Problems of the real world sound attenuation of hearing protectors with respect to the peak sound pressure level

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Introduction

The limitation on the exposure to peak sound pressure levels imposed by law has been considerably restricted by the revised version of the directive 2003/10/EC on the minimum safety requirements regarding the exposure of workers to the risks arising from physical agents (noise). The previous Noise Directive 86/188/EC contained only one peak sound level limitation at p_{peak} = 200 Pa as an action level which required the implementation of technical measures to reduce the noise. In the case of exceeding this action value hearing protectors were to be used and the programme of noise reduction measures ought to be established.

Regulation

The current directive 2003/10/EC on the contrary contains three peak values:

- The lower action value of 112 Pa respectively 135 dB(C)

- The upper action value of 140 Pa respectively 137 dB(C)

- The Exposure limit value of 200 Pa respectively 140 dB(C).

These action values trigger the provision of hearing protectors, medical surveillance, information and instruction of the workers, the implementation of technical measures to reduce the noise exposure as far as the marking of the hearing protection zone.

Under no circumstances shall the exposure of the worker exceed the both exposure limit values: the daily noise exposure limit value ($L_{EX,8h}$ = 87 dB(A)) as well as the peak exposure limit value (p_{peak} = 200 Pa). On applying the exposure limit values the determination of the workers effective exposure shall take into account the attenuation provided by the hearing protectors worn by the worker.

This regulation leads to difficulties in fulfilling the limitation of the daily noise exposure level and especially of the peak sound level. One problem is to select an appropriate hearing protector that complies with both exposure limit values. In addition the check for compliance has to be performed for every individual.

The measuring method as well as the calculation system to assess the sound pressure level at the ear makes it difficult to compare the results with the limits.

The measuring methods are not able to give a complete comparability with the free field sound pressure level. Until this is possible, calculational assessment systems are necessary. All approaches doing that are based upon the sound attenuation values of the HPD's determined by the EC type examination. However, these sound attenuations are laboratory values, which are higher than the sound attenuation in practical usage. Compliance with the exposure limit values according to 2003/10/EC different methods considering the real world sound attenuation (derating) are used in Great Britain, France and Germany and another method is recommended by NIOSH in the USA. In general they are used only to check the daily noise exposure value.

Reduced sound attenuation for peak sound pressure levels

There are manifold reasons for the reduced effectiveness of the hearing protectors (derating). For example, we have to take into account false insertion of ear plugs, simultaneous wearing of spectacles or goggles and ear muffs, but also head movements and according to that leakage of custom-moulded ear plugs. Table 1 lists the most important factors that cause a reduction of the sound attenuation.

Ear muffs	Ear plugs
obsolete or damaged cushions	insufficient rolling-up or pressing of the user-formable ear-plugs
simultaneous wearing of spectacles or goggles	insufficiently deep insertion of the ear-plugs in the ear canal
strong hair of head	too short fixing of the inserted ear plugs inside the ear canal
earrings	inappropriate size of the ear plugs
cushions, smashed-in from storage	
simultaneous use of a respirator mask	
use of a protective helmet unsuited to the helmet-mounted ear muff	
aging of the headband	

Table 1: Causes for derating

And we have to deal with a special problem for peak sound pressure levels. We have to clarify the question in which cases the peak sound pressure levels are so high that the derating has to be taken into account to test compliance with the peak sound pressure limit value. Peak sound pressure levels higher than 140 dB (C) are seldom to be found in industrial production areas. Apart from straightening of big steel plates or structures (up to 157 dB

for straightening inside a tank) or bursting of tubes (up to 170 dB) we find much higher values up to $L_{,peak}$ = 190 dB (bazooka) in the military field [1]. For military exposure the strong air pressure oscillation during detonations (low frequencies) causes' additional leakage for ear muffs [1]. The use of combinations of ear muffs and ear plugs or special military ear plugs may be necessary and the additional consideration of frequency and energy of the blast is useful.

In the private sector hearing protectors are often not used, although for example also fireworks can cause hearing damages.

Derating

In general, the labelling of HPD is based upon the type examination method according to EN ISO 4869-1 [2] which is a subjective measuring method at the threshold of hearing and determines the sound attenuation of the HPD.

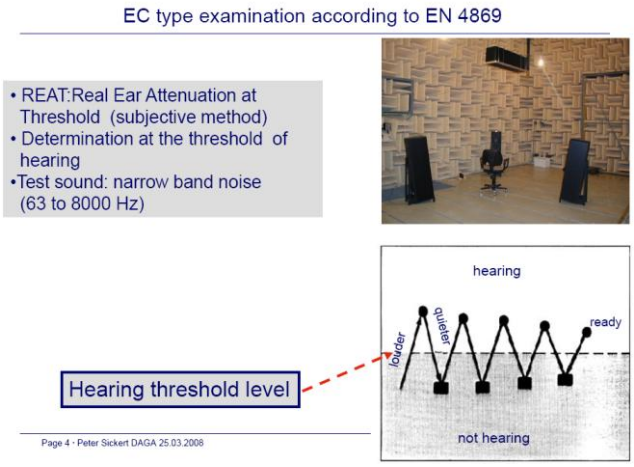

Figure1: EC type examination (Source: BGIA)

According to the series of European standards EN 352 "Hearing protectors" [3], there is a general labelling with the HML-values and SNR-value.

