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Assessment of the Risk of Auditory Damage due to Narrow-Band Noise

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The international standard ISO 1999-1990 indicates the noise-induced hearing loss (NIHL) to be expected at different audiometric frequencies as a function of noise exposure. It is based on statistical data of hearing loss due to exposure to broadband noise. Whereas industrial noise is most often of a broadband type, this is not the case for sounds produced by electro-acoustic systems and devices, such as warning signals or a howl-around of a sound reinforcement system. From the point of view of physiology, a concentration of the sound energy into one frequency band is equivalent to an increased load on small part of the basilar membrane. Compared to an exposure to a broadband signal of equal energy, this may increase the risk of hearing damage. Several cases of hearing loss or tinnitus (ringing) due to such narrow-band signals have been filed by Suva. For the assessment of such compensation cases, a tentative correction K_{NB} (NB = narrow-band) based on the frequency spectrum in one-third octave bands has been developed. The main parameter is the number of frequency bands carrying 75 % of the total A-weighted sound energy.

1 Introduction

1.1 Suva and its role

Suva – the Swiss National Accident Insurance Fund founded in 1918 – is the compulsory insurance for accidents and occupational diseases for 2/3 of the working population in Switzerland. It is managed by the social partners and financially independent from the government.

Suva is more than an insurance company or a compensation board: Suva has a mandate given by the government regarding safety at work and is the supervisory body for the prevention of occupational diseases – such as noise-induced hearing loss (NIHL) - for all branches, from forestry to orchestra, all over Switzerland [1].

Suva runs a centralized hearing examination service using 5 mobile units or "Audiomobiles".

Figure 1 : Mobile hearing examination unit "audiomobile"

1.2 Tasks of Suva's acoustic experts

Suva's acoustic experts support companies in noise control at workplaces. Based on their many noise measurements at workplaces, they publish the noise-level tables used by the majority of companies in Switzerland for a simple assessment of the occupational noise exposure of the employees. Moreover, Suva's acoustic experts have the duty to assess the noise exposure in compensation cases for occupational hearing loss or tinnitus.

1.3 Compensation claims for hearing damage

Suva files between 1500 and 2000 claims per year for compensation (including payment of medical treatment and hearing aids) for hearing loss or hearing damage (which includes permanent severe tinnitus).

Such a hearing damage may be induced by long-term occupational noise exposure or short-term acoustic overload (e.g. due to impulse noise) or head injuries after accidents. In any case, a technical assessment (estimation of noise exposure) as well as a medical assessment (evaluation of possible other reasons for the hearing damage) is necessary. Whenever the data base of Suva's acoustic team is not sufficient for the assessment of the noise exposure, specific measurements or – if feasible – a reconstruction of the exposure claimed to have induced the hearing damage have to be done. The diversity of such acoustic accidents makes statistic evaluation difficult. Nevertheless due to the centralized processing the experience from all these cases accumulates. This is the background of our proposal regarding the evaluation of narrow-band noise.

2 Hearing damage due to narrow-band noise exposure

2.1 Literature and DRCs

There has been considerable research on permanent hearing loss due to continuous and intermittent noise and also due to impulse noise (e.g. blasts from large weapons and shooting noise from firearms), but there are only few studies on hearing damage due to pure-tone or narrow-band signals [2, 3], and all of them rely on TTS as an indicator of a possible hearing loss.

To our knowledge, no specific damage risk criteria (DRC) for pure-tone or narrow-band noise exposure exist. ISO 1999-1990 states that it is based on data from broad-band noise exposure and that application to narrow-band noise is to be seen as an extrapolation, and that some experts may like to add up to 5 dB for tonal noise.

2.2 Experience from compensation cases at Suva

Among the 1000 to 2000 cases of hearing damage to be assessed for acceptance every year, there is a growing number of cases caused by narrow band or pure-tone exposure, most often from electro-acoustic sources, e.g.:
- accidental howl-around of a sound reinforcement system
- alarm signals from intrusion protection systems
- alarm signals from theft protection systems in shops
- signals from acoustical anti-cat or anti-dog devices
- in-house portable telephone ringing through headset
- high-pitched noise from switched power supplies
- humming from engines of a cruising turboprop aircraft

The majority of these compensation claims were not because of hearing loss, but because of permanent severe tinnitus. In several cases, it seemed highly probable that the tinnitus was due to the acoustic exposure, even if the action levels for noise at work were not exceeded.

