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# Assessment of Impulse Noise Hazard and the Use of Hearing Protection Devices in Workplaces where Forging Hammers are Used

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The impulse noise is agent harmful to health not only in the case of shots from firearms and the explosions of explosive materials. This kind of noise is also present in many workplaces in the industry. The paper presents the results of noise parameters measurements in workplaces where four different die forging hammers were used. The measured values of the $C$-weighted peak sound pressure level, the $A$-weighted maximum sound pressure level and $A$-weighted noise exposure level normalized to an 8 h working day (daily noise exposure level) exceeded the exposure limit values. For example, the highest measured value of the $C$-weighted peak sound pressure level was 148.9 dB. In this study possibility of the protection of hearing with the use of earplugs or earmuffs was assessed. The measurement method for the measurements of noise parameters under hearing protection devices using an acoustical test fixture instead of testing with the participation of subjects was used. The results of these measurements allows for assessment which of two tested earplugs and two tested earmuffs sufficiently protect hearing of workers in workplaces where forging hammers are used.

**Keywords:** impulse noise, noise attenuation, hearing protection device, die forging hammer.

## 1. Introduction

Impulse noise poses a risk for hearing both in the case of gunshots and explosions and in the case of many workplaces related to metalworking. Among the machines used at such workplaces, the highest values of $C$-weighted peak sound pressure level ($L_{C\text{peak}}$) of impulse noise are generated by die forging hammers in forges – they can reach 147 dB (Młyński *et al.*, 2012). Peak sound pressure level ($L_{\text{peak}}$) of impulse noise generated in the forging process can produce values in the 120–140 dB range with occasional occurrences of values in the 150–160 dB range (Taylor *et al.*, 1984).

Issues related to the characterization of noise produced by hammers, the assessment of the risk posed by noise generated during forging, and hearing protection against this kind of noise have been dealt with over the years (Młyński *et al.*, 2012; Taylor *et al.*, 1984; Sulkowski, Lipowczan, 1982; Starck *et al.*, 2002; Smeatham, Wheeler, 1998). These works show that impulse noise generated by hammers presents a risk of hearing loss. Hence, providing hearing protection for people working in forges is essential. The obligation to pay special attention to impulse noise is also imposed on the employer under the provisions of Directive 2003/10/EC (2003). Moreover, longtime exposure to noise, regardless of noise source, may cause i.a hearing loss (Pawlaczyk-Łuszczyńska *et al.*, 2013; Dobrucki *et al.*, 2013).

At high values of $C$-weighted peak sound pressure level (exceeding exposure limit value) produced in a forge, organizational methods of noise reduction are ineffective. The need of operating a hammer manually during the metalworking process makes the use of technical means, such as enclosures, inapplicable. In most cases, the nature of the risk posed by the impulse noise produced by hammers makes it impossible to introduce sound reduction methods other than the application of hearing protection devices. Therefore, the correct selection of hearing protection devices is essential for providing sufficient sound pressure level reduction of the noise reaching the ear.

The objective of this work is to determine the characteristics of noise produced by four different die forging hammers and to assess the associated risk of hearing damage, in accordance with the criterion applied to workplaces (Minister of Economy and Labour, 2005). In addition, the method of determining noise parameter values under hearing protection devices is presented in order to evaluate the degree of noise reduction provided by these devices. The assessment of the suitability of two types of earplugs and two types of earmuffs for hearing protection at the studied workplaces in the forge was carried out on the basis of measurements taken using an acoustic test fixture – a head and torso simulator. The presented method of assessing hearing protection devices makes it possible to avoid exposing subjects to impulse noise characterized by high values of peak sound pressure level.

## 2. Method

### *2.1. Measurements and assessment of noise exposure at a workplace*

The scope of impulse noise measurements at workplaces in the forge covered the determination of the following noise parameters: the $C$-weighted peak sound pressure level ($L_{C\text{peak}}$), $A$-weighted noise exposure level normalized to an 8 h working day ($L_{EX,8\,\text{h}}$) (daily noise exposure level) and the $A$-weighted maximum sound pressure level ($L_{A\,\text{max}}$). These parameters are required in compliance with the noise exposure assessment criterion applied to workplaces in Poland (Minister of Economy and Labour, 2005). Measurements were performed in accordance with the ISO 9612 standard (2009).

