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Ultrasonic Noise Sources in a Work Environment

Bożena SMAGOWSKA

Central Institute for Labour Protection – National Research Institute
Czerniakowska 16, 00-701 Warszawa, Poland; e-mail: bosma@ciop.pl

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The use of ultrasonic energy has created versatile possibilities of their applications in many areas of life, especially in hydro location and underwater telecommunications, industry and medicine. The consequence of a widespread use of high intensity ultrasonics in technology is the increased number of people who are exposed to such ultrasonic noise. Therefore it is important to determine the types of machines and other devices that are responsible for the emission of ultrasonic noise (10–40 kHz of central frequencies of one-third octave bands) as harmful and annoying hazard in the work environment. This paper presents ultrasonic noise sources frequently used in industry and preventive measures reducing the exposure to ultrasonic noise. Two types of ultrasonic noise sources have been distinguished: machines and other devices used to carry out or improve production processes, the so-called technological sources and sources in which ultrasonic noise exists as a non-intentional result of operation of many machines and systems, the so-called non-technological sources of ultrasonic noise. The emission of SPL has been determined for each groups of devices based on own measurement results.

Keywords: ultrasonic noise, assessment, exposure, sources.

1. Introduction

Acoustic vibrations of frequency over 16 kHz (above the audible range) spreading in a form of elastic waves in gas environments, fluids and solids are defined as ultrasounds or ultrasonics. The practical use of ultrasonics is very versatile and the upper frequency limit is 10 GHz (Pawlaczyk-Łuszczyńska, 1999; Śliwiński, 2001; Nowicki, 2010). The consequence of the common use of high intensity ultrasonics in technology, medicine and everyday life is an increase of the number of people who are exposed to such ultrasonic noise. In respect of the frequency ranges, the low frequency ultrasonics (not exceeding 100 kHz) and high frequency ultrasonics (exceeding 100 kHz) are classified. The frequency range of ultrasonic noise according to the practical agreement definition used in Poland and other countries (*Regulation of the Minister of Labour and Social Policy of 29 November*, 2002) includes audible high frequency components (10–16 kHz of central frequencies of one-third octave bands) and low ultrasonic frequencies (up to 40 kHz band) that has extended the noise frequency spectrum with regard to the audible noise measuring range (usually covering the range from 125 Hz – 8 kHz of central frequencies of one-third octave bands).

Tests concerning the impact that ultrasonic noise has on people carried out so far show that this factor may have a harmful influence on the auditory system, causing loss of hearing, and may have a negative impact on the ear vestibule resulting in a perturbation of balance and nausea (Pawlaczyk-Łuszczyńska *et al.*, 2001). As regards impacts other than those related to hearing, it turned out that occupational exposure to ultrasonic noise of levels exceeding 80 dB in the audible frequency range and over 100 dB in the low ultrasonic frequency range cause vegetative-vascular changes (Pawlaczyk-Łuszczyńska *et al.*, 1999; 2001).

Examination of the hearing damage of people exposed to noise in a work environment is carried out mainly in low frequency ranges, i.e. 125–8000 Hz (as above mentioned), due to frequencies responsible for the understanding speech. On the basis of hearing loss examinations of people exposed to audible industrial noise over 85 dB for over an 8-year period of working in high frequency ranges (>8 kHz), it was proven that in the examined group of people quicker and higher changes of the hearing thresholds occur in high frequency audiometry (8–20 kHz) (Przeklasa *et al.*, 2008; Amir *et al.*, 2011). During the operation of some ultrasonic devices (e.g. during ultrasonic welding), the generated noise is similar to an impulse noise, which has an essential impact on the hearing damage (Pawlaczyk-Łuszczyńska *et al.*, 2007a; 2007b; Smagowska, 2010). Moreover, the operation of ototoxic agents (organic solvents, substances causing suffocation and heavy metals) on people occupationally exposed to noise may accelerate the process of shifting the hearing threshold (Śliwińska-Kowalska *et al.*, 2000).

To prevent the consequences of exposure to ultrasonic noise and the hearing damage, this factor has been listed as a health hazard (*Regulation of the Minister of Labour and Social Policy of 29 November*, 2002). As already mentioned the assessment of the exposure to ultrasonic noise in the work environment in Poland is carried out within the range of 10 kHz to 40 kHz central frequencies of third octave bands (*Regulation of the Minister of Labour and Social Policy of 29 November*, 2002). Thus, the identification of ultrasonic noise sources, i.e. machines and other equipment in the surrounding area, which cause the emission of ultrasonic noise as a harmful or bothersome factor in the work environment, is essential (Engel *et al.*, 2005; 2009) for the assessment of the hazard factor.

