A MEASUREMENT PROCEDURE FOR THE ASSESSMENT OF INDUSTRIAL ULTRASONIC NOISE

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Introduction: Although the possible negative health effects of exposure to high energetic ultrasonic noise, as emitted by industrial ultrasonic appliances, were discussed since the adoption of the technology in the first half of the twentieth century, no major research was conducted on this topic since the late twentieth century and it only regained focus approximately 10 years ago. The Ears II project was brought to life under the umbrella of the “European Metrology Programme for Innovation and Research”, to investigate the human perception of non-audible sound and its possible effects on human health. In this context the Institute for Occupational Safety and Health and the National Metrology Institute of Germany developed a measurement procedure for measuring industrial ultrasonic noise. Methods: Existing measurement techniques for audible sound were evaluated for their applicability to measuring ultrasound. Through evaluation of existing data a reference workplace was developed for laboratory measurements. These comprised simulated practical measurements and high spatial resolution scans of the sound field of an ultrasonic welding machine. Additionally, influences of environmental factors and by the presence of workers were investigated. Finally, a method was developed and tested in field measurements. Conclusion: The existing standards are mostly insufficient for the assessment of the exposure to ultrasonic noise. Either applicability to ultrasound is ruled out a priori or the methods or technical specifications are insufficient for the measurement of ultrasound, because the frequency range of interest is not covered and the allowed measurement uncertainties are too high, for example. Based on ISO 9612 and an existing German guideline a novel procedure was developed, which was adapted to practical needs after evaluation by occupational safety experts.

Keywords: airborne ultrasound, ultrasonic noise, risk assessment, measurement procedure, occupational safety

1. Introduction

Although the possible negative health effects of exposure to high energetic ultrasonic noise, as emitted by industrial ultrasonic appliances, were discussed since the adoption of the technology in the first half of the twentieth century, no major research was conducted on this topic since the late twentieth century. Measured by contemporary scientific standards the mode of action and the damage potential are also largely unknown [1]. Thus, airborne ultrasound poses a potential health risk for the exposed workers, who are increasing in numbers. While a measurement procedure and threshold values are standardised for audible frequency sound (16 Hz to 16 kHz) [2] this is not the case for airborne ultrasound. Thus, the exposition of workers to airborne ultrasound cannot reliably be determined.
The Ears II project [3] was brought to life under the umbrella of the "European Metrology Programme for Innovation and Research", to investigate the human perception of non-audible sound and its possible effects on human health. In this context the Institute for Occupational Safety and Health (IFA) and the Physikalisch-Technische Bundesanstalt (PTB) developed a measurement procedure for measuring industrial ultrasonic noise. We will present a draft of the novel method and the steps that led to its development.

2. Development of the procedure

Existing measurement techniques for audible sound [2, 4] were evaluated for their applicability to measuring airborne ultrasound. The abundance of machine categories was investigated by evaluation of existing data from ultrasound exposed workplaces of the IFA and the German Social Accident Insurance Institution for the energy, textile, electrical and media products sectors [5]. Using this data a representative machine category was chosen as source type for a reference workplace, which was developed for laboratory measurements. These comprised simulated practical measurements and high spatial resolution scans for characterisation of the sound field of the machine. Then, the procedure was drafted and presented to occupational safety experts and practitioners for evaluation. Finally, the procedure was tested in in-situ measurements for its practical applicability.

2.1 Preliminary survey and formation of hypotheses

The evaluation of the existing data yielded ultrasonic welding machines to be most abundant. A reference workplace was developed with such a machine as source. The evaluation of standardised methods showed that those methods do not account for the special properties of ultrasound fields, especially in terms of high spatial variability [6]. It was shown by Walther and Kling [7] that spatial variability and complexity of ultrasound fields increases with increasing frequency.

The results of the survey led to the hypothesis that the established procedures for audible sound cannot be used for airborne ultrasound. Stationary measurements, as described in these methods, are deemed insufficient due to the expected complex and unpredictable interference patterns within the sound fields. As an alternative to stationary measurements, an averaging approach was tested, which is supposed to enable reliable and reproducible determination of sound pressure levels at ultrasound associated workplaces.

2.2 Laboratory measurements

The established methods were compared with a novel spatially averaging approach. A reference workplace was built, to allow for reproducible and comparable measurements. At the IFA, measurements were carried out in a semi-anechoic room and at the PTB, the measurements were performed in the semi-anechoic chamber of a 3-axis-scanner.

2.2.1 Experimental set-up

At the IFA, the set-up was built upon a 3 m x 3 m reference platform. It consists of four square shaped elements with 1.5 m edge length. For coordinate determination the platform was laser engraved with a equidistant 2 cm grid. A laser distance meter of type "Leica Disto S910" was used for coordinate determination. A table was set-up at the middle of the reference platform. The reference machine was put on top of this table (cf. Figure 1). This is a representative set-up for this type of machine. Furthermore, this allows for easy alteration of the set-up, e.g. to introduce reflective surfaces into the sound field to simulate in-situ conditions. A "HiQ solid PropControl" ultrasonic welding machine was used as sound source, which was provided by Herrmann Ultraschalltechnik.
GmbH & Co KG. The machine was equipped with a cylindrical sonotrode (welding tool). It was operated without any product being welded. An external "Ultrabond digital 48.20" generator was used for this set-up.