Exposure limit values specified in Polish regulations (Minister of Labour and Social Policy, 2002) were used for the noise exposure assessment. Exposure limit values for specific noise parameters are equal to: $L_{C\text{peak}}$ – 135 dB, $L_{EX,8\,\text{h}}$ – 85 dB, $L_{A\,\text{max}}$ – 115 dB.

### *2.2. Determining sound pressure levels under hearing protection devices*

Using hearing protection devices requires making a careful selection in order to ensure a sufficient reduction of sound pressure level of the noise reaching the employee. There are calculation methods for selecting hearing protection devices that allow for the assessment of the $A$-weighted equivalent sound pressure level ($L_{Aeq}$) under a hearing protection device (ISO 4869-2, 1994) or enable the estimation of the peak sound pressure level ($L_{\text{peak}}$) under a device – see information Appendix B to the EN 458 standard (2004). However, these methods cannot be used for the determination of any noise parameters. If the exposure limit values of the $L_{C\text{peak}}$ or $L_{A\,\text{max}}$ parameters are exceeded at a workplace, there is a need of verifying whether the values of these parameters under a hearing protection device are reduced below the level defined in the hearing damage risk criterion. The aforementioned calculation methods do not allow for the determination of the $L_{C\text{peak}}$ and $L_{A\,\text{max}}$ parameters under hearing protection devices. In addition, their accuracy is limited (Lenzuni *et al.*, 2012; Młyński, Kozłowski, 2013).

In view of the fact that when hearing protection devices are used there is no possibility of calculating noise parameters such as $L_{C\text{peak}}$ and $L_{A\,\text{max}}$ in a simple way, the assessment of exposure to impulse noise reaching the ears of an employee can be performed by carrying out measurements of the sound pressure level of impulse noise reaching underneath the hearing protection devices. The assessment of the impact of using hearing protection devices by means of measurements must not be performed with human subjects, as the impulse noise sound pressure level produced at workplaces in a forge exceeds exposure limit values. In such a situation, a hearing protection device that provides a potentially insufficient sound reduction for the noise at the workplace would pose a hearing damage risk for the subject participating in the research.

Due to impossibility of carrying out measurements with the participation of subjects, the consequences of using hearing protection devices can only be studied using head and torso simulators (Lenzuni *et al.*, 2012). Nevertheless, such an approach involves certain limitations regarding the precision of the simulation (Berger *et al.*, 2012). Specific corrections can then be applied in order to approximate the results obtained using head and torso simulators – acoustic test fixtures – to the results obtained when hearing protection devices are used by human subjects. Such corrections may include taking into account the occlusion effect, physiological masking and bone conduction (Giguère, Kunov, 1989) and have been applied in the studies of the effectiveness of impulse noise reduction by firearms (Lenzuni *et al.*, 2012), for example. A correction taking into account the influence of bone conduction is also recommended by the ANSI/ASA S12.42-2010 standard (2010).

In the present study, the measurements of noise parameters under hearing protection devices were performed using an acoustic test fixture described in chapter 4. In order to minimize the influence of the limited accuracy of the simulation of human features by the acoustic test fixture used in the study, individual correction frequency response was applied to each of the hearing protection devices under investigation, taking into account overall factors related to the use of hearing protection devices by humans. In order to correct noise time waveforms registered using the acoustic test fixture at workplaces in the forge, sound attenuation values were applied in reference to the noise attenuation values measured using the acoustic test fixture in the laboratory.

The sound attenuation values applied are taken from the data published in the user's manual of the hearing protection device. Sound attenuation is determined based on the threshold of hearing measurements (ISO 4869-1, 1990) and is specified in seven or eight one-third-octave frequency bands of the test signal. The attenuation of the hearing protection devices studied in the present work was measured for the same test signal using the acoustic test fixture.

During the construction phase of correction functions it was assumed that the assumed protection value provided by the studied earplugs and earmuffs would apply to 98% of the population of people using hearing protection devices. This assumption requires taking into consideration the data for sound attenuation of hearing protection devices (included in Table 1) in the form of the difference between mean attenuation and the doubled standard deviation for this attenuation (Voix, Zeidan, 2010; Lenzuni, 2009).