In Germany values for the derating correction factors have been determined by studies done within the last years and have been established in 2007 [4], [5]. The correction factors are included in the selection of HPD by subtracting them from the laboratory sound attenuation using a modified HML-Check according to EN 458 [4] [6].

- $L'_{EX,8h} = L_{EX,8h} - (M - K_s)$ for high or medium frequency noises
- $L'_{EX,8h} = L_{EX,8h} - (L - K_s)$ for low frequency noises
- M/L ……..attenuation value of hearing protectors (HPD) according to the type test (as shown on the packaging)
- K_s…….reduction for field use as correction value of attenuation
- $L'_{EX,8h}$….sound level effective to the ear

The correction values were determined as

- Ear plugs formable Ks = 9 dB
- Ear plugs pre-formed Ks = 5 dB
- Banded ear plugs Ks = 5 dB
- Ear muffs Ks = 5 dB
- Custom moulded Ks = 6 dB
- Custom moulded with fitting check Ks = 3 dB
- Combination of ear muffs with formable ear plugs Ks = 9 dB

The situation for peak sound pressure is more complicated. The reasons, why a test method is not established in the EC type examination until now are numerous:

1. Until the release of the new noise directive there was no exposure peak limit value effective to the worker's ear.

2. A comparable measuring of the sound attenuation of the peaks is difficult to realise. Smoorenburg [7] came in 1996 to the result that the determination of free field-related sound pressure level beneath the hearing protectors is not easy to execute.

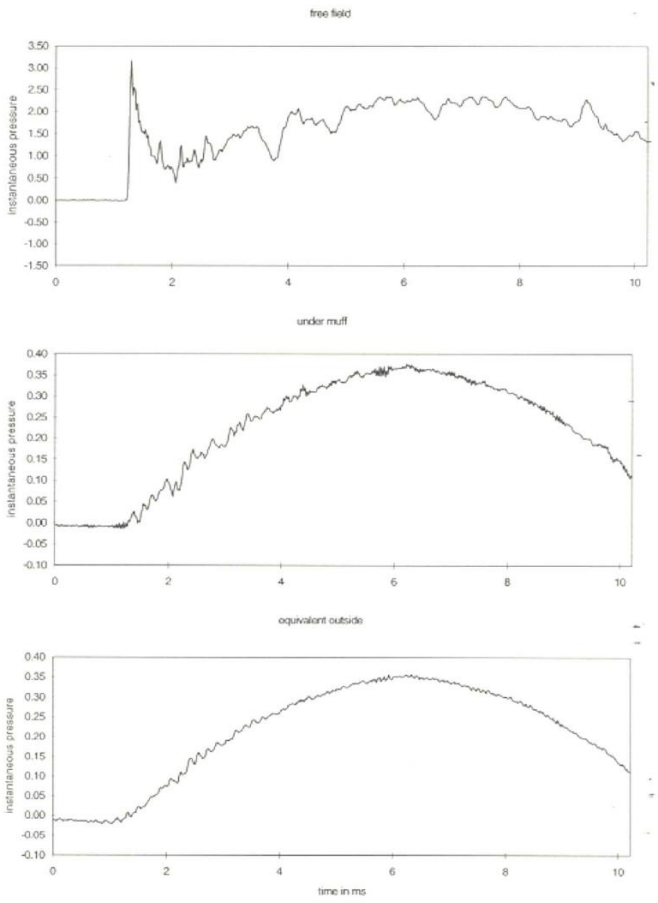

Figure 2: Free-field sound pressure, pressure measured beneath the HPD and corresponding free-field corrected outside pressure (in arbitrary units) [7]

As the first two pictures show, the characteristic structure of the peak (external sound field) cannot be identified any more in the signal under the HPD due to the low-pass filter effect of the ear muff.

In fact, the test of compliance with the peak exposure limit value is not common and hardly to accomplish. The free field peak pressure is deformed underneath the hearing protector and the retransformation to a free field-related value (i.e. using the transfer function of the ear canal) is difficult and complex [7].

Test for measuring the peak sound attenuation of HPDs were done within the last years by some test houses. In the BGIA a foil blaster has been used.

A foil or a paperboard has been used which was fixed on the foil blaster loaded with a pressure of 3 bar and cut with a knife.

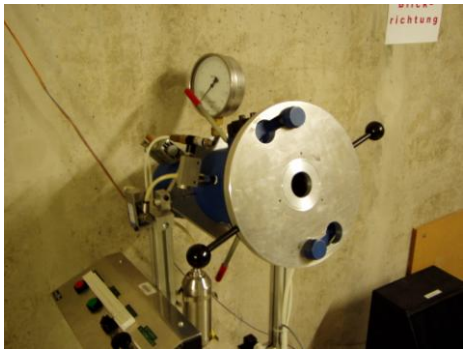

Figure 3: BGIA foil blaster (Source: BGIA)

The results of these measurements have not been introduced in the standard measuring procedure until now, because the conversion from the measured pressure in Voltage in decibel is difficult by the lack of knowledge of the transfer function.

