Airborne ultrasound at german workplaces

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ABSTRACT

The presence of ultrasound technology at german workplaces has been continuously rising over the last decades. Being energy-efficient and low in costs, for example welding techniques using ultrasound are nowadays well-established processing procedures.
To include this new kind of noise exposure into german occupational health and safety, VDI-guideline 3766 "Ultrasound — Work place — Measurement, assessment, judgement and reduction" was published in September 2012. The guideline describes a specific procedure how to measure, assess and rate exposure to sound with shares of airborne ultrasound.
Unfortunately, this guideline does not provide answers to all important questions rising in the context of airborne ultrasound exposure at workplaces. For example no assessment criteria exist for preventing potential damage, caused by airborne ultrasound frequencies, to the human ear at frequencies above 8 kHz – for the reason, that no comprehensive and authoritative studies are available. Also, the guiding values provided in the german guidelines VDI 3766 (10) and VDI 2058-2 (11) are incomplete. From an occupational health and safety point of view, these gaps have to be closed urgently. The guideline VDI 3766 is presented and potential problems and approaches to solve them are being discussed.

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1. Measurement, assessment and judgement of airborne ultrasound

The German regulation for safety at work against hazards from noise and vibration (1) and the corresponding Technical Rules deal with measurement, assessment, judgement and reduction of exposure to audible noise. Audible noise in this case is defined as sound with frequencies between 16 Hz and 16 kHz. Here, it is not clearly stated whether the frequencies 16 Hz and 16 kHz are limit frequencies or whether the thirds with center frequencies 16 Hz and 16 kHz are limit third or even if they should be interpreted as center frequencies of octaves. Effects caused by infrasound and ultrasound are explicitly excluded by the technical rules.

When using conventional measurement procedures for audible sound for the assessment of noise exposure at the workplace, the results can be influenced by the presence of airborne ultrasound. This may lead to a wrong judgement of the noise exposure. One reason can be found in the tolerances within which a sound level meter has to implement the A-weighting according to DIN EN 61672-1 (4). While for a type approved sound level meter of class 1, the allowed tolerances between 100 Hz and 8 kHz amount to +2,1 dB and -3,6 dB maximum, this band widens up significantly for higher frequencies until it ranges from +4 dB to -∞ dB at 20 kHz.

Furthermore, the A-weighting of the standard DIN EN 61672-1 is defined only up to 20 kHz. But not every sound level meter cuts the frequency levels above 20 kHz. Depending on the sound level meter, the microphone, and the user adjustments, frequencies above 20 kHz contribute to the overall sound levels – often damped, but to various, not exactly predictable degrees.

To deal with these and other imponderabilities, the german guideline VDI 3766, describing a special procedure for measurement, assessment, judgement and reduction of airborne ultrasound, was published. Following this guideline, only the frequency-weighting AU (3) should be used whenever airborne ultrasound is present. The weighting curve is identical to the A-weighting up to 10 kHz. Higher frequencies are suppressed more strongly than by the A-weighting. Figure 1 shows the weighting curves as function of the frequency.

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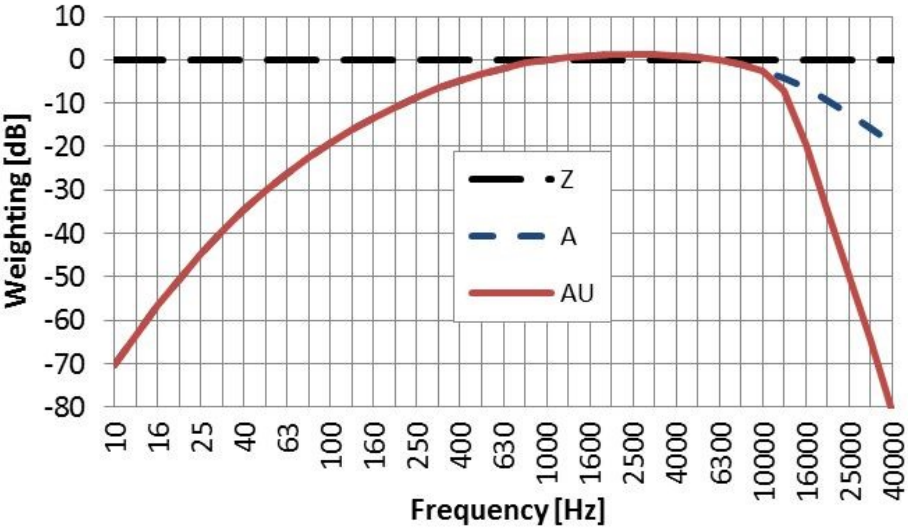