In this article, we have specified the method of the assessment of the exposure to ultrasonic noise at work stations and presented the assessment results for two kinds of ultrasonic noise sources distinguishing the so called technology (Smagowska, Mikulski, 2008), and non-technology sources of the professional exposure to these factors (Smagowska, 2012b) (as per own testing). On the basis of the long term own testing, we have provided, in a further section of this article, measurement results of equivalent sound pressure levels for selected workstations in that operated equipments that emit ultrasonic noise. Measurements were taken in the surrounding area of machines or devices during their operation in places where the worker is stationed and at a distance of 0.5–1 m (except for the furnace servicing station in the rolling-mill, which was measured at a distance of ca. 4 m). Preventive actions are also specified, regarding the limitation of exposure to this hazard factor.

2. Assessment of the exposure to ultrasonic noise

The assessment of the exposure to ultrasonic noise is carried out by the comparison of the selected values of the sound pressure level for a given one-third octave frequency band to the determined admissible values. For the purpose of assessing the exposure of a worker at a given work station to a particular type of noise, the measurement of ultrasonic noise is carried out at locations typical for the worker at the given work station considering all operations carried out by that person and standard conditions of the use of a tool, machine or device being the source of such noise (PN-N-18002:2011).

The admissible values of ultrasonic noise in respect of health protection (MAI – Maximum Admissible Intensity values) for workers in general, valid in Poland, are specified in the Regulation of the Minister of Labour and Social Policy of 29 November 2002. On the basis of the measurements, the physical values characterizing ultrasonic noise are identified as follows:

- equivalent sound pressure levels determined for the one-third octave frequency bands with the center frequencies f of: 10 kHz, 12.5 kHz, 16 kHz, 20 kHz, 25 kHz, 31.5 kHz and 40 kHz, in reference to an 8-hour labour day, $L_{feq,8\,\mathrm{h}}$ (or to a labour week $L_{feq,w}$ – in the case of exposure of a human body to ultrasonic noise at an irregular manner over individual days in a week or if a person works another number of days a week than 5);
- maximum sound pressure levels determined for the one-third octave frequency bands with the center frequencies f of: 10 kHz, 12.5 kHz, 16 kHz, 20 kHz, 25 kHz, 31.5 kHz and 40 kHz, $L_{f\,\max,d}$ during a labour day (or a labour week $L_{f\,\max,w}$).

Tables 1–3 specify the admissible values of ultrasonic noise at workstations for workers in general with the consideration of particular risk groups: pregnant women and young persons.

Table 1. Admissible values of equivalent sound pressure levels and maximum sound pressure levels at workstations for ultrasonic noise for general workers.

Central frequencies of terce bands of frequency f [kHz]	Admissible equivalent sound pressure levels $L_{feq,8\,\mathrm{h,dop}}$ or $L_{feq,w,\mathrm{dop}}$ [dB]	Admissible maximum equivalent sound pressure levels $L_{f\,\max,d,\mathrm{dop}}$ or $L_{f\,\max,w,\mathrm{dop}}$ [dB]
10; 12.5; 16	80	100
20	90	110
25	105	125
31.5; 40	110	130

Table 2. Admissible values of equivalent sound pressure levels and maximum sound pressure levels at workstations for ultrasonic noise in the case of pregnant women being employed.

Central frequencies of terce bands of frequency f [kHz]	Admissible equivalent sound pressure levels $L_{feq,8\,\mathrm{h,dop}}$ or $L_{feq,w,\mathrm{dop}}$ dB	Admissible maximum equivalent sound pressure levels $L_{f\,\max,d,\mathrm{dop}}$ or $L_{f\,\max,w,\mathrm{dop}}$ dB
10; 12.5; 16	77	100
20	87	110
25	102	125
31.5; 40	107	130

Table 3. Admissible values of equivalent sound pressure levels and maximum sound pressure levels at workstations for ultrasonic noise in the case of young persons being employed.

