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Determination of sound immissions from sources placed close to the ears - such as head- and earphones

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Abstract

When determining sound immissions from head- or earphones used to reproduce music or speech the problem arises, that procedures usually used for the determination of sound immissions cannot be applied: The sound pressure levels measured at the position of the exposed person but with the person absent do not adequately represent the sound exposure. Therefore miniature or probe microphones inserted in the ears of humans (Microphone in Real Ears, MIRE-technique) or manikins equipped with ear simulators including microphones (manikin-technique) are used. But sound pressure levels measured in the ear canal of exposed humans or exposed manikins do not bring about the assessment of the exposure by means of well established criteria. This assessment is enabled by the conversion of the measurement result into a corresponding free-field or diffuse-field level. This level is virtual - but only such a level can be compared to levels given by regulations. For comparable results obtained by measurement and conversion working group 6 of ISO Technical Committee 43 "Acoustics" elaborated drafts of standards for "Determination of sound immission from sound sources placed close to the ear".

1. Introduction

The sound field generated by a headphone which gives rise for the perception of this sound by the wearer is affected by his pinnae and ear canal. Therefor a measurement using a microphone without a human or simulated pinnae and ear canal will not adequately represent the sound exposure.

Figure 1 shows in the upper line the signal observed by a microphone in a free field as a result of the interference of 5 sinusoidal signals in octave distances and of the same amplitude. The replacement of the microphone by a Microphone in a Real Ear (e.g. a test subject with the miniature microphone in its ear canal) results in the situation shown in the lower line: The signal presented on the left is observed by the miniature microphone - without changing the adjustments and positions of the sound generators. The shape of the signal is changed and its analyze results in the original sinusoidal signals with the original frequencies but with a change of amplitudes which depends on the frequency as shown on the right.