### *2.3. Assessment of the effectiveness of using hearing protection devices*

The measurements of exposure limit values of noise parameters at a workplace (Minister of Labour and Social Policy, 2002) used in the hearing damage risk criterion in accordance with the methodology of carrying out noise measurements at a workplace (ISO 9612, 2009) are performed in the absence of the worker or using a microphone located 10 cm away from the worker's head. In the present study, the measurements of noise parameters reaching underneath hearing protection devices were taken by means of the acoustic test fixture's microphone. It is therefore necessary to make reference between the values measured under the hearing protection device with the acoustic test fixture's microphone and the actual values that would be present at the location of the person exposed to noise.

The sound pressure levels $L_{C\text{peak}}$, $L_{EX,8\,\text{h}}$, $L_{A\,\text{max}}$ measured under the hearing protection device were compared to the levels occurring at the distance of 10 cm from the acoustic test fixture located at the investigated workplace using $\Delta L_{C\text{peak}}$, $\Delta L_{EX,8\,\text{h}}$, $\Delta L_{A\,\text{max}}$ determined in compliance with the relationships (1)–(3):

$$\Delta L_{C\text{peak}} = L_{C\text{peak},\,ATF\_no\_HPD} - L_{C\text{peak},\,10\text{ cm}}, \quad (1)$$

$$\Delta L_{EX,8\,\text{h}} = L_{EX,8\,\text{h},\,ATF\_no\_HPD} - L_{EX,8\,\text{h},\,10\text{ cm}}, \quad (2)$$

$$\Delta L_{A\,\text{max}} = L_{A\,\text{max},\,ATF\_no\_HPD} - L_{A\,\text{max},\,10\text{ cm}}, \quad (3)$$

where: – the index "$_{ATF\_no\_HPD}$" denominates the sound pressure level at the acoustic test fixture's microphone location without a hearing protection device put on the fixture, – the index "$_{10\text{ cm}}$" denominates the sound pressure level measured using the microphone located 10 cm away from the acoustic test fixture.

The assessment of the values of noise affecting the worker using hearing protection devices, in accordance with the aforementioned assumptions, is performed based on sound pressure levels measured using the acoustic test fixture's microphone under the hearing protection device, corrected in compliance with the sound attenuation data for a given hearing protection device and reduced by the determined $\Delta L_{C\text{peak}}$, $\Delta L_{EX,8\,\text{h}}$ and $\Delta L_{A\,\text{max}}$ values.

The criterion for assessing whether sufficient hearing protection is provided by specific earplugs and earmuffs was taken from the result of the comparison between the determined noise parameters values under hearing protection devices and of a certain limit value. Hearing protection devices are selected correctly when there is no risk of hearing damage (Directive 2003/10/EC, 2003; Minister of Economy and Labour, 2005). Therefore, verification was performed to check whether the determined values of the $L_{C\text{peak}}$ and $L_{A\,\text{max}}$ parameters did not exceed exposure limit values (Minister of Labour and Social Policy, 2002). Then, the hearing protection devices that resulted in reducing the $A$-weighted noise exposure level normalized to an 8 h working day ($L_{EX,8\,\text{h}}$) to the value that did not exceed the lower exposure action value were considered sufficient for providing hearing protection at the investigated workplaces. The lower exposure action value is lower by 5 dB from the exposure limit value and equals 80 dB (Directive 2003/10/EC, 2003; Minister of Economy and Labour, 2005). Taking the value of $L_{EX,8\,\text{h}}$ equal 80 dB as a criterion is justified by the fact that below this value there is practically no risk of causing hearing loss (Pawlaczyk-Łuszczyńska, 2010; ISO 1999, 1990).

## 3. Test object

### *3.1. Workplaces*

Measurements were taken at operator workplaces of four die forging hammers (position: forger): LASCO-400, LASCO-315, MPM 3150 and MPM 1600. Research was also carried out at trimming press or forge rolling machine operator workplaces (position: trimming machine operator) that neighbour the hammer operator workplaces, located approximately 4 m away.