Central frequencies of terce bands of frequency f [kHz]	Admissible equivalent sound pressure levels $L_{feq,8\,\mathrm{h,dop}}$, or $L_{feq,w,\mathrm{dop}}$ [dB]	Admissible maximum equivalent sound pressure levels $L_{f\,\max,d,\mathrm{dop}}$, or $L_{f\,\max,w,\mathrm{dop}}$ [dB]
10; 12.5; 16	75	100
20	85	110
25	100	125
31.5; 40	105	130

3. Technology ultrasonic noise sources

Technologies using ultrasonics are increasingly widely used, e.g. in typography, electronics, automotive, textile, alimentary, watch-making, jewellers, optical and PVC producing industries (including packaging producing plants), mechanic workshops (including automotive workshops), medical centres, dentist and prosthetics offices, in laboratories and dispensaries as well as in medicine: diagnostics, physical therapy and surgery (Pawlaczyk-Łuszczyńska, 1999; Śliwiński, 2001; Nowicki, 2010). Densities of ultrasound power used for industrial purposes are within the range of 10 mW/cm^2 to 10 000 W/cm^2.

Apart from industrial production processing, ultrasonics are used for: powder pressing, dust removal, production of emulsify agents, aerosols, hydrosols etc., or in such commonly used equipment as: anti-burglary alarm equipment, dog whistles, bird and rodent deterrent equipment, air humidifiers and inhalation units. Moreover, ultrasonics are generated by medical equipment such as: diagnostic, physical therapy and surgical equipment. For physical therapy purposes, ultrasonics within the range of 0.5–1 MHz are used for deep treatments and 2.5–3 MHz for surface treatments (Pawlaczyk-Łuszczyńska, 1999). For diagnostic purposes, low power ultrasounds within the frequency range of 1–10 MHz are used (up to 30 MHz in ophthalmology). The intensities of ultrasounds generated by such equipment vary from 0.06 mW/cm^2 to 4 W/cm^2.

The main sources of ultrasonic noise in the work environment are technology sources of ultrasonic noise, i.e. machines and other equipment in which ultrasonics are used to execute or improve certain production processes. They generate ultrasound vibrations with a nominal frequency of 16–40 kHz (Pawlaczyk-Łuszczyńska *et al.*, 2007a; 2007b; Śliwiński, 2001; Nowicki, 2010). Most of these devices include the word "ultrasonic" as designation in their names. Namely, the technology ultrasonic equipment group includes: ultrasonic washers, ultrasonic welders (for plastic, metal and hardly wieldable materials), ultrasonic drills, manual soldering units, ultrasonic crucibles, fabric treatment machines (jet machines, lace machines and quilting machines), dental devices used for tartar removing – so called scalars, as well as ultrasonic guillotines, ultrasonic knives or ultrasonic curtains.

The basic frequency of operation of ultrasonic washers is within the range of 20–40 kHz with the ultrasonic component levels reaching 135 dB (Pawlaczyk-Łuszczyńska *et al.*, 2001).

For ultrasonic welders, the basic frequency of operation is within the range of 18–22 kHz with the ultrasonic component levels reaching 140 dB (Pawlaczyk-Łuszczyńska *et al.*, 2001). For ultrasonic drills the operation frequency range is typically between 16–30 kHz. The equivalent sound pressure levels at workstations with drills, depending on whether casings are provided for the equipment or not, varies between 90–120 dB (Smagowska, Mikulski, 2008).

The following figures present few examples of measurement results characterising ultrasonic noise sources in the work environment. Figure 1 presents example values of equivalent sound pressure levels in reference to 8 hours at technology work stations with the following ultrasonic equipments: a welder, a washer and a drill. The highest values exceeding those characterizing ultrasonic noise at these workstations occur in the one-third octave-bands centre frequencies close to the nominal frequency of operation (this is most often the 20 kHz central frequency band).