3 Narrow-band noise exposure

3.1 "Narrow-band" in the context of hearing damage

In the context of hearing damage, it is the mechanical behaviour of the basilar membrane that counts – not so much the subsequent filtering involving the active processes (outer ear cells) and the brain. The bandwidth of these mechanical filters or critical bands is similar to third-octave bands for frequencies above 500 Hz (see e.g. Zwicker loudness calculation in ISO 532).

Despite the fact that spectral analysis in third-octave bands gives a good indication of what is going on in the critical bands, there is one shortcoming: Frequency analysis in acoustics is based on fixed centre frequencies of these bands (1000 Hz, 1250 Hz, 1600 Hz etc.). This is of course not the case for the basilar membrane which has a continuous frequency scale.

In order to be *perceived* as "tonal" or "narrow-band", it is sufficient that a noise contains a pure tone or narrow-band component that emerges from the broad-band spectrum by just a few decibels. Nevertheless the sound energy may be spread over several critical bands. In the context of possible hearing damage such a signal is not to be considered as "narrow-band".

For *hearing damage*, a noise may be considered as narrow band if the essential part – say 75 % - of the total A-weighted sound energy is concentrated in 1 or 2 critical bands.

But the penalty for a pure-tone signal should not exceed 10 dB as the concentration of the energy into a single band represents a tenfold increase of the load (sound energy to be dealt with) compared to a more or less evenly distributed spectrum.

3.2 Tentative definition of a narrow-band penalty

The tentative definition of a narrow-band penalty is in line with this idea: We calculate the number of third-octave bands (#TB) which carry 75 % of the total A-weighted sound energy, and as a reference spectrum we choose a flat distribution in third-octave band analysis, i.e. Pink Noise:

$$K_{NB} = 10 \cdot \log\left(\frac{\#TB_{Pink\ Noise}}{\#TB}\right) \qquad 1$$

For Pink Noise, the number of third-octave bands carrying 75 % of the total A-weighted sound energy is 11. K_{NB} will be 0 dB. For a pure tone, K_{NB} will be about 10 dB.

3.3 Simplified calculation of narrow-band correction

There is an alternative method which is easier to calculate and produces similar results: We calculate the decrease of the A-weighted sound level if the two highest third-octave bands would be removed from the spectrum. The reason that the *two* highest bands are taken into account is that a pure tone may be located exactly at the limit between two third-octave bands, e.g. at 1118 Hz. Such a signal will appear in the two bands 1000 Hz and 1250 Hz, but with 3 dB less than a pure tone of equal amplitude but a frequency of 1000 or 1250 Hz.

In the case of a sinusoidal signal, removing the two highest bands causes the A-weighted total level to decrease by 18 dB, but as shown above, the narrow-band correction should not exceed 10 dB. So the numerical result has to be clipped at 10 dB. The designation for results calculated according to this method shall be K_{NBs}