Figure 1 – Weighting curves for A-, AU-, and Z-weighting

To assess the hazard caused by airborne ultrasound at the workplace, the AU-weighted noise exposure level $L_{EXAU,8h}$ can be determined following the procedures described in DIN EN ISO 9612. Additionally, the Z-weighted peak level L_{Zpeak} has to be measured. To avoid a loss of hearing within the audio frequency regime (up to 8 kHz), the AU-weighted noise exposure level $L_{EXAU,8h}$ should not exceed 85 dB according to VDI 3766. Also, the Z-weighted peak level should be lower than 140 dB. Another german guideline VDI 2058-2 states that the sound pressure level in the third with center frequency 20 kHz should not exceed 110 dB. Then, permant hearing damages are not likely to occur. An overview of the german guidance values is given in table 1.

Table 1 – Guidance values from VDI 3766 and VDI 2058-2

Name	Guidance value	Origin
$L_{EX,AU,8h}$	85 dB	VDI 3766
L_{Zpeak}	140 dB	VDI 3766
$L_{Third,20kHz}$	110 dB	VDI 2058-2

Additionally, intensive ultrasound should not enter the body by direct contact to the skull. Also other kinds of penetration of ultrasound into the body should be avoided. For example when working at an ultrasonic cleaning device without wearing adequeate protective gloves. Otherwise, local effects like circulative disturbances or other adverse effects on the autonomic nervous system can occur (9).

2. Measurement procedure

Caused by the very short wavelengths, the behavior of ultrasound is more extreme in certain aspects than known from the audible frequency regime. The absorption of ultrasound in air is higher and emission is highly directional when compared to audible sound. Thus, ultrasound fields at the workplace are expected to have strong free field character. As a consequence, strong local fields and high local differences in sound levels are likely to occur in the vicinity of ultrasound sources. This leads to problems when performing measurements as the sound pressure level can vary drastically when the microphone position is shifted only by a few centimeters.

These characteristics lead to a high efficiency of enclosures as measure to reduce ultrasound exposure on the one hand. On the other hand, tiny gaps in such enclosures can lead to local areas with unchanged high ultrasound exposure.

The highly directional emission hinders a correct rating of ultrasound at the workplace. In contrast to the common measurement techniques for audible sound like stationary measurements or trailing of moving persons, for airborne ultrasound, the area has to be scanned systematically to find even small regions of high ultrasound exposure the employee could be exposed to. For a given situation, the measurement results could depend significantly on the diligence of the measurement execution.

3. Limit values

The german limit values mentioned in VDI 3766 and VDI 2058-2 for protection from hazards caused by airborne ultrasound show gaps and are not absolutely consistent with the German regulation for safety at work against hazards from noise and vibration within the scope of the directive. As an example, VDI 2058-2 states, the sound pressure level of the third with center frequency 20 kHz should not exceed 110 dB (with frequency weighting Z). But no guidance values are given for the neighboring thirds, especially not for the third with center frequency 16 kHz.

But the suppression of a sound with a pronounced share of energy in the 16 kHz-third is nearly 15 dB higher in the AU-weighting than in the A-weighting – although the sound belongs to the audible frequency regime. In some cases this leads to an exceedance of the obligatory A-rated exposure level given in the German regulation for safety at work against hazards from noise and vibration, while the sound level measured and rated in accordance with VDI 3766 is still way below the guide value.

The majority of machines working with ultrasound uses dominant frequencies between 20 and 40 kHz. Often, subharmonics at half of the dominant frequency can be detected, as well as harmonics at multiples of the dominant frequency. Subharmonics with frequencies in the audible regime can be highly annoying, even when the pressure level itself is not damaging to the ear. Even when no subharmonic frequency can be measured, the ear drum can be excited by unmodulated ultrasound (7). For these high frequency sounds, no guidance values for annoyance or even damage potential in the high frequency audible regime are given.