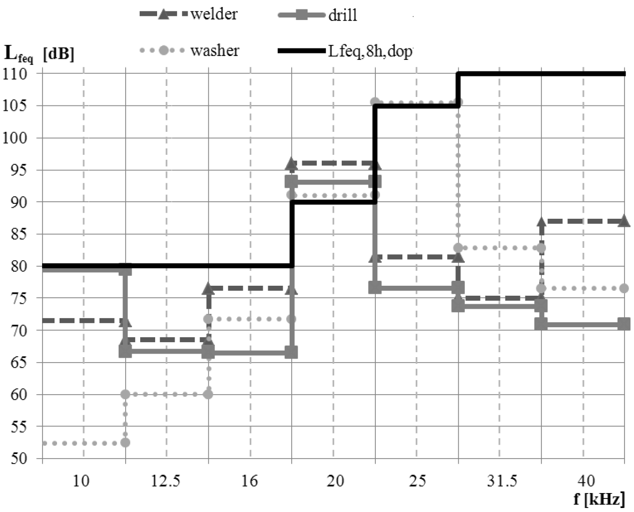

Fig. 1. Measurements results of equivalent sound pressure levels at work stations with: a typical welder, a washer and a drill ($L_{feq,8\,\mathrm{h,dop}}$ = MAI).

Over the last years, a significant group of technology ultrasonic equipment of low frequencies has been composed of ultrasonic machines for the finishing of fabric products or for decorative finishing of fabrics (e.g. jet machines, lace machines and quilting machines). The nominal frequency of operation of such equipment is within the range of 20–40 kHz with the ultrasound component levels reaching 120 dB.

Figure 2 presents the results of measurements of equivalent sound pressure levels in the one-third octave-bands at a workstation with a jet machine (a machine used for welding decorative stones into fabric). The highest value of this parameter occurs in the one-third octave-band centre frequency of 25 kHz and reaches the admissible value defined for this frequency band (105 dB).

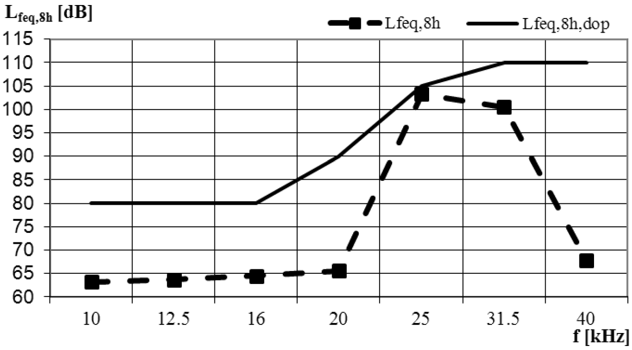

Fig. 2. Results of measurements of equivalent sound pressure levels in one-third octave frequency bands at a workstation with a jet machine ($L_{feq,8\,\mathrm{h,dop}}$ = MAI).

Increasingly more often automatic units and production lines are installed in production plants (e.g. for the production of disposable head covers of nonwoven fabric, shoe covers, disposable head covers of plastic foils or knives for cutting of tags or edible masses) using ultrasonic converters in their operation processes within the range of 20–40 kHz. In most cases, such equipment has covers, but even minuscule gaps may be a source of the ultrasonic noise component penetrating outside the cover, where the levels of such noise may reach up to ca. 110 dB and, depending on the location of the work station, may have a harmful effect on the operating person.

Moreover, ultrasonic guillotines and knives are commonly used in the food industry, the nominal frequency of operation of which is 20 kHz with the ultrasound component levels reaching 100 dB. Figure 3 presents the results of measurements of equivalent sound pressure levels in one-third octave-bands at a workstation for servicing a document cutting line. The highest value of this level is 95 dB in the one-third octave-band centre frequency of 20 kHz and exceeds the admissible value 90 dB defined for this frequency band.

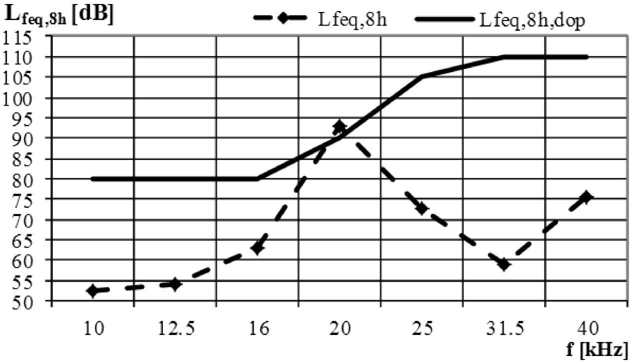

Fig. 3. Equivalent sound pressure levels in one-third octave frequency bands at a workstation of a document cutting line ($L_{feq,8\,\mathrm{h,dop}}$ = MAI).