4 Examples

4.1 Pink Noise

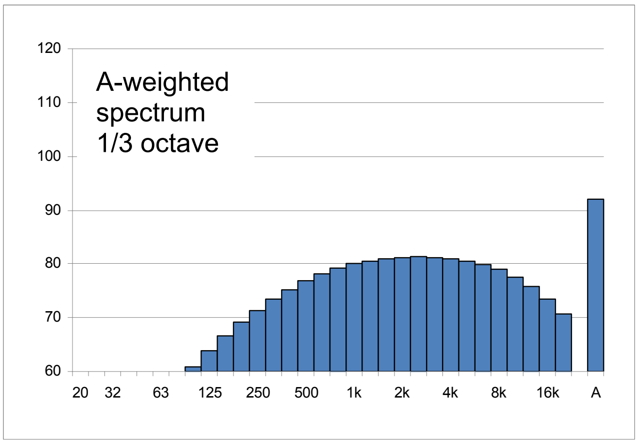

Figure 2: spectral analysis of pure tone:
K_{NB} = 0.0 dB, K_{NBs} = 0.8 dB

4.2 Sinusoidal signal (pure tone)

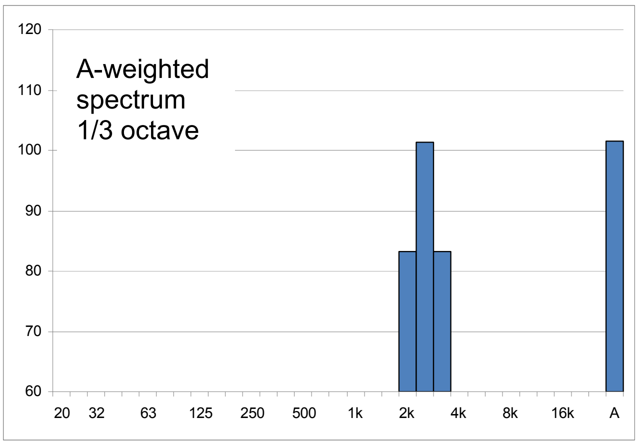

Figure 3: spectral analysis of pure tone:
K_{NB} = 10.0 dB, K_{NBs} = 10.0 dB

4.3 Fire detector alarm

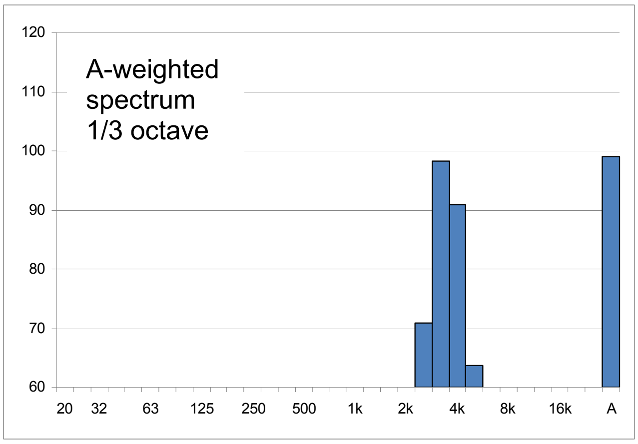

Figure 4: spectral analysis of fire detector alarm:
K_{NB} = 10.0 dB, K_{NBs} = 10.0 dB

This is a nearly pure-tone signal where the fundamental frequency is located right between two centre frequencies.

4.4 Ultrasonic cleaning

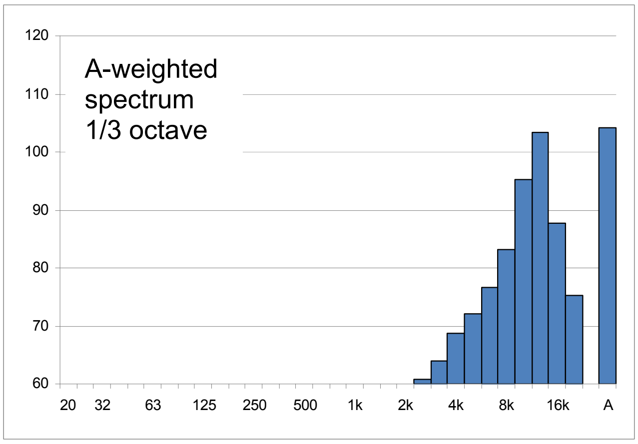

Figure 5: spectral analysis of ultrasonic cleaning:
KNB = 10.0 dB, K_{NBs} = 10.0 dB

