Special Methods for Selecting Hearing Protectors for Very Low Frequency Noise

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Summary
It is difficult to reduce low frequency noise by technical measures. Regularly persons concerned ask for use of HPD against low frequency noise. Therefore, the question of selecting an appropriate hearing protector arises. After basic knowledge to this topic, the methods for selecting HPDs are discussed. The different methods for selection are compared and referenced to the octave band method. For ear muffs the structure of the muff leads to mechanical resonances that reduce the attenuation in the range of about 50 Hz. Ear plugs show different sound attenuations at the low frequency region, independent from type of the plug. Very small leakages reduce the sound attenuation at frequencies lower than 100 Hz to 0 dB. The use of HPD with active noise control seems to be a solution for the problem of low frequency noise at work places.

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1. Introduction

Arising from the noise of wind power plants the low frequency noise is an important environmental problem and is under discussion.
In contrary to this, until now the exposure to low frequency noise at industrial work places is not in the focus of investigation and prevention.
If we have low frequency noise, mostly these are situations with noise levels beneath 80 dB (A). There is no risk of hearing loss. Nevertheless, we have extra-aural problems with low frequency noise. If we take the case of a locomotive driver we have noise levels from 70 to 75 dB (A) in the driver's cabin. The driver has a feeling of disturbance from the low frequency noise and wants to use an HPD. Other questions like hearing of warning signals and other informative sounds are contradictory against the use of HPD. Is it necessary to use a hearing protector in this case?
The presentation gives examples of low frequency noise characteristics and the performance of hearing protectors that can be expected for these situations.

2. Specific problem of low frequency

At the work places, high- and middle frequency noise is the normal situation. In many cases, there are sound levels which can damage the hearing. Well known is the professional disease "noise induced hearing loss". Health and safety experts have been investigating the situation for many years to prevent noise induced hearing loss. From this point of view, low frequency noise is seldom important. At work places with low frequency noise, typically we have no risk of hearing loss. In nearly all cases, the A-weighted sound pressure level is not high enough. However, many extra-aural noise effects result from low frequency noise. Important are psychic effects like mental stress. With the change of the character of the job situation (e.g. when high concentration is required), psychic stress becomes more important.
Since it is difficult to reduce low frequency noise by technical measures the question of the use of appropriate hearing protectors arise. Is it possible to reduce the extra-aural problems by the sound attenuation of the HPD?
On the other hand, low frequency noise is not clearly defined. The German standard DIN 45680 "Measurement and evaluation of low-frequency environmental noise" [1] defines it as noise whose acoustic energy is concentrated below a frequency of 90 Hz. In this case, the difference between the C-weighted and the A-weighted sound pressure level is greater than 20 dB (L_C - $L_A \geq 20$ dB). For the selection of HPD the European standard EN 458 "Hearing protectors – Recommendations for selection, use, care and maintenance" [2] defines L_C - $L_A \geq 5$ dB as a low frequency noise according to the HML-check.

An additional characteristic is that the low frequency noise penetrates the HPD much stronger than middle frequency noise. Accordingly small is the sound attenuation.

3. Examples of low frequency noise in the industry

Depending on the specific working technique machinery noise mostly has the main part of the sound energy around 1000 Hz. Low frequency noise is typical for excavators, converters, electric melting furnaces or cupola furnaces (see Fig. 1 and 2 and EN 458).

Figure 1. Melting furnace

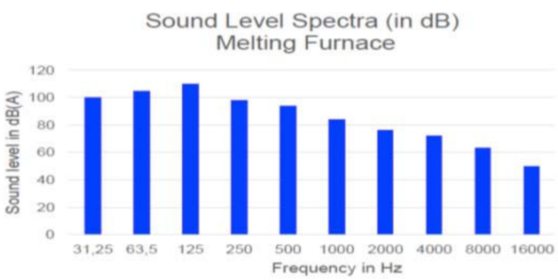

Figure 2. Sound level spectrum of a melting furnace
(L_{Aeq} = 97 dB, L_{Ceq} = 112 dB, L_C-L_A = 15 dB)

Low frequency noise according to the definition of DIN 45680 is easily found in situations in the industry with L_A lower than 85 dB, but only rarely with higher levels (see Figure 1, 2 and 3).
Looking on an S-train driver's cabin with open window, we have a typical low frequency noise problem at a work place (see figure 3). It has a sound pressure level of L_{Aeq} = 69 dB and the spectral balance is L_C-L_A = 27 dB. The driver has the sensation of discomfort, but is not in risk of hearing loss. He would like to use hearing protectors, but has to hear warning signals and additional acoustic information that can give a warning in the case of a hazardous situation. The example shows a typical problem of the use of HPD in low frequency noise.