### *3.2. Hearing protection devices*

Two models of popular foam earplugs and two types of popular earmuffs were selected for the study. Of the selected earmuffs, one type was intentionally chosen with small sound attenuation and the other one –with large attenuation. The hearing protection devices chosen for the study are listed in Table 1. The table also specifies the following values of their characteristic parameters, as published in the user information (ISO 4869-2, 1994): sound attenuation, H (high-frequency attenuation value), M (medium-frequency attenuation value), L (low-frequency attenuation value) and SNR (single number rating).

Table 1. Sound attenuation of the investigated earplugs and earmuffs in one-third-octave frequency bands: $m_f$ – mean value, $s_f$ – standard deviation; the values of the SNR, $H$, $M$, $L$ parameters characterizing the acoustic properties of the investigated earplugs and earmuffs. Values are given in dB.

| Hearing protection device | | One-third-octave-band centre frequency [Hz] | | | | | | | | SNR | $H$ | $M$ | $L$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 | | | | |
| Earplugs | | | | | | | | | | | | | |
| Howard Leight MAX (HL MAX) | $m_f$ | 34.6 | 37.1 | 37.4 | 38.8 | 38.2 | 37.9 | 47.3 | 44.8 | 37 | 36 | 35 | 34 |
| | $s_f$ | 3.0 | 4.5 | 4.3 | 3.7 | 3.5 | 4.0 | 3.5 | 7.2 | | | | |
| 3M 1100 | $m_f$ | 30.0 | 33.1 | 36.3 | 38.4 | 38.7 | 39.7 | 48.3 | 44.4 | 37 | 37 | 34 | 31 |
| | $s_f$ | 3.9 | 5.0 | 7.4 | 6.2 | 5.6 | 4.3 | 4.5 | 4.4 | | | | |
| Earmuffs | | | | | | | | | | | | | |
| Peltor Optime I | $m_f$ | | 11.6 | 18.7 | 27.5 | 32.9 | 33.6 | 36.1 | 35.8 | 27 | 32 | 25 | 15 |
| | $s_f$ | | 4.3 | 3.6 | 2.5 | 2.7 | 3.4 | 3.0 | 3.8 | | | | |
| Peltor Optime III | $m_f$ | | 17.4 | 24.7 | 34.7 | 41.4 | 39.3 | 47.5 | 42.6 | 35 | 40 | 32 | 23 |
| | $s_f$ | | 2.1 | 2.6 | 2.0 | 2.1 | 1.5 | 4.5 | 2.6 | | | | |

## 4. Measurement setup

A diagram of the measurement system used in the study is shown in Fig. 1. In order to record the time waveform of the noise sound pressure, a Brüel & Kjær 4135 microphone was used, which has a measurement range of up to 164 dB. The microphone was located 10 cm from the worker's head at the "ear" level.

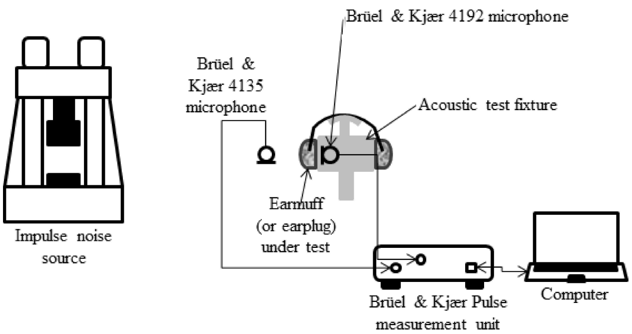


Fig. 1. Diagram of the measurement system.

Measurements under the cups of earmuffs and under earplugs were taken using an acoustic test fixture compliant with the ISO 4869-3 standard (2007). The test fixture is additionally equipped with two coupled chambers with a Brüel & Kjær 4192 measurement microphone. One of the aforementioned chambers – conical tube – simulates the dimensions and geometry of the external ear canal. Its dimensions correspond with the average dimensions of the human external ear canal. The chamber was lined with a layer of an elastic material resembling human skin. The second chamber of the acoustic test fixture serves to imitate the acoustic properties of the middle ear.