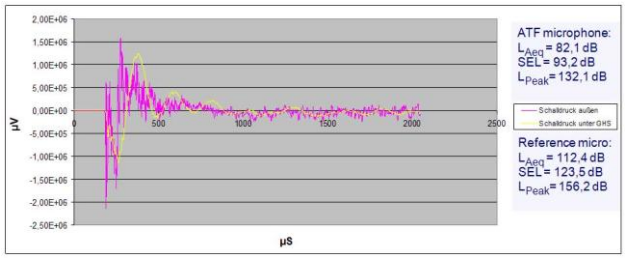

Figure 4: Sound pressure versus time diagram obtained with an ATF (acoustic test fixture) and a reference microphone. Pink: free-field sound pressure outside, yellow: sound pressure under the ear muff (Source: BGIA)

Much more difficult is the determination of the derating for peak sound pressure. That arises by reason of handling in the practical measurements and the ear transfer function for an artificial head [8], [9].

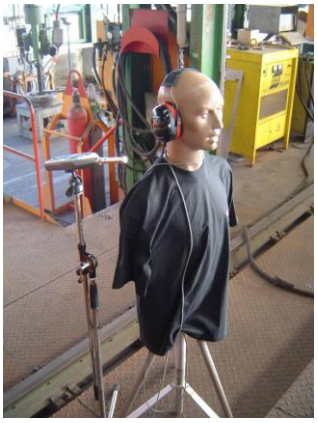

Figure 4: Practical peak sound pressure measurements beneath the HPD

measure ment	Ref-micro 1	Ref-micro 2	Kemar	Difference 1	Difference 2
	level [dB(C)]				
1	128,2	131,6	136,0	7,8	4,4
2	133,7	133,8	138,1	4,4	4,3
3	131,0	131,1	136,8	5,8	5,5
4	127,7	130,6	138,8	11,1	8,2
5	125,5	127,8	137,4	11,9	9,6

Table 2: Peak sound pressure inside and outside the ear muff by usage of an ATF (Kemar)

The measured data from ATF (Kemar) provide an estimate of the transfer function of the ATF for the peak values, but no exact determination is possible. For that the spectrum of the peak would be necessary. This is possible but requires more complex analyses technique.

Selection of HPD for impulsive noise

As a result of this, the derating method used for peak sound levels is still the same as the method for continuous noise with regard to the daily noise exposure level (according to the EN 458, HML- check).

- $L'_{C,peak} = L_{C,peak} - (M - K_s)$ for high or medium frequency noises
- $L'_{C,peak} = L_{C,peak} - (L - K_s - 5)$ for low frequency noises
- M/L……attenuation value of hearing protectors according to the type test (as shown on the packaging)
- K_s…… reduction for field use as correction value of attenuation
- $L'_{C,peak}$ …..sound level effective to the ear

With the knowledge, that the maximum peak sound pressure levels in industry are not higher than 157 dB and using this calculation method it can be established that all ear muffs with a sound attenuation of more than M = 22 dB or L = 27 dB and all formable earplugs with more than M = 26 dB or L = 32 dB would be usable. For low

frequency noise it means, that we have to use a combination of ear plugs and ear muffs.

HPD with electronic transmission (level-dependent sound attenuation) can show resonance effects due to impulsive excitation and should be carefully selected.

Further investigations to the real world sound attenuation of hearing protectors during peak sound pressure levels are necessary. If the results show that there are differences in the sound attenuation and/or the derating, an additional peak sound pressure labelling for HPD's will be appropriate.

References

[1] Karl Buck, F-Saint Louis, ISL-Report R102/2002D

[2] EN ISO 4869-1 „Acoustics; Hearing Protectors, Subjective method for the measurement of sound attenuation" October 1991

[3] EN 352 "Hearing protectors - Safety requirements and testing" 2002

[4] BGR/GUV-R 194: Benutzung von Gehörschutz, Deutsche Gesetzliche Unfallversicherung (2008)

[5] E.H. Berger: The Naked Truth about Noise Reduction Ratings, Hearing Instruments **45** (2), S. 8 (1994)

[6] DIN EN 458 "Hearing protectors, Recommendations for selection, use, care and maintenance", Guidance document, February 2005

[7] G.F. Smoorenburg: Assessment of Hearing Protector Performance in impulsive noise, TNO Report TM-96-CO42, 1996-11-13

[8] E.H. Berger: Preferred Methods of Measuring Hearing Protector Attenuation, Internoise, Rio de Janeiro 2005:

[9] EN ISO 11904-2:2002, Acoustics – Determination of sound immission from sound sources placed close to the ear – Part 2: Technique using a manikin