome any hints on similar approaches.

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