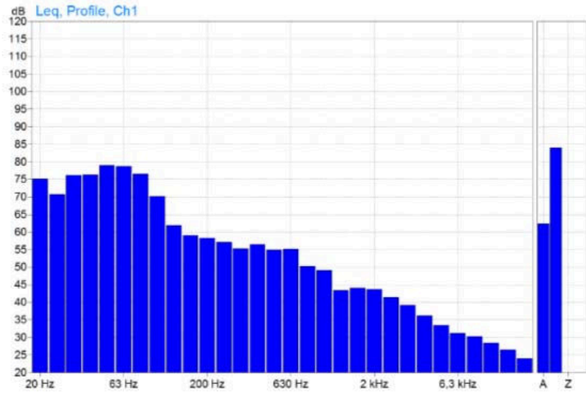

Figure 3. Sound level spectrum of an S-train (driver's cabin, open window)

4. Sound attenuation of HPD

4.1. Passive sound attenuation of HPD

Before deciding on the best selection method it is important to know the behavior of the HPD in low frequency noise. Rudzyn and Fischer [3] published measurements with active noise reduction devices realized with a head and torso simulator (HATS). With pink noise generating a diffuse sound field in a large reverberation room, they found that the passive attenuation of ear muffs at 100 Hz can be very low (about 0 - 10 dB).
Own measurements in collaboration with the IFA show a dependency on the cushion pressure of the ear muffs. An additional fixation with an elastic strap resulted in an increase of 8 dB in the frequency range of 100 Hz for the ATF and an increase from 3 dB to 18 dB for the Kemar.
Ear plugs have the same problem. Essential is the fitting in the ear canal. That is more important than the question of formable or pre-formed type. At the measurements the ATF and the Kemar showed different fittings for ear plugs. Especially the flanged ear plug had problems. Flanged ear plugs with rough lamella constructions showed leakages at the test fixture that were not possible to avoid. As a result the sound attenuation was near 0 dB for one flanged ear plug and one user formable plug.
These results are independent from the used noise level. Figure 4 shows the results for an L_{eq} of 95 dB(A).

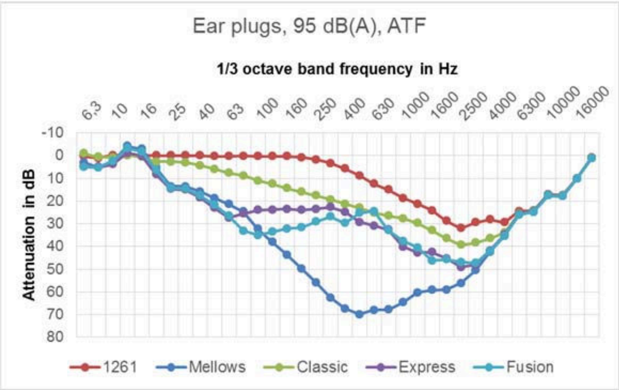

Figure 4. Comparison of sound attenuation of different ear plugs measured with low frequency noise on an ATF.

4.2. HPDs with active noise control

A solution for the problem of low frequency noise seems to be the use of HPD with active noise control. While an HPD with flat attenuation curve in the frequency range of 125 to 500 Hz can produce reasonable results by passive attenuation, it may not be good for frequencies lower than 100 Hz. In this case, an active sound attenuation (ANR) may be appropriate. The effect of ANR is visible in low frequency noise aroun 100 Hz. The measurements from Rudzyn and Fisher show an active part of the sound attenuation of about 15-20 dB. According to the own measurements (see figure 5) the sound attenuation with different measurement systems (ATF, Kemar) and different noise levels (90, 100, 110 dB) at 100 Hz is nearly the same. The sound attenuation by the active noise control at 63 Hz lies between 15 to 20 dB, depending on the measurement system fixture and noise level.