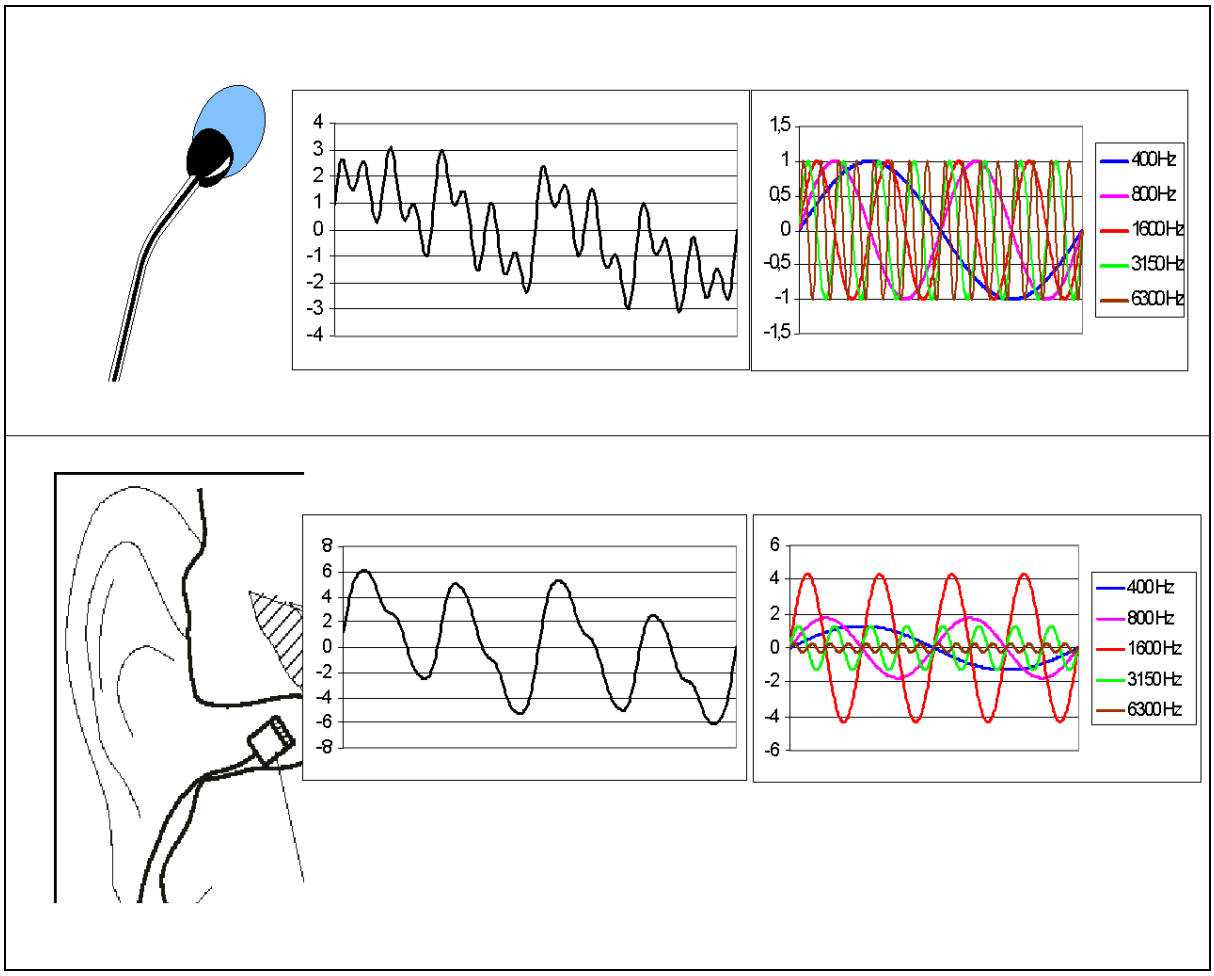

Figure 1: The amplitudes of sound pressures are shown.
Upper line: Free field microphone exposed to five sinusoidal signals in octave distances showing the same amplitude (s. right diagram). The result is shown in the left diagram.
Lower line: Microphone in a Real Ear exposed to the same free field signal. The signal observed by the microphone is shown in the left diagram. The analyze of this signal results in the signals shown in the right diagram.

Sound pressure levels measured at individual human's ear drum would constitute a better background for estimation of the individual risk of hearing impairment, because individual characteristics e.g. shape of pinnae and ear canal are considered. But to assess the risk of hearing impairment by means of well established criteria (s. ISO 1999, [1]) no individual characteristics may be taken into account.

The following determination of sound exposure strives for results representing the risk of hearing impairment by means of well established criteria. The sound exposure shall be given in terms of sound pressure levels of free or diffuse sound fields which show risks of hearing impairment equivalent to those risks of the sound field in the ear canal. Effects from individual's characteristics shall be excluded.

2. Determination of sound exposure

The procedures described here (and in ISO 11904, [2,3]) may be applied to equipment tests, determination of noise exposure at the workplace or other exposure from sources close to the

ears such as head- and earphones used to reproduce music or speech whether at the workplace or during leisure, nailguns used close to the head, and combined exposure from a close-to-ear sound source and an external sound field.

The test subject, equipped with the miniature microphone in its ear canal, is exposed to the sound source(s) in question. The sound pressure level is measured in one-third-octave bands, $L_{ear,exp,f}$. Each of the one-third-octave band levels $L_{ear,exp,f}$ is adjusted with the diffuse-field frequency response $\Delta L_{DF,ear,f}$.
The diffuse-field frequency response $\Delta L_{DF,ear,f}$ is determined or - if suitable and preferred - taken from tables. ISO/DIS 11904-1:2000 [2] shows a list of $\Delta L_{DF,ear,f}$–values at three different ear canal measurement positions: i) at the eardrum, ii) at the open entrance, and iii) at the blocked entrance of the ear canal. $\Delta L_{DF,ear,f}$ is the difference, as a function of one-third-octave frequency bands *f*, between 1) the sound pressure level $L_{DF,ear,f}$ at the ear canal measurement position with the subject exposed to a diffuse reference sound field, and 2) the sound pressure level $L_{ref,DF,f}$ of the same reference sound field with the subject absent (ref: measured with a reference microphone). It is given in one-third-octave bands.
By the adjustment with the diffuse-field frequency response $\Delta L_{DF,ear,f}$ the corresponding diffuse field related one-third-octave band sound pressure levels are obtained. Further adjustment using the A-weighting constants and subsequent combination of the one-third-octave band levels lead to the final result: The diffuse-field related equivalent continuous A-weighted sound pressure level, $L_{DF,Aeq}$. That means that $L_{DF,Aeq}$ is determined as follows:

$$L_{DF,Aeq} = 10 \lg \left\{ \sum_f 10^{(L_{ear,\exp,f} - \Delta L_{DF,ear,f} + A_f)/10} \right\} \quad dB \tag{1}$$

whereas $\Delta L_{DF,ear,f}$ is determined by:

$$\Delta L_{DF,ear,f} = L_{ear,DF,f} - L_{ref,DF,f} \tag{2}$$

The determination of the free-field related equivalent continuous A-weighted sound pressure level, $L_{FF,Aeq}$ is also possible. It is analogous to the determination of $L_{DF,Aeq}$ using 'FF' instead of 'DF' and correspondingly a free reference field (ref,FF) - instead of a diffuse reference field - but then combined with a free-field frequency response $\Delta L_{FF,ear,f}$. $\Delta L_{FF,ear,f}$ is the difference, as a function of one-third-octave frequency bands *f*, between 1) the sound pressure level $L_{FF,ear.f}$ at the ear canal measurement position with the subject exposed to a frontally incident plane sound wave, and 2) the sound pressure level $L_{ref,FF,f}$ of the same sound field with the subject absent. The tabled $\Delta L_{FF,ear,f}$ –values are listed in ISO/DIS 11904-1:2000 [2] for the three ear canal measurement positions: i) at the eardrum, ii) at the open entrance, and iii) at the blocked entrance of the ear canal.