The next work environment in which ultrasonic equipment is used are dentists' offices, in which units removing tartar are used, the so called scalers. The nominal frequency of operation of such equipment is 25 kHz with the ultrasonic component levels reaching 80 dB. Low frequency ultrasonic technology equipment includes also soldering units and ultrasonic crucibles used for soldering and galvanizing of various elements. Their industrial use is, however, significantly limited in respect of other equipments described above (Śliwiński, 2001).

4. Non technology sources of ultrasonic noise

Apart from the equipment listed above in which ultrasound vibrations are a working factor used in the technology process, ultrasonic noise is also generated as a non-intentional result of operation of many machines and equipment units and are described as non-technology sources of ultrasonic noise. Such equipment does not bear the name "ultrasonic device". Its identification as sources of potential ultrasonic noise at a workstation is difficult since the ultrasound components are not audible. Such identification I can be achieved only as a result of measurements. Most often, the noise spectrum emitted by such equipment includes significant sound pressure levels in a high audible frequency range and are recognized by persons exposed to such factors as squeaking, whistling and whooshing sounds. The small amount of literature available states that the presence of ultrasound components of significant sound pressure levels has been encountered in the surrounding areas of such equipment units during the operation of which aerodynamic or mechanic phenomena occur, as well as during other processes, such as e.g. welding or plasma cutting (Pawlaczyk-Łuszczyńska *et al.*, 2001; 2007a; Smagowska, Mikulski, 2008; Smagowska, 2012a).

The first group of equipment (during operation of which aerodynamic phenomena occur) includes among others: compressors, press units, burners, valves and pneumatic tools (including e.g. manual pneumatic tools, pneumatic wrenches and grinding machines).

Figure 4 presents as an example the results of equivalent sound pressure levels at workstations with vulcanisation press, washer tearing and cutting machines. The highest value of the emitted noise level oscillates around 83 dB in the one-third octave-band

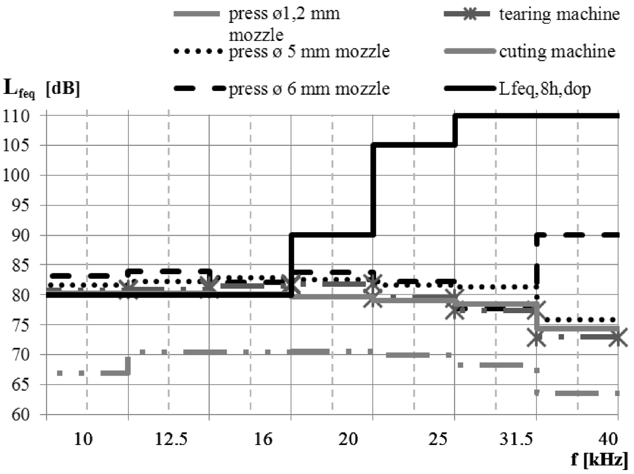

Fig. 4. Measurement results of equivalent sound pressure levels at workstations with a vulcanization press as well as the washer tearing and cutting machines ($L_{feq,8\,\mathrm{h,dop}}$ = MAI).

centre frequency of 12.5 kHz and exceeds the admissible value (80 dB) defined for this frequency band (Smagowska, 2010).

At detail cleaning workstations, during the use of valves with compressed air the equivalent sound pressure level in one-third octave-bands centre frequencies of 10 kHz; 12.5 kHz and 16 kHz is within the range of 90–98 dB. Figure 5 presents the results of equivalent sound pressure levels at workstations where detail drying (screen printing mask) and cleaning (printed plates and dishes) occur using compressed air. The exceeding of the admissible value of this parameter occurs at one-third octave-bands centre frequencies: 10 kHz; 12.5 kHz, 16 kHz and 20 kHz during the detail cleaning (Smagowska, 2010).

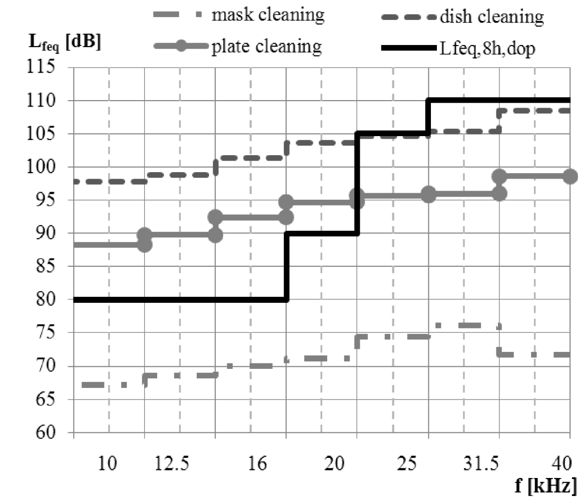

Fig. 5. Measurement results of equivalent sound pressure levels at workstations with detail drying and cleaning units using compressed air ($L_{feq,8\,\mathrm{h,dop}}$ = MAI).