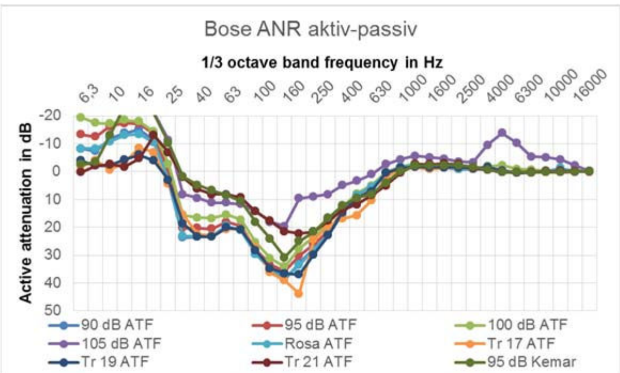

Figure 5. Effect of active noise control (difference between active and passive mode) for a ANR headset (no HPD) and different test noises (level and spectral content).

5. Selection methods for HPD

The standard procedure for selecting hearing protectors is the HML check or the HML method with the attenuation values for high-, middle- and low-frequency noise calculated according to EN ISO 4869-2 [4]. For low frequency noise normally the L-value is applied which is defined as the attenuation performance of the hearing protector for a noise with a spectral balance L_C-L_A of 10 dB. However, at some workplaces noises can occur that have an even higher value of L_C-L_A, e.g. diesel locomotives, airplanes, ships. As reference value, the octave band method will be used. It describes exactly the calculated value of sound attenuation of the HPD.

6. Comparison of the selection methods

Calculation methods to determine the usability of HPDs in low frequency noise situations are described in EN 458 and EN ISO 4869-2.

6.1. Octave band method

It is the basic and reference method. For each frequency the noise reduction is calculated. The calculation of the rating level effective is made by using the following equation:

$$L'_A = 10 \log \left(\sum_{f=125}^{8000} 10^{0,1 \cdot (L_f + A_f - APV_f)} \right) \text{dB} \quad (1)$$

with:
f centre frequency of the octave band

L_f octave band sound pressure level of the noise

A_f frequency rating A according to DIN EN 60651

APV_f assumed protection value of the hearing protector

$$APV_f = m_f - \alpha s_f \quad (2)$$

With:
m_f is the mean sound attenuation in accordance with ISO 4869-1,
s_f is the standard deviation,
α is a constant representing the level of protection

6.2. HML method

The attenuation values H, M and L combined with a measurement of the A- and C-weighted sound pressure levels of the noise are used to calculate the Predicted Noise Level Reduction (PNR) which is then subtracted from the observed A-weighted sound pressure level to calculate the A-weighted sound pressure level (L'_A) effective to the ear when the hearing protector is worn.

If $L_C - L_A \leqq 2dB$:

$$PNR = M - [(H - M) / 4] \cdot (L_C - L_A - 2) \qquad (3)$$

or if $L_C - L_A > 2dB$:

$$PNR = M - [(M - L) / 8] \cdot (L_C - L_A - 2) \qquad (4)$$

And the sound pressure level effective to the ear:

$$L'_A = L_A - PNR \qquad (5)$$

This method can also be performed also in a graphical way.

6.3. HML check

It is a short method using general knowledge about the low, middle or high frequency character of the noise and using the L_A value at the workplace and the M- and L-value determined at the type examination.

High and middle frequency noise:

$$L_C - L_A \leq 5 \text{ dB}: L'_A = L_A - M \qquad (6)$$

Low frequency noise:

$$L_C - L_A > 5 \text{ dB}: L'_A = L_A - L \qquad (7)$$

6.4. SNR method

The sound pressure level at the ear L'_A is calculated from L_A value at the workplace and the difference between C- weighted and A-weighted sound pressure level:

$$L'_A = L_A + (L_C - L_A) - SNR \qquad (8)$$

7. Selection

The level of discomfort by low frequency noise is not clear defined until now. The disturbance limit is often nearby to the threshold of hearing. The frequency range we are looking for is the range of 20 to 100 Hz. Information to disturbance levels of low frequency noise are given by VDI 2058 part 3 [5], DIN 45680 or M. Schmidt [6]. The A-weighting sound pressure level is not an appropriate indicator.