Another possibility is the determination of $L_{FF,Aeq}$ or $L_{DF,Aeq}$ using a manikin instead of a test subject. The manikin shall be equipped with ear simulators including microphones. Replace 'test subject' by 'manikin' in the description of the determination of sound exposure above. But the microphones of the ear simulator are not miniature microphones and the positions of the microphones are defined by the design of the manikin and ear simulator. Furthermore 'ear' has to be replaced by 'M' within the symbols.

3. Instrumentation

The sound pressure in the ear canal of a test subject shall be measured by a microphone, which is either a miniature microphone placed in the open ear canal as shown in Figure 2 a), or a probe microphone consisting of a microphone placed outside the ear and equipped with a probe tube placed in the ear canal, s. Figure 2 b) or a miniature microphone placed at the entrance of the blocked ear canal presented in Figure 2 c).
The microphones in the ear canals shall be used in such a manner as to avoid any risk of damaging the ear. In cases where the sound exposure exceeds limit values laid down by regulations the blocked ear canal technique providing sufficient sound attenuation for the test subject shall be used.
To confirm the medically safe use on subjects a qualified person should assess the ear canal measurement microphones and their mounting. This person should also specify the hygiene requirements to ensure safe use.

In case a manikin is used it shall satisfy the requirements of 3.4 and 4 of IEC 60959:1990 [4].

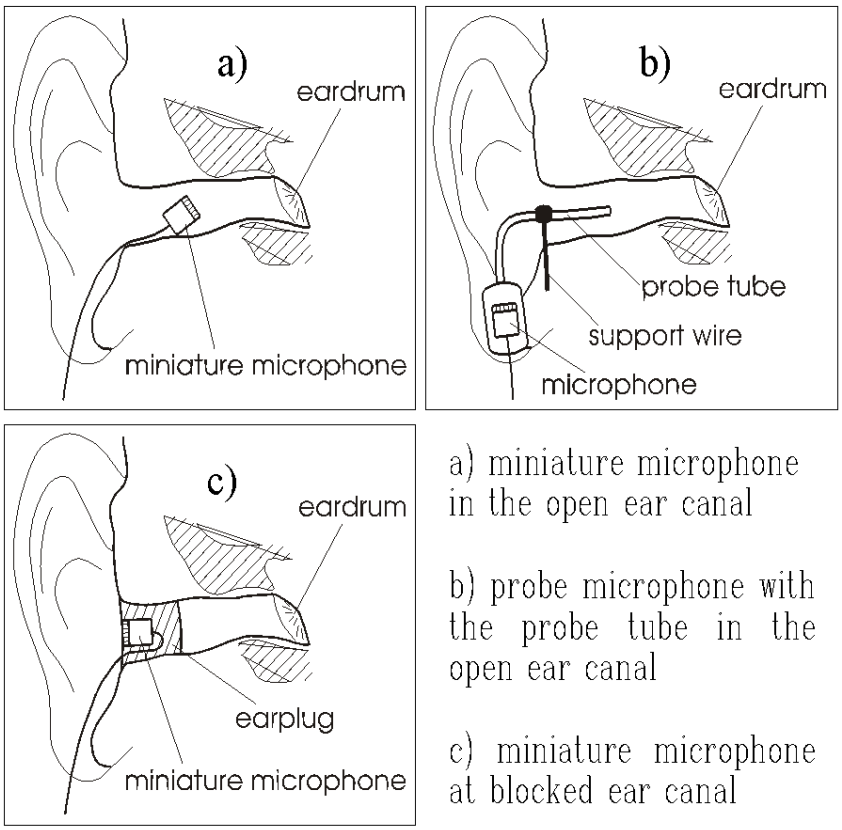

Figure 2: MIRE-technique measurement instrumentation as shown in ISO/DIS 11904-1 [2].

4. Selection of measurement procedure

MIRE-technique and Manikin-technique strive for the same result, the mean value for a population of the diffuse-field or the free-field related level.
Whether MIRE- or manikin-technique is applicable depends on different aspects.