For the group of such pneumatic tools as: chase rammers, pneumatic wrenches and grinders, the equivalent sound pressure levels, mainly in the one-third octave-band of centre frequency of 10 kHz vary between 85–92 dB. During the work with use of pneumatic hammers and compressors, the value of this level in one-third octave-bands centre frequencies of 10 kHz, 12.5 kHz and 16 kHz occurs within the range of 100–115 dB.

Another group of equipment generating ultrasonic noise components (in which the source of ultrasounds are mechanical processes) includes such units as: high-speed planers, milling machines, grinders, circular saws and some textile manufacturing machines (e.g. looms, throttles, stretching machines, twisters, winders and cards). For mechanical processing machines, i.e. timber planers and milling machines, the equivalent sound pressure level in the one-third octave-bands centre frequencies of 10 kHz and 12.5 kHz reaches 98 dB. For (angle) grinders and sledgehammers (with weights of 1,500 and 2,000 kG), the equivalent sound pressure level in the one-third octave band of central frequency of 10 kHz reaches 91 dB.

For the group of circular saws and cross saws for timber as well as belt saws for metal, the equivalent sound pressure level in the one-third octave-bands centre frequencies of 10 kHz, 12.5 kHz and 16 kHz occurs within the range of 95–100 dB. Figure 6 presents an example of results of the equivalent sound pressure levels in the one-third octave-bands during metal grinding using an angle grinder. The admissible values of this level (80 dB) are exceeded in the one-third octave-band of centre frequencies of 10 kHz, 12.5 kHz and 16 kHz.

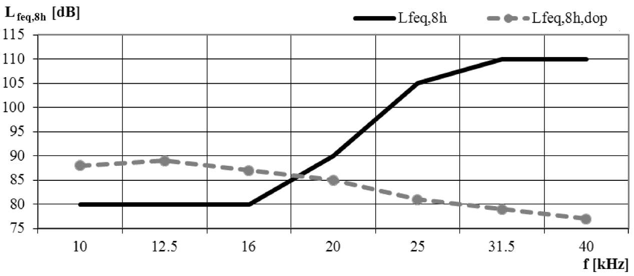

Fig. 6. Results of measurements of equivalent sound pressure levels in the one-third octave frequency bands at a workstation with a grinder ($L_{feq,8\,\mathrm{h,dop}}$ = MAI).

For the group of textile manufacturing machines (e.g. looms, throstles, stretching machines, twisters, winders and cards) the equivalent sound pressure levels vary within the range of 80–90 dB and the highest level values are measured in one-third octave-bands centre frequencies of 10 kHz, 12.5 kHz and 16 kHz (Smagowska, 2012a).

Figure 7 presents example values of equivalent sound pressure levels in reference to 8 hours at textile manufacturing workstations. For such ultrasonic noise sources, the highest values of levels characterizing ultrasonic noise occur in one-third octave-bands centre

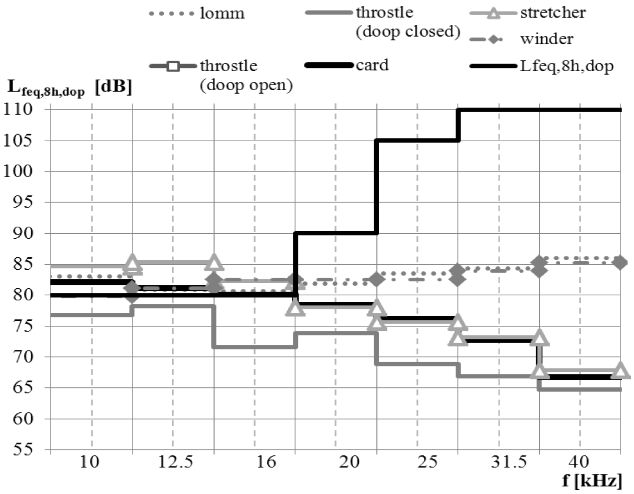

Fig. 7. Measurement results of equivalent sound pressure levels at textile manufacturing workstations ($L_{feq,8\,\mathrm{h,dop}}$ = MAI).

frequencies of 10 kHz, 12.5 kHz and 16 kHz. On the basis of the noise level results at a throstle workstation it is seen that major differences between the sound pressure levels (10 dB) occur in such bands both with open and closed doors to the machine.