## 5. Results

### *5.1. Sound pressure level at workplaces*

The values of the $C$-weighted peak sound pressure level ($L_{C\mathrm{peak}}$), the $A$-weighted maximum sound pressure level ($L_{A\max}$) and the $A$-weighted noise exposure level normalized to an 8 h working day ($L_{EX,8\,\mathrm{h}}$) determined at forgers' and trimming machine operators' workplaces for the four die forging hammers considered in the study are shown in Figs. 2-4. Exposure limit values of the noise parameter considered in each case are also marked in the figures. In order to determine the $A$-weighted noise exposure level normalized to an 8 h working day ($L_{EX,8\,\mathrm{h}}$) it was assumed that the exposure time related to the operation of hammers and at adjacent workplaces equaled to 360 minutes during a workday.

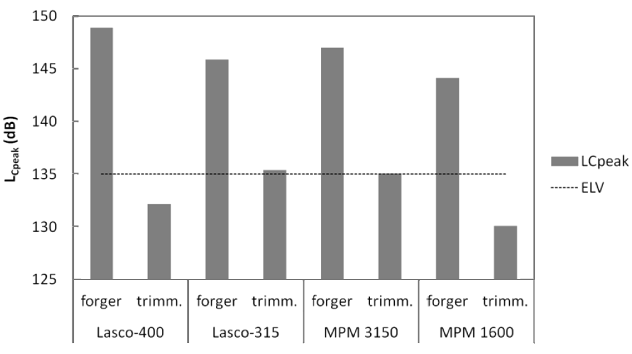


Fig. 2. $C$-weighted peak sound pressure level ($L_{C\mathrm{peak}}$) determined at workplaces in the forge. ELV – exposure limit value, trimm. – trimming machine operator.

The noise measurements demonstrated that the exposure limit values of the $C$-weighted peak sound pressure level ($L_{C\mathrm{peak}}$), $A$-weighted maximum sound pres-

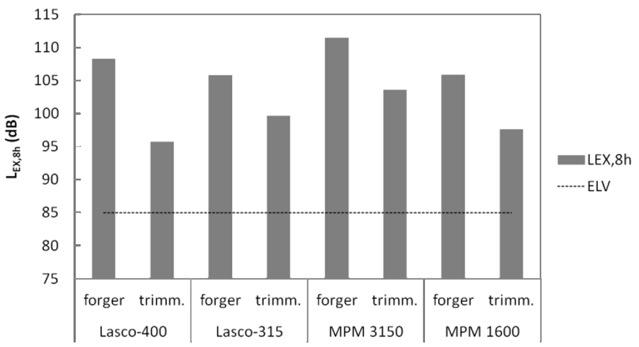


Fig. 3. $A$-weighted noise exposure level normalized to an 8 h working day ($L_{EX,8\,\mathrm{h}}$) determined at workplaces in the forge. ELV – exposure limit value, trimm. – trimming machine operator.

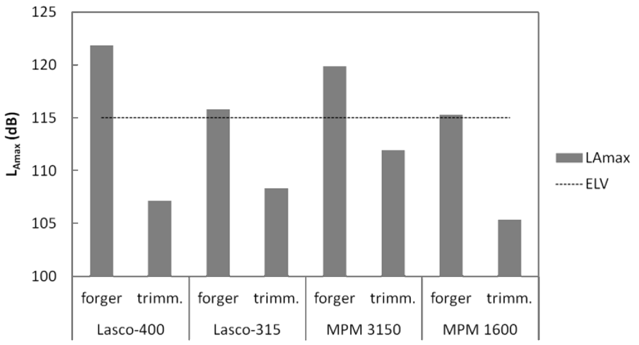


Fig. 4. $A$-weighted maximum sound pressure level ($L_{A\,\max}$) determined at workplaces in the forge. ELV – exposure limit value, trimm. – trimming machine operator.

sure level ($L_{A\,\max}$) and the $A$-weighted noise exposure level normalized to an 8 h working day ($L_{EX,8\,\mathrm{h}}$) were exceeded at workplaces of operators (forgers) of all the studied hammers. For workplaces adjacent to the hammer operator workplaces, the exposure limit values of the $A$-weighted noise exposure level normalized to an 8 h working day ($L_{EX,8\,\mathrm{h}}$) were exceeded for all the studied hammers and the $C$-weighted peak sound pressure level ($L_{C\mathrm{peak}}$) value was exceeded in the case of the Lasco-315 hammer.