![Ultrasonic welding machine](image)

Figure 1: Reference workplace with reference platform, table and ultrasonic welding machine in the semi-anechoic room at the IFA.

### 2.2.2 Test execution

The practically oriented measurements were performed according to an international standard for measuring audible sound [2] and a German national guideline for measurements of audible sound in the presence of ultrasound [4]. These were compared to a spatially averaging approach. For the stationary measurements according to ISO 9612 and VDI 3766 a 1/4"-microphone (Microtech Gefell MK301E) with a 1/2"-pre-amplifier (Microtech Gefell MV210) was positioned in the reference height for standing and sedentary workplaces of 1.55 m and 1.33 m (80 cm above seat), respectively. These positions are marked by orange stars in Figure 2. Spatially averaging measurements were performed within a window of ± 7.5 cm for standing workplaces and ± 5 cm for sedentary workplaces. The width of the window was chosen in accordance with the machine width. The measurements were carried out for two different sine-shaped paths and a semi-erratic pattern. One of the sine-shaped paths was vertically and the other horizontally oriented. Additionally, measurements were performed with one and two transitions within the window.

The measurement duration was 1 min. The machine was set to 500 ms welding duration with cycle durations of 2 s, 3 s, 4 s and 6 s. Additionally the machine was configured for continuous emission. Measurements were performed three times for every possible combination of configurations.

### 2.3 Results

Figure 3 shows the continuous equivalent sound pressure level in the 20-kHz one-third octave band grouped by mode of operation and different measurement heights. It was observed that the relation between stationary and averaging measurements is inverted for standing and sedentary position. Furthermore, a continuous level decrease was observed for the clocked machine configurations. The continuous mode of operations is shown for comparison.
3. Discussion of the results and hypotheses

The ultrasonic welding machine was chosen from the data collected by the IFA prior to this study. However, it must be noted that the existing workplace data are not representative [6]. Measurements at ultrasound associated workplaces are not mandatory in Germany and thus usually only carried out if there are any complaints or concerns.

The results of the laboratory measurements support the assumption that ultrasound fields produced by industrial ultrasonic appliances are complex. While different stationary positions seem to have a rather large impact on the recorded level, the different tested paths have very little observable impact on the results. If the stationary measurements were carried out at local extrema, it could account for the observed effect. The spatially averaging yields more reliable results.

4. Draft of the new procedure

It was shown that stationary measurements of airborne ultrasound do not yield reliable and reproducible results. The proposed method distinguishes between measurements in absence and presence of the employee. This is based on the insights concerning the complexity of ultrasound fields and the ultrasound associated workplaces. At some of those the presence is required for operation (e.g. welding machines, quality control at cutting machines in the food industry) while this is not necessary at other machines.

Since there are no insights of spatial influences and the impact of the presence of machine operators on the sound field yet, we will present only the part for measurements in absence of personnel. The measurement device must fulfil the requirements for sound level meters [8] and the extended criteria for measuring ultrasound [4, 8]. Measurements are performed without protective grid. A work analysis according to ISO 9612 is carried out before the measurements to choose representative tasks. The measurement height is calculated from the statistical average height of the group of employees working at this machine. The 1/4"-microphone is moved within a plane or volume, which is chosen in accordance with the representative movement pattern of the employee.
Figure 3: Results of the lab measurements at IFA. The welding duration (sound emission) was kept constant at 500 ms and the cycle duration was varied between 2 s, 3 s, 4 s, 6 s. The machine was additionally operated in continuous mode. Measurements were performed stationary, according to VDI 3766, and spatially averaging. Different patterns were chosen for the averaging approach (cf. Figure 2).

5. Conclusion

The existing standards are mostly insufficient for the assessment of the exposure to ultrasonic noise. Either applicability to ultrasound is ruled out a priori or the methods or technical specifications are insufficient for the measurement of ultrasound, because the frequency range of interest is not covered and the allowed measurement uncertainties are too high, for example. Based on ISO 9612 and an existing German guideline a novel procedure was developed, which was adapted to practical needs after evaluation by occupational safety experts.

In a preliminary survey, existing data was analysed to choose a reference machine. This was incorporated into a reference workplace, which was used for extensive laboratory measurements. The results of the practically oriented measurements and of the high spatial resolution scans were combined into a draft for a practical measurement method.

This draft does not account for workplaces which require the presence of an employee at all times. To come up with a method suitable for the latter case, investigations into the influences of spatial parameters and the presence of worker on the ultrasound field are required. While the measurements for determination of spatial influences were already carried out and are currently analysed, the analysis of influences of the presence of workers is planned to be investigated by a study with a subject group.

To us, another important part of the development of a new measurement procedure is the evaluation by seasoned experts. The method will be adapted based on the feedback from these experts with respect to practical applicability.

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