4.1 Fit of the head- or earphone to the measurement arrangement

When using MIRE-technique for the measurement of sound from earphones of insert and stethoscopic types, practical problems may occur with positioning of the miniature or probe microphone.

The manikin-technique may only be used in case the head- or earphone can be coupled to the pinnae simulator and the ear canal of a manikin in a way similar to the way it is coupled to the human ear. Where head- or earphones or other objects touch the pinnae, a possible deviation in stiffness or shape of the artificial pinnae from the human pinnae has a significant impact on the result and may even make the results invalid. For determination of the representative sound exposure pinnae with a more appropriate stiffness or MIRE-technique - if applicable - may be used.

The measurement procedures described above may be applicable for the determination of sound exposure at the workplace. But in some cases the exposed person can not be replaced by a manikin because the person has to operate equipment.

4.2 Accuracy and availability of measurement equipment

MIRE-technique: The number of test subjects affects the accuracy.

In case tabled values for the diffuse- or free-field frequency response $\Delta L_{DF,ear,f}$ or $\Delta L_{FF,ear,f}$ are used main contributions affecting accuracy come from the calibration of the ear canal microphones and the positioning of the miniature or probe microphones in the ear canals. A standardized calibration method for miniature microphones is not available up to now.

Other ear canal measurement positions than listed in ISO/DIS 11904-1:2000 [2] requires the use of individual values for the diffuse- or free-field frequency response $\Delta L_{DF,ear,f}$ or $\Delta L_{FF,ear,f}$.

By using individual values for $\Delta L_{DF,ear,f}$ or $\Delta L_{FF,ear,f}$ the final accuracy is mainly affected by the quality of the reference field and the stability of the frequency response as well as the position of the ear canal microphone.

For earphones and headphones which occupy the majority of the volume immediately outside the ear canal entrance, the measurement with a blocked ear canal may result in a reduced accuracy if the sound under test has significant narrow band components above approximately 3 kHz.

Manikin-technique: The main issue concerning the achievable accuracy is the similarity of manikins to humans. The use of individual values for the diffuse- or free-field frequency response $\Delta L_{DF,ear,f}$ or $\Delta L_{FF,ear,f}$ requires a sufficient quality of the reference sound field.

Examples of uncertainty analysis are given in ISO/DIS 11904-1:2000 [2] and ISO/CD 11904-2:2000 [3] which are based on the " Guide to the expression of uncertainty in measurement (GUM)" [5].

5. Remarks

The individual diffuse- or free-field frequency response $\Delta L_{DF,ear,f}$ or $\Delta L_{FF,ear,f}$ reflects individual characteristics of the ear canal, pinnae, head, and torso and therefor it allows any measurement position in the ear canal and reduces uncertainties e.g. those coming from positioning. But for the determination of an exposure value for sound generated by a head- or earphone representing the risk of hearing impairment for a population of human adults a procedure using averaged (tabled) data of pinnae, ear canal(, head, and torso) may be expected to give more reliable results - by the use of individual frequency responses individual characteristics may be introduced which do not affect the ear canal sound field but may affect the result by this introduction. In general the corresponding effects are considered

to be small but may also affect the selection of individual or tabled frequency responses. Effects of individual characteristics should be reflected within the conversion to the final diffuse- or free-field related sound exposure level only for a combined sound exposure where the sound of an external field dominates the total sound exposure.

In case the relevant conditions of IEC 268-7:1996 [7] are not fulfilled by the free reference sound field, a quasi-free sound field as described in 5.3 of ISO 8253-2:1993 [8] may be used accepting a reduced accuracy.

For equipment tests, where reference fields of sufficient quality are available, the use of individual frequency responses might be preferred as shown by the decision of the CEN Technical Committee 159 'Hearing protection'. For the test of level-dependent ear muffs it selected the individual frequency response to be taken for the conversion from ear canal sound pressure levels to diffuse-field related sound pressure levels [6]. By that the position of the ear canal microphone as well as its calibration is not critical.

The operating conditions as well as the test signals for equipment tests are not specified by ISO 11904 [2,3]. They may be taken from other standards.
See ISO 11904 [2,3] for more detailed specifications of the required equipment and additional information.

Conclusions

For the measurement of sound sources placed close to the ear ISO 11904 [2,3] specifies several measurement procedures which aim at the same result: The mean value of the free-field or the diffuse field related level for a population when exposed to the sound under test which reflects the risk of hearing impairment in terms of well established criteria, i.e. a diffuse-field or free-field related sound level. The selection of the suitable procedure is affected by limitations within the procedures as well as the achievable accuracy and the reasonable expenditure and effort.

References

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