### *5.2. Sound pressure level under hearing protection devices*

The results of the determination of parameters of noise to which the workers (forgers and trimming machine operators) are exposed when using hearing protection devices at workplaces in the forge are presented in Figs. 5–7. The assessment criterion values of the noise parameter considered in each case are also marked in the figures. Values shown in Figs. 5–7 are sound pressure levels measured using the acoustic test fixture's microphone under a hearing protection device and corrected in accordance with the methodology described in chapters 2.2 and 2.3. In order to determine the $A$-weighted noise exposure level normalized to an 8 h working day ($L_{EX,8\,\mathrm{h}}$), similar as in the case of noise measurements at workplaces, it was assumed that the exposure time related to the operation of hammers and at adjacent workplaces equaled to 360 minutes during a workday.

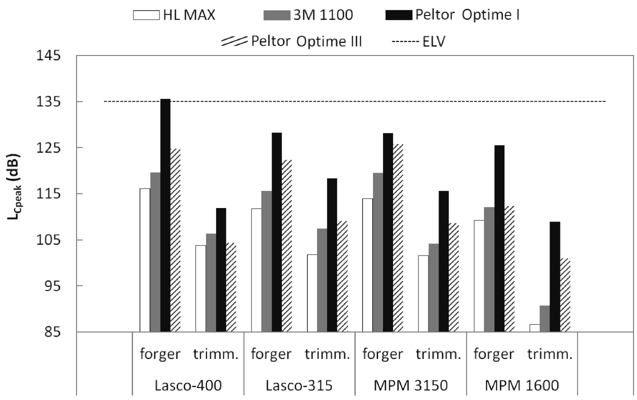


Fig. 5. $C$-weighted peak sound pressure level ($L_{C\mathrm{peak}}$) determined under hearing protection devices used at workplaces in the forge. ELV – exposure limit value, trimm. – trimming machine operator.

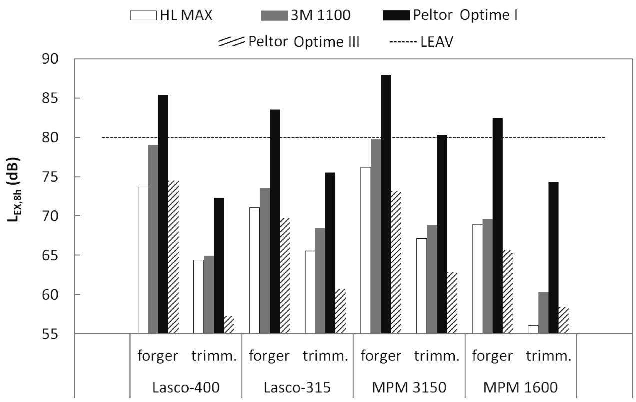


Fig. 6. $A$-weighted noise exposure level normalized to an 8 h working day ($L_{EX,8\,\mathrm{h}}$) determined under hearing protection devices used at workplaces in the forge. LEAV – lower exposure action value, trimm. – trimming machine operator.

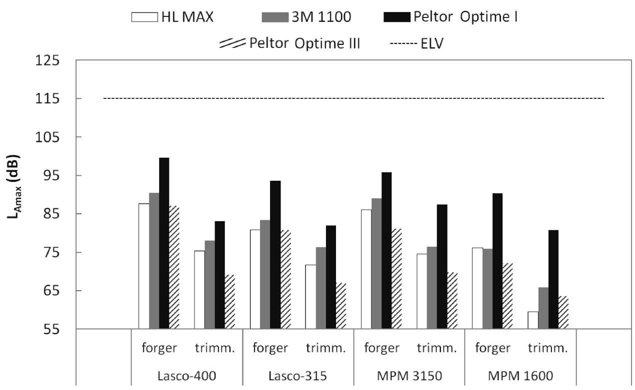


Fig. 7. $A$-weighted maximum sound pressure level ($L_{A\,\max}$) determined under hearing protection devices used at workplaces in the forge. ELV – exposure limit value, trimm. – trimming machine operator.