In Germany several guidance values from the guidelines VDI 3766 and VDI 2058-2 exist and can be used for risk assessment by airborne ultrasound, but all of these guidance values are concerned only with the damage potential of the ear in the audio frequency regime up to 8 kHz, not in the audible regime, which reaches up to 16 kHz. For these higher frequencies only few studies exist. One reason surely is that standard audiometry is carried out only up to 8 kHz and high frequency audiometry is difficult to perform. Furthermore, the german guideline for airborne ultrasound VDI 3766 gives no statement on damage potential from pure airborne ultrasound, although many people complain about extraaural symptoms like nausea, headache, dizziness, or feeling of pressure on the ear when exposed to ultrasound at higher pressure levels. The mechanism of action is not known yet (8). More studies are needed to make a statement on the damage potential of airborne ultrasound on the whole audible frequency regime and to define well-confirmed guide values. To avoid extraaural symptoms, Maue (5) recommends to expand the existing german guide values according to table 2.

This expansion of the guide values integrates well into several other national regulations. In (6) Lawton gives an international overview of existing regulations.

Table 2 – Recommendation of guidance values by (5)

Centerfrequency of thirds in kHz	Maximal sound level of thirds measured over 5 minutes $L_{Z,Third,5min}$ in dB
16	90
20	110
25	110
31,5	110
40	110

4. Personal Protective Equipment

The functioning of any type of closed hearing protector in the ultrasound regime can be considered as proven. Crabtree and Behar (13) as well as Berger (14) investigated the damping of different types of hearing protectors for ultrasound frequencies. Only for hearing protectors with open filter elements like found in some otoplastics or pre-shaped multi-use hearing protectors investigations are lacking.

As can be seen in many companies, devices working with ultrasound often carry the symbol for hazardeous noise areas. But in practice employees often do not wear hearing protection when working at these devices. Very frequently, the subjective impression that it is not noisy at the workplace coincides with the measurements and the daily exposure levels at the workplaces are below 85 dB. At these workplaces much sound energy is found in the high-frequency regime starting from 16 kHz, which is suppressed by the A- and the AU-weighting. But when hearing protection has to be worn, although the workplace does not seem noisy, workers can feel isolated. Communication with other employees is hindered, events occuring in the vicinity of the workplace cannot be heard properly. These effects lead to a bad acceptance of hearing protection. On the other hand the perceptibility of alarm signal might be decreased due to the damping of the hearing protector. So it is important to rate the damage potential of airborne ultrasound correctly and fit, if necessary, well adapted hearing protectors. By avoiding unnecessary safeguards, the employees could be better protected from hazards at the workplace.

5. Dose-effect relationship

A major problem when dealing with the risk assessment caused by airborne ultrasound is the lack of a dose-effect relationship. For conventional audible noise at the workplace, a dose-effect relationship can be derived from DIN EN ISO 1999 (2). This standard is based on audiometric data from several thousand people with a well-defined noise exposure at the workplace and in the leisure time. With the help of this data, a relationship between the individual hearing losses and the noise exposure at the workplace has been established. In Germany this led to the development of an effective noise dose called ELD (12).

Such a relationship is available neither for airborne ultrasound nor for conventional audible noise at the workplace in combination with airborne ultrasound. Studies are difficult since far less people are exposed to ultrasound than to audible noise at the workplace. In addition, the true exposure of the ear to sound and ultrasound becomes more and more difficult to determine as the presence of ear protection at workplaces grows but its usage by the employees cannot be monitored in every detail.

6. Conclusions

The industrial use of ultrasound technology is constantly growing. The scope of the German regulation for safety at work against hazards from noise and vibration that should be concerned with all hazards caused by noise at the workplace is, according to the interpreting technical rules, limited to noise within the audible frequency regime. Infrasound as well as ultrasound are explicitly excluded by the technical rules. Instead, the VDI 3766 specifies two guidance values for assessment and rating of the noise exposition at the work place caused by airborne ultrasound. Namely, the noise exposition level $L_{EXAU,8h}$ should not exceed 85 dB and the Z-rated peak level L_{Zpeak} should not exceed 140 dB. Additionally, the guideline VDI 2058-2 states a limit value of 110 dB for the (Z-weighted) sound pressure level $L_{Z,Third,5min}$ of the third with center frequency 20 kHz.

In general a profound uncertainness on the hazards caused by exposition to airborne ultrasound can be observed. Evidence give for example the strong variations in guidance and/or limit values between different countries. Since not sufficient data is available and so far a dose-effect-relationship could not be established the situation is not expected to change in the short term.

In the medium term it has to be goal of the prevention to measure airborne ultrasound at workplaces correctly and to involve it into the risk assessement. Without further knowledge the author suggests to use the guidance values of VDI 3766 along with the recommendations of Maue (5) when measuring and rating workplaces with airborne ultrasound.

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