IMPLEMENTATION AND EVALUATION OF A MEASUREMENT PROCEDURE FOR THE ACOUSTICAL TRANSFER IMPEDANCE OF EAR SIMULATORS

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ABSTRACT

The testing of hearing ability is based on mean threshold sound pressure levels which are determined by means of psychoacoustic measurements under reference conditions with young otologically normal test subjects. The dissemination of these levels uses the concept of Reference Equivalent Threshold Sound Pressure Levels (RETSPLs). They are specified as the output sound pressure level produced by a specific audiometric earphone which is driven with exactly the same excitation signal as needed to reach the mean hearing threshold of the reference test subjects on an ear simulator, e.g. according to IEC 60318-1. A periodic test of the ear simulators is required for a traceable calibration of audiometers. The main test criterion is the conformance with the specification of the ear simulators’ acoustical transfer impedance given in the IEC standard. The recent version of IEC 60318-1, however, neither specifies tolerances nor gives a measurement procedure for the acoustical transfer impedance. Currently, the standard is under revision, aiming at the inclusion of those specifications. This paper reports on the implementation and evaluation of a direct measurement procedure for the acoustical transfer impedance of ear simulators in the PTB.

INTRODUCTION

The measurement of human hearing ability carries great weight in the field of hearing conservation. Furthermore, audiometry represents an essential diagnostic tool for otorhinolaryngologists and it forms the basis for a successful hearing aid fitting. The PTB (Physikalisch-Technische Bundesanstalt) provides reference data for the human hearing which are determined by means of subjective measurements with groups of reference test subjects. The specification of these data and their dissemination requires a traced-back measurement chain from the reference subjects to the audiometric equipment in practical use.

Important parts of this measurement chain are ear simulators and acoustic couplers. They are used both for the specification of the reference values in the laboratory and for the audiometer calibration in the field.

Currently, the periodic test of ear simulators is performed by a comparison measurement of the device under test with reference devices. This situation is due to the fact that, in the present state of the relevant standards, there is no information available which is suitable for a comprehensive acoustic test. Within the revision of these standards a direct measurement procedure for the acoustical transfer impedance of ear simulators for supra-aural and circumaural earphones had been proposed and the task was derived to set up reference values with tolerances for testing ear simulators.

REFERENCE THRESHOLDS IN AUDIOMETRY

Reference thresholds for audiometry are determined with at least 25 young otologically normal test subjects [1] by means of threshold measurements with a particular audiometric headphone. Their dissemination follows the concept of Reference Equivalent Threshold Sound Pressure Levels (RETSPLs). They are specified as the output sound pressure level produced by a particular audiometric earphone which is driven with exactly the same excitation signal as...
needed to reach the mean hearing threshold of the reference test subjects on a specified ear simulator. For audiometric headphones the ear simulator currently conforms to the International Standard IEC 60318-1:1998 [2].

TESTING OF EAR SIMULATORS

German regulations require a periodic maintenance and calibration of the audiometric equipment performed by registered maintenance service providers [3,4]. This gives rise to the need for a regular test of the measurement equipment used by these providers, including the ear simulators.

Current state of testing

The ear simulator for the calibration of supra-aural headphones as described in IEC 60318-1 basically consists of three coupled cavities. The specification of the characteristics of the device refers to the mechanical design, i.e. the dimensions of the cavities and to the description of the impedance of the coupling elements. IEC 60318-2 [5] describes adapters which allow, when used with the ear simulator, measurements of circumaural headphones, including the extended high frequency range up to 16 kHz.

Since the specifications of IEC 60318-1:1998 do not allow a direct measurement of the ear simulator performance, the following comparison procedure is applied at present.

A supra-aural audiometric earphone type Beyer DT48 is coupled to the ear simulator with the cushion removed and by means of a special adaptor ring, see Figure 1.

![Figure 1. - Setup for the comparison measurement of ear simulators](image)

Using this configuration, the output voltage of the microphone preamplifier as a function of the earphone excitation voltage is measured and recorded for the reference ear simulator. Because of the mechanically precise coupling between earphone and ear simulator and due to the stability of all devices involved, this measurement can be performed with an uncertainty of 0.1 dB within the frequency range from 125 Hz to 8 kHz. Then, retaining everything else, including the microphone, the reference ear simulator is replaced by the ear simulator under test and the difference of the transfer function to that of the reference ear simulator is measured. Resulting from experience and due to the requirements of audiology, a value of ±0.35 dB was fixed as a tolerance for this difference. The central part and, at the same time, the main problem of this test procedure is the predefinition, the check and the justification of the reference ear simulator which has to be done by means of mechanical and visual tests and by a continuously conducted comparison against a 'population' of ear simulators that have passed the test.
Revision of IEC 318-1

In the Working Group 21 "Head and ear simulators" of the IEC Technical Committee 29 "Electroacoustics" the standard IEC 60318-1 is under revision [6]. A new edition will define an ear simulator for the calibration of supra-aural and circumaural headphones and so replace the recent parts 1 and 2 of the series. In addition to specifications of the dimensions of the cavities and coupling elements the acoustical transfer impedance for the coupling of an earphone put on the coupler to the built-in microphone will be specified as a main characteristic. If this transfer impedance is specified with tolerances, and maximum permitted uncertainties for the test of conformance to the requirements are given, it will be possible to test ear simulators directly by measuring their acoustical transfer impedance. A measurement principle will be proposed in an informative annex. Therefore, the task was set to determine the acoustical transfer impedance reference values and their tolerances, as well as to implement and to test a measurement procedure following the principle outlined in the annex.