4.5 Dental drill

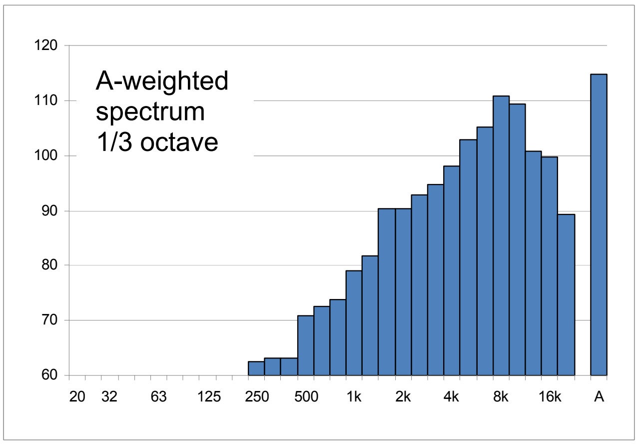

Figure 6: Dental drill:
K_{NB} = 5.6 dB, K_{NBs} = 5.3 dB

4.6 Civil protection siren

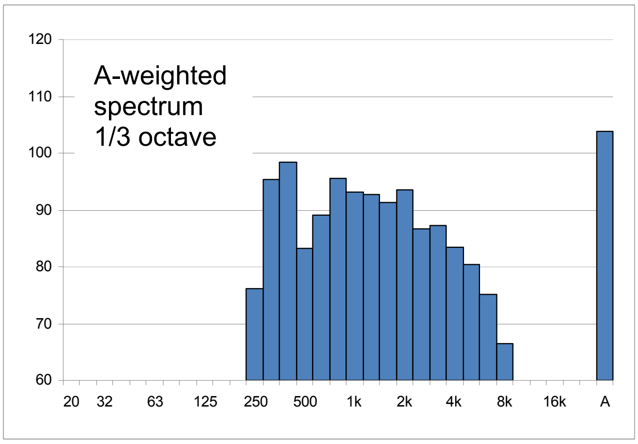

Figure 7: civil protection siren:
K_{NB} = 3.4 dB, K_{NBs} = 2.5 dB

Despite the visible (and audible!) tonal components, the narrow-band correction is just about 3 dB for this signal.

4.7 Pneumatic horn

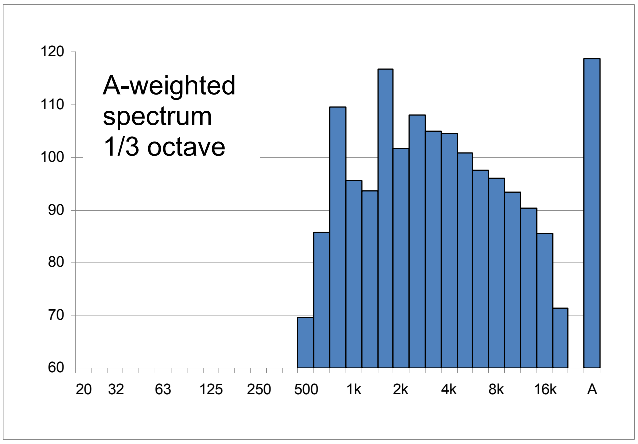

Figure 8: Pneumatic horn:
K_{NB} = 7.4 dB, K_{NBs} = 6.5 dB

4.8 Pump, tunnel construction

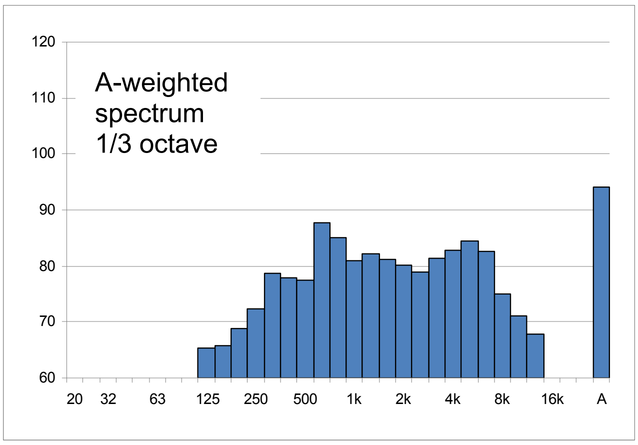

Figure 9: Pump, tunnel construction:
K_{NB} = 1.4 dB, K_{NBs} = 1.9 dB

5 Discussion

5.1 Application of K_{NB}

Because of the tentative character of this concept and the weak scientific basis, K_{NB} should not be added to the A-weighted level but indicated separately to be taken into account during the medical assessment of the compensation case.

As ISO 1999-1990 may also be based on a certain amount of narrow-band noise exposure from industrial sources (but not from electro-acoustic sources), some degree of K_{NB} may already be included. Therefore just values for K_{NB} exceeding 3 dB should be taken into account (or K_{NB} could systematically be reduced by 3 dB).

As a stable pure-tone or narrow-band noise exposure during a long period is rather rare (with the exception of flight personnel in turboprop aircrafts), K_{NB} should only be applied to intense *short-term* acoustic exposures in the sense of acoustical accidents (e.g. howl-around of a sound reinforcement system during some seconds).

According to our experience, the aspect of narrow-band noise exposure seems to be more important for the deployment of tinnitus than for noise-induced hearing loss. That is why K_{NB} should only be taken into account in cases of noise-induced tinnitus.

Narrow-band noise exposure is however just one one of the problems for an adequate technical assessment of hearing damage claims. Two other limitations are discussed in 5.2. and 5.3.