Looking on the low frequency noise situation it is to decide what method describes the situation as well as possible.

Taking into account the disturbance effect of the low frequencies it seems most important to know how strong these frequencies are reduced.

For the determination it is possible to measure the one-third octave frequencies at the ear. Easier is the approximation by the calculation methods above. If we select one of these methods it is to decide which calculation method is the best approximation. The octave band results are the comparison standard. A method should deliver values that are near the octave band results.

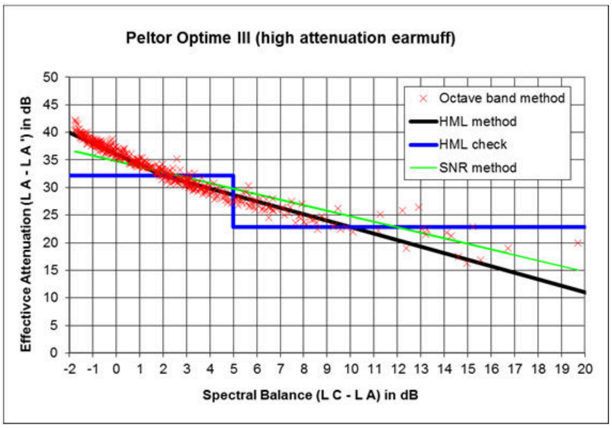

Figure 6. Effective sound attenuation calculated with different methods for HPD with steeply rising frequency response (Peltor Optime III).

Figure 6 shows a high attenuation ear muff with strongly increasing attenuation at higher frequencies. For deep frequency noise (L_C- L_A > 10 dB) the HML method and the SNR method deliver results near to the octave band method.

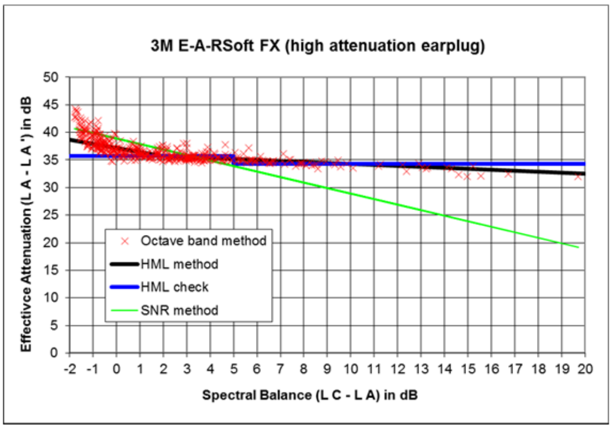

Figure 7. Effective sound attenuation calculated for 3M E-A-RSoft FX with different methods.

Figure 7 shows results for the foam ear plug 3M E-A-RSoft FX, designed with flat attenuation rate and a high sound attenuation. The SNR is generally not usable in this case. HML method and HML check are usable.
The compliance between the octave band method and other methods depends on the frequency response of the hearing protector. In the case of an HPD with flat frequency response there is no accordance between octave band method and SNR method.
The SNR has the additional disadvantage that the L_C is normally not known at the work situation. The selection of HPD should be done by using the HML values. For very low frequency noises the HML method is preferable against the HML check since the L-value normally overestimates the protection performance for very high values of $L_C – L_A$.

8. Conclusions

Passive HPDs often don't provide enough sound attenuation to avoid disturbance (extra-aural effects) by low frequency noise. For disturbing noise with main frequency parts beneath 100 Hz it is possible that the reduction of higher frequencies create an even higher disturbance resulting from the lack of the masking effect.
Even very low leakages reduce the sound attenuation in the frequency range beneath 100 Hz to about 0 dB. This problem affects the designed sound attenuation and the selection of the type of HPD.

To conclude, passive HPD are not usable to prevent the disturbance by low frequency noise. HPDs with active noise control are a solution for noise dominated by frequencies lower than 100 Hz.

Acknowledgement

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References

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