Earplugs provided the biggest reduction in the value of the $C$-weighted peak sound pressure level ($L_{C\text{peak}}$), but it shall be noted that this was demonstrated when they were put very deeply (inserted almost completely) into the testing device's chamber that simulated the external ear canal. In practice, achieving a similar level of protection requires good skills for placing the earplugs in the ear in an equally careful way.

In the case of the $A$-weighted noise exposure level normalized to an 8 h working day ($L_{EX,8\,\text{h}}$), the lowest values of this parameter were demonstrated when Peltor Optime III earmuffs were used. Protection proved to be insufficient in the case of Peltor Optime I earmuffs with small sound attenuation.

The lowest values of the $A$-weighted maximum sound pressure level ($L_{A\,\text{max}}$), similar as in the case of the $L_{EX,8\,\text{h}}$ parameter, were determined when Peltor Optime III earmuffs were used, whereas using Peltor Optime I earmuffs resulted in the highest sound pressure levels. However, for the $L_{A\,\text{max}}$ parameter, the reduction to a value below the exposure limit is achieved by each of the hearing protection devices considered in the study.

The results shown in Figs. 5–7 demonstrated that at all the investigated workplaces in the forge, hearing can be protected by using any of the two studied models of earplugs (Howard Leight MAX, 3M 1100) and the Peltor Optime III earmuffs.

In the case of the Peltor Optime I earmuffs with lower sound attenuation values than for Peltor Optime III, the values assumed as the criterion for the peak sound pressure level $L_{C\text{peak}}$ were exceeded at the workplace of the forger operating the Lasco-400 hammer. Exceeding the criterion value of the $A$-weighted noise exposure level normalized to an 8 h working day ($L_{EX,8\,\text{h}}$), related to the use of Peltor Optime I earmuffs occurred at workplaces of forgers operating all four die forging hammers, as well as the trimming machine operator of the MPM 3150 hammer. Lower attenuation earmuffs (Peltor Optime I) can only be used at workplaces of trimming machine operators close to the Lasco-400, Lasco-315 and MPM 1600 hammers.

## 6. Summary and conclusions

Using an acoustic test fixture allows for taking measurements of noise parameters under hearing protection devices without exposing human subjects to noise produced at workplaces. Using the measurement method to evaluate the results of using hearing protection devices provided means of assessing noise parameters under hearing protection devices (as it reaches a person's ear), i.e. of the $A$-weighted noise exposure level normalized to an 8 h working day ($L_{EX,8\,\text{h}}$), of the $C$-weighted peak sound pressure level ($L_{C\text{peak}}$) and of the $A$-weighted maximum sound pressure level ($L_{A\,\text{max}}$). In the case of the last two parameters, the determination and assessment of these values is not possible using calculation methods for the selection of hearing protection devices.

The study presents a method of analyzing measurement data obtained using an acoustic test fixture that gives results representing noise parameter values that would be determined in the case of using hearing protection devices by humans.

For impulse noise produced by industrial sources, the assessment of hearing damage risk must take into account the parameter related both to the equivalent sound pressure level ($L_{EX,8\,\text{h}}$), and to the values referring to instantaneous sound pressure levels ($L_{C\text{peak}}$ and $L_{A\,\text{max}}$). The assessment of the noise generated by die forging hammers in the forge demonstrated that exposure limit values are exceeded in the case of all three parameters mentioned above. Therefore, the verification of whether hearing protection devices would provide sufficient reduction of the value of each of these parameters was necessary. It turned out that not every hearing protection device is suitable against impulse noise in the forge, both in terms of the value of the $L_{EX,8\,\text{h}}$ parameter and of the $L_{C\text{peak}}$ parameter.

Due to the eventual migration of workers between individual workplaces in the forge, it is recommended to use the hearing protection devices that meet the requirement of providing sufficient protection at all workplaces.

The earplugs and earmuffs selected for using at specific workplaces shall effectively reduce the noise sound pressure level if they are used in an appropriate way, i.e. correctly placed, frequently inspected in terms of their technical condition and used continuously during the stay in an environment exposed to noise.


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