5.2 Limitations of the assessment in frequency domain

Even if A-weighting is universally accepted, it should be acknowledged that it represents a simplification: Unfortunately in the frequency range where the human ear is most sensitive, i.e. between 2 kHz and 6 kHz, A-weighting underestimates the hazard to hearing by up to 10 dB. This may be less of a problem for broad-band signals, but it is a critical issue for noise with strong components in this frequency range. Perhaps after 50 years A-weighting could be reassessed. But at least A-weighting is more appropriate than C-weighting, also for impulse noise.

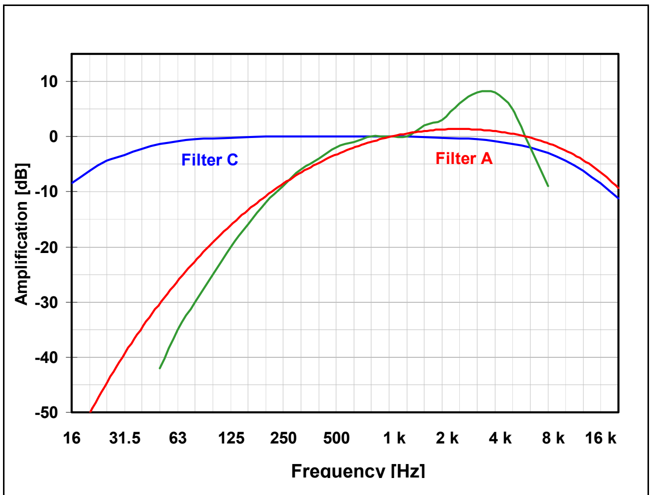

Figure 10: Inverted hearing threshold (minimum audible field MAF, ISO 226) and weighting filters A and C

5.2 Limitations of the assessment in the time domain

Peak sound pressure is used as an action level in the EU directive, but it is almost irrelevant for the potential hazard to hearing, and the (A-weighted) short-term energy L_E is much more relevant [4].

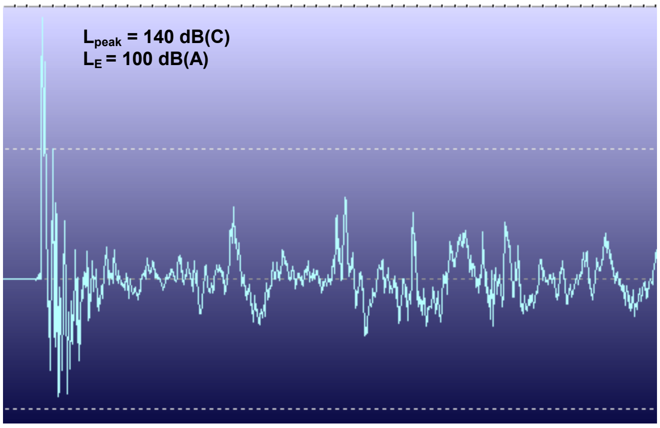

Figure 11: Stub welding – time domain

Example: Stub welding produces peak sound pressure levels of about 140 dB. But the sound energy of a single shot is rather small, and hearing damage is not probable even when up to 100 shots are fired.
The peak sound pressure level should only be used for preventive measures, but not for the technical assessment of hearing damage claims [5].

6 Conclusion

From Suva's point of view, the possible additional hazard to hearing due to a narrow-band or sinusoidal type of the exposure should be taken into account in the technical assessment of hearing damage compensation claims. But as the scientific base is weak, a discussion of the rational and the proposal presented here will be extremely helpful. Any critical remarks will be appreciated!

Literature

[1] Hohmann B., Lips W., Waldmann H.: "Bruit dangereux pour l'ouïe aux postes de travail / Gehörgefährdender Lärm am Arbeitsplatz". SUVA 44057 d/f, 2007. www.suva.ch/waswo/44057

[2] Harding G.W., Bohne B.A.: "Distribution of focal lesions in the chinchilla organ of Corti following exposure to a 4-kHz or a 0.5-kHz octave band of noise", Hearing Research 225 (2007) 50-59

[3] Young I. M., Lowry L.D.: "Temporary threshold shift after exposure to a narrow-band noise, frequency-modulated tones, continuously variable frequency tones and a pure tone", 113th Meeting: Acoustical Society of America, 876

[4] Hohmann B.W.: "Untersuchungen zur Gehörschädlichkeit von Impulslärm", Ph.D. thesis No. 7504, ETH Zürich.

[5] Liedtke M.: "Akute Gehörschäden durch extrem hohe Schalldruckpegel", HNO 2010 · 58:106–109.