Moreover, significant sound pressure levels in the scope of ultrasonic noise occur during welding (72 dB), cutting a metal sheet by means of an oxy-fuel cutting torch (75 dB), plasma cutting (87 dB) or rolling processes (80 dB).

Figure 8 presents example values of sound pressure levels in the one-third octave-bands while cutting a 25 mm thick metal sheet by an oxy-fuel cutting torch and cooling furnace semi-products (in a rolling-mill). For such operations, the highest values of the sound pressure levels occur in the one-third octave-band centre frequencies of 10 kHz, 12.5 kHz and 16 kHz and vary within the range of 75–80 dB.

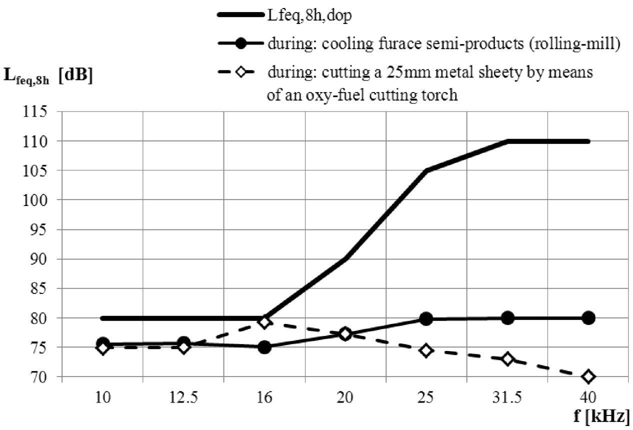

Fig. 8. Sound pressure levels during cooling furnace semi-products (rolling-mill) and cutting a 25 mm metal sheet by means of an oxy-fuel cutting torch ($L_{feq,8\,\mathrm{h}}$ = MAI).

5. Summary and conclusions

It should be stated that in reference to the technology ultrasonic noise sources, the highest values characterizing this hazard factor occur most often within the operating frequency of the equipment and in case of non-technology ultrasonic noise sources, in the three first one-third octave bands of central frequencies of 10 kHz; 12.5 kHz and 16 kHz. Due to the fact that these frequency bands overlap clearly with the upper range of audible sound frequencies, the risk of occurrence of hearing damage is assessed as high. Information presented in the article regarding machines and other equipments being non technology ultrasound noise sources is important to bring attention to the problem of exposure to this hazard factor in a work environment.

The harmful impact of ultrasonic noise may be limited in the case of exposure to operators in a work environment by taking the following relevant prevention steps *(Regulation of the Minister of Health and Social Policy of 30 May*, 1996; *Regulation of the Minister of Economy and Labour of 5 August*, 2005; PN-N-18002:2011; Dobrucki, 2010):

- limiting ultrasonic noise emission by changing the structure of the ultrasonic equipment,
- training the operating workers to use the ultrasonic equipment according to the principles of proper and safe unit servicing,
- educating the operating workers on the harmful impact of ultrasounds on the human body,
- use of common protection means (covers, casings and acoustic screens) limiting noise propagation,
- use of ear protection (properly selected for the noise spectrum) and head covers (helmets with transparent visors, e.g. made of Plexiglas),
- limiting the exposure by organizational methods (e.g. by proper location of workstations, forming silent centres and the rotation of staff),
- in case of exposure to noise in reference to an 8-hour work time being above the NDN values a shorter time of work should be adopted,
- carrying out initial and periodical preventive medical examinations (Engel *et al.*, 2005).

Moreover as a general conclusion one should state that the problem of assessment of ultrasonic noise in a work environment as a hazard factor present and is an important problem to recognize by further research and measurements. The classification of the ultrasonic noise sources in two groups the technology and non-technology ones as presented in the paper is a useful way in distinction of two kinds of situations existing in the ultrasonic noise impact on the human body and especially on hearing losses that seems to be more evident in the case of the second type of sources.

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