MEASUREMENT PROCEDURE FOR THE ACOUSTICAL TRANSFER IMPEDANCE

Principle

The measurement procedure has been derived from the pressure reciprocity calibration of microphones according to IEC 61094-2 [7]. Two microphones $M_1$ and $M_2$ are acoustically coupled by means of a cylindrical coupler with an acoustical transfer impedance $Z_a$ which can be calculated from the dimensions of the coupler and the properties of the enclosed gas. Driving one of the microphones with an electrical current $i$ and measuring the electrical output voltage $U$ of the other microphone, one can determine the product of the sensitivities $M_1 M_2$, see Eq. 1:

$$M_1 M_2 = \frac{1}{Z_a} \frac{U}{i} \quad \text{(Eq. 1)}$$

If the sensitivities $M_1$ and $M_2$ are known, it is possible to calculate the acoustical transfer impedance $Z_a$ of the ear simulator, acting as acoustical coupling of the microphones from the measured values of $U$ and $i$, see Figure 2.

![Block diagram for the determination of the acoustical transfer impedance](from [6])

1. Signal generator
2. Microphone power supply
3. Transmitter microphone
4. Adapter
5. Ear simulator
6. Receiver microphone in ear simulator
7. Microphone preamplifier and power supply
Measuring the current \( i \) as the voltage drop across a calibrated condenser \( C \) and determining the complex voltage ratio \( U_1/U_2 \), e.g. by means of a dual channel analyzer, the transfer impedance \( Z_a \) will be

\[
Z_a = \frac{1}{M_1 \cdot M_2} \cdot \frac{U_1}{U_2} \cdot \frac{1}{j\omega C} \quad (\text{Eq. 2})
\]

where \( \omega \) is the angular frequency.

**Realization of a set-up in the PTB**

The acoustical part of the set-up was realized by using an adaptor Brüel&Kjaer DB 3977 which aligns a ½-inch working standard (WS2P) transmitter microphone B&K 4134 with its protection grid removed and fitted with an ½-inch to 1-inch adapter B&K DB 0225 mounted on a transmitter unit B&K ZE 0796 (containing a calibrated measurement capacitor with 4,741 nF capacitance) to the ear simulator. The transmitter unit was connected to a modified microphone front-end type Norsonic 336 which provided power to the transmitter unit and the polarization voltage for the transmitter microphone. The adapter B&K DB 3977 was fixed to the artificial ear to be measured by means of three rubber strings. Figure 3 shows an overview of the set-up and details of the transmitter arrangement.

Inside the ear simulator a WS2P microphone with its protection grid mounted was acting as receiver microphone. A microphone pre-amplifier type B&K 2639 and a microphone power supply B&K 2807 were used for the conditioning of the receiver microphone output signal.

The voltage ratio \( U_1/U_2 \) was measured by means of a dual-channel frequency response analyzer type Solartron 1255 with an integration time of 10 seconds in the frequency range from 63 Hz to 10 kHz. The driving voltage was chosen to be 3 V r.m.s. for the WS2P transmitter microphone in order to achieve a sufficiently high sound pressure level in the cavity.

For one measurement of the acoustical transfer impedance the transmitter configuration was mounted three times, and the result was calculated as the average of the single data.
Both transmitter and receiver microphones were pressure reciprocity calibrated in order to determine their open-circuit pressure sensitivities. The attenuation of the B&K 2639 pre-amplifier was determined separately and a correction was introduced to Eq. 2 to take the attenuation into account.

The acoustical transfer impedance was calculated according to Eq. 2 and then expressed on a logarithmic scale in dB re 1 Pa s m\(^{-3}\).

**Results**

Measurements with the procedure and the set-up described above were performed on three ear simulators. The average transfer impedance level, the standard deviation for repeated measurements on one and the same device, and the standard deviation over different devices are given together with the measurement uncertainty. The data are valid for a static pressure of 99.8 kPa and a temperature of 23 °C.

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Acoustical transfer impedance level (dB re 1 Pa s m(^{-3}))</th>
<th>Standard deviation for repeated measurements (dB re 1 Pa s m(^{-3}))</th>
<th>Standard deviation over different ear simulators (dB re 1 Pa s m(^{-3}))</th>
<th>Measurement uncertainty (k = 2) (dB re 1 Pa s m(^{-3}))</th>
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Table I.- Acoustical transfer impedance level, measured as the average of three ear simulators. Data valid for static pressure 99.8 kPa and temperature 23 °C

The measurement uncertainty was determined using a simple linear model of the measurement procedure and according to the ISO/IEC GUIDE EXPRES: 1995, *Guide to the expression of uncertainty in measurement* [8]. The uncertainty contributions considered were:

- Determined or reported as standard uncertainties
  - repeatability
  - calibration uncertainties for receiver and transmitter microphone
  - calibration uncertainties for the measurement capacitor
Estimated as semi-ranges

- uncertainty of the measurement of the voltage ratio
- influence of cross-talk
- rounding error
- influence of differing environmental conditions
- uncertainty of preamplifier gain

The uncertainty did not exceed 0.3 dB over the whole frequency range.

CONCLUSIONS

A practical implementation of the measurement procedure for the acoustical transfer impedance of ear simulators proposed in the new draft of the standard IEC 60318-1 [6] was established at the PTB. Measurements performed by means of this set-up on a number of ear simulators revealed a typical repeatability (expressed as standard deviation) on a given device of less than 0.1 dB. The maximum spread of the measured samples was around 0.4 dB (standard deviation). Taking into account the target values of the tolerance in magnitude of around 1 dB and the maximum permitted uncertainty of 0.5 dB, the test procedure seems to be suitable for a test of ear simulators according to the new standard.

References:


