# Determining the impact of noise exposure of mining enterprises' workers

*Ivan* Petrenko[1*], *Dmytro* Rieznik[2], *Volodymyr* Shevchenko[1], *Oleksandr* Volkov[3], *Kateryna* Bilousova[2], and *Piotr* Toś[4]

[1]M.S. Poliakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine, Department of Vibro-Pneumotransport Systems and Complexes, 2a Simferopolska St., 49005 Dnipro, Ukraine
[2]Kremenchuk Mykhailo Ostrohradskyi National University, Department of Civil Safety, Labor Protection, Geodesy and Land Management, 20 University St., 39600 Kremenchuk, Ukraine
[3]Scientific-Research Institute of Military Intelligence, Scientific-Research Department, 81 Yuriia Illienka St., 04050 Kyiv, Ukraine
[4]Jestrzębska Jastrzębska Spółka Węglowa S.A., 4 Jana Pawła II Al., 44330 Jastrzębie-Zdrój, Poland

**Abstract.** This study investigated one of the main harmful factors at work, namely the impact of noise exposure on employees. The study was conducted in several stages. At the first stage, an on-site measurement was carried out using a calibrated sound level meter and a special smartphone application in the immediate vicinity of the ore grinding mill. It was found that the noise level is not constant. At the second stage, a mathematical dependence of the noise measurement results on the mill operating time was obtained to compare the measurement accuracy of the sound level meter and the app. As a result, it was determined that the application has sufficient accuracy compared to the calibrated instrument. The third stage resulted in the calculation of the risk of hearing loss for employees from noise exposure at workplaces based on the measurements of the calibrated sound level meter. The calculations showed that the level of this risk is high. At the fourth stage, personal protective equipment was selected using the relevant guidelines from NIOSH and EU-OSHA, as well as considering the results of field measurements, the maximum permissible noise level established by state sanitary standards, and the level of hearing loss risk.

## 1 Introduction

Mining and processing (M&P) is an important industry with significant impacts on the economy, geopolitics, environment, and people's lives. A crucial stage in the beneficiation process of various types of ores is their crushing, for which various types of mills are employed. This process involves the movement and fragmentation of ore from coarse to fine fractions using special abrasive materials such as metal balls of various diameters or special rods, driven by the mill's torque through mechanical drive components, resulting in significant noise pollution in workplaces. Noise pollution stands as one of the primary harmful factors affecting the health and performance of mill operators. Prolonged exposure to abnormal noise loads

* Corresponding author: i.s.petrenko95@gmail.com

carries significant physiological and psychological consequences for workers [1 – 3].

Determining the impact of noise exposure on workers in mining enterprises is a multifaceted endeavor requiring careful consideration of various factors [4, 5]. The first step involves conducting comprehensive noise measurements within the mining environment to accurately assess workers' levels of noise exposure. This entails utilizing specialized equipment like sound level meters and dosimeters to measure noise levels at different locations throughout the mining operation [4, 6].

Once noise levels are measured, the subsequent step is to evaluate workers' actual exposure to noise over time [7]. This necessitates gathering data on individual workers' locations and tasks performed during their shifts to ascertain their cumulative noise exposure. Armed with data on noise exposure levels and duration, the subsequent step is to assess potential health effects on workers [8]. While noise-induced hearing loss (NIHL) is a common concern in mining environments, other health issues such as stress, fatigue, and cardiovascular problems may also correlate with prolonged exposure to high noise levels [9]. Audiometric testing is essential for assessing workers' hearing health and detecting early signs of noise-induced hearing loss. Regular audiometric testing should be part of a comprehensive hearing conservation program to monitor workers' hearing status over time [10, 11].

Implementing engineering controls to mitigate noise at its source is crucial for lessening the impact of noise exposure on workers [12 – 14]. This may entail installing noise barriers, enclosing noisy equipment, or employing quieter machinery and equipment. In addition to engineering controls, administrative measures such as job rotation, exposure time limitation, and provision of quiet areas for rest breaks can contribute to reducing workers' overall noise exposure [10, 15]. Personal protective equipment (PPE) like earplugs and earmuffs plays a vital role in shielding workers from excessive noise exposure [10, 16]. However, PPE should be considered a last resort after implementing engineering and administrative controls [15, 17].

By following these steps and implementing comprehensive noise control measures, mining enterprises can effectively safeguard their workers from the adverse effects of noise exposure while maintaining a safe and healthy work environment. While standard certified measuring instruments are conventionally used to gauge hazardous and harmful factors at work, recent research has demonstrated the feasibility of employing modern information and computer technologies [18, 19].

## 2 The choice of object to study

An analysis of workplace maps and risk maps at mining and processing plants (MPPs) has shown that the impact of noise on workers in ore processing and crushing is the most significant. The workplaces are located directly next to the mill's operating mechanisms, which creates a risk of chronic processes in the employee's body that can lead to hearing loss.

The most common machine used in crushing and processing plants to crush minerals is a ball mill with central discharge (BMP) (Fig. 1). Steel or cast-iron balls with a diameter of 40 to 150 mm are loaded into the mill drum, which is approximately half full. As the drum rotates, the balls move, roll, or fall, which causes the mineral grains to be crushed. The ore is crushed mainly by the impact of the crushing media and partially by their abrasion and grinding.

The technical characteristics of the mill BMP 4.5 × 6 are displayed comprehensively in Table 1. This table provides detailed information on the specifications of the mill, allowing for a thorough understanding of its capabilities. Engineers and operators can refer to this table to assess the dimensions, capacities, and other key parameters of the BMP 4.5 × 6 mill. Such detailed specifications facilitate informed decision-making and efficient utilization of the equipment in various industrial settings.

**Fig. 1.** Exterior of BMP mills.

**Table 1.** Technical characteristics of the mill BMP 4.5 × 6.

| Technical characteristics | Value |
|---|---|
| Lining thickness | 120 mm |
| Inner diameter of the drum (without lining) | 4500 mm |
| Working diameter of the drum (light) | 4260 mm |
| Drum length | 6000 mm |
| Working volume of the drum | 85 $m^3$ |
| Drum rotation speed | 16.5 rpm |
| Ball load weight | 165 t |
| Weight of the cutter | 355 t |
| Electric motor power | 2500 kW |
| Speed | 150 rpm |
| Dimensions | 16000 × 9100 × 6800 mm |

It is worth noting that the mills operate around the clock and only stop completely for routine maintenance or for reloading.

At the MPP, employees work in three shifts of 8 hours each. Out of this eight-hour working day, 2 hours are allocated for a break, leaving 6 hours for work processes. Therefore, the noise load measurements were carried out in a 6-hour period with an interval of 30 minutes.

According to the state sanitary standards, the maximum permissible noise level at permanent workplaces should not exceed 80 dB(A) (Performance of all types of work at permanent workplaces in production facilities and on the territory of enterprises) [20].

## 3 Research methods

At the first stage of the study, the noise pollution of the mill operator's workplace was measured simultaneously using a testo 816-1 sound level meter (calibration certificate No. UA/22/23124/000083 dated 24.01.2023, valid until 24.01.24) and a smartphone microphone using the NIOSH Sound Level Meter application. This application allows you to measure in A-weighted decibels (i.e. those that affect human hearing): instantaneous noise level, LAeq, Lmax, LCpeak, TWA, Dose, Projected dose, and a measurement log is available in the application. In the settings, you can also change the noise threshold and other parameters. The app can also use an external microphone for more accurate measurements. The choice of this app was based on the developer's specifications [21], and studies on its accuracy [22, 23].

The appearance of the device and the application is shown in Fig. 2.

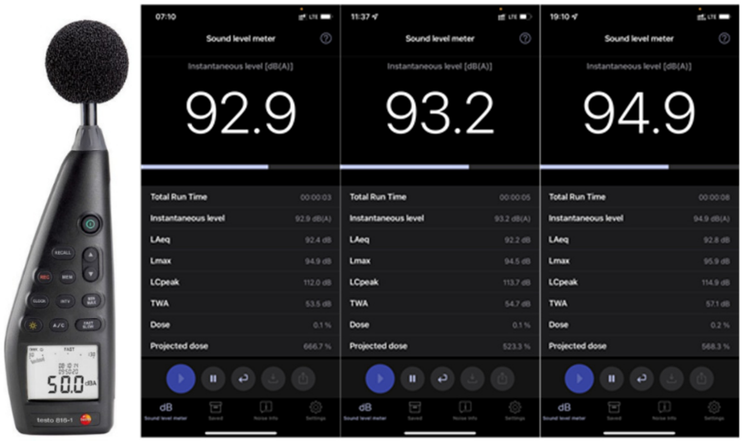


**Fig. 2.** Testo 816-1 sound level meter and the appearance of the NIOSH Sound Level Meter application.

At the second stage of the study, a specialized mathematical software tool for processing statistical data was used to validate the results and assess the accuracy of the measurements. Therefore, for the sake of the purity of the comparison results, a 7th degree polynomial regression model was chosen to be applied to both measurement results. This mathematical model best describes the relation between sound level change and measurement time, mainly for the testo 816-1 sound level meter since it has a calibration certificate and therefore its measurement results can be considered as a reference.

During the third and fourth stages of the study, the risk of hearing loss from constant noise exposure was calculated and recommendations were made on the use of personal hearing protection equipment for workers, respectively.

# 4 Research results

## 4.1 Measurement of the noise pollution

Figs. 3 and 4 depict the outcomes derived from the measurements conducted using both the testo 816-1 and NIOSH Sound Level Meter. These graphical representations offer a visual insight into the data gathered from the assessment. By examining the results we can gain a comprehensive understanding of the noise levels detected by each device. Such visual aids facilitate a thorough analysis and comparison of the performance of the measurement instruments.

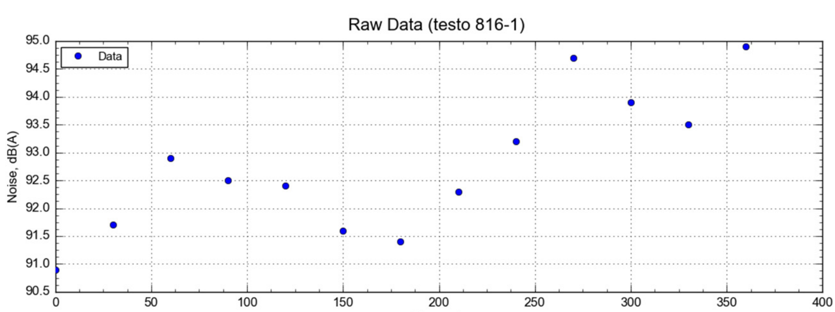


**Fig. 3.** Noise level measurements with the testo 816-1 sound level meter (X-axis – time, min; Y-axis – A-weighted equivalent continuous sound level, dB).

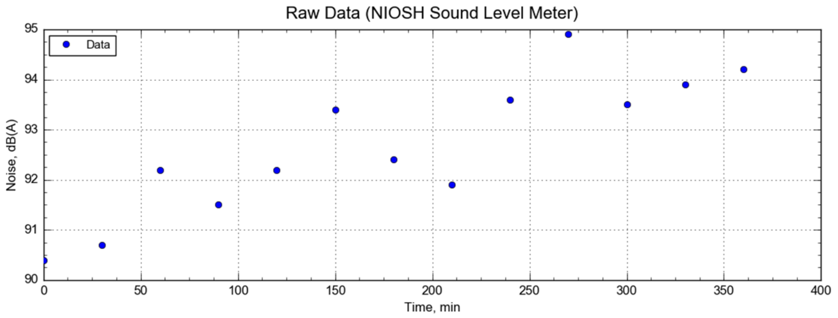


**Fig. 4.** Noise level measurements using the NIOSH Sound Level Meter app (X-axis – time, min; Y-axis – A-weighted equivalent continuous sound level, dB).

It's notable that based on the measurement outcomes, the noise levels vary intermittently during mill operation. This observation suggests that the noise produced by the mill fluctuates over time rather than remaining constant. Understanding this variability is crucial for accurately assessing the overall noise exposure experienced by workers during mill operations. Further investigation into the factors contributing to these fluctuations may be necessary to implement effective noise control measures.

## 4.2 Validation of results and assessment of measurement accuracy

Based on the results of the polynomial regression approximation shown in Figs. 5 and 6, the regression formula (1) was obtained, and Tables 2 and 3 show the regression coefficients, standard error of measurement, correlation, and determination coefficients of the model.

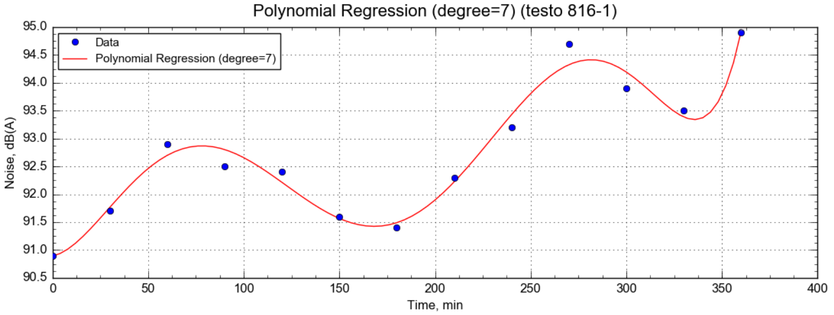


**Fig. 5.** Graph of approximate sound level dependence on operating time (testo 816-1).

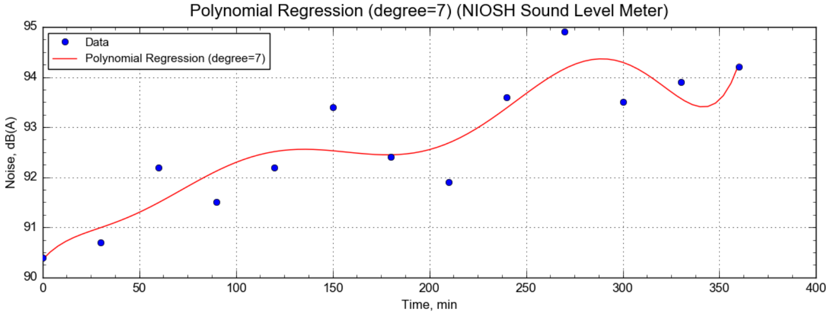


**Fig. 6.** Graph of the approximate sound level dependence on operating time (NIOSH Sound Level Meter application).

A mathematical expression that provides a basis for understanding the dynamics of sound levels during a work process:

$$L(t) = a + bt + ct^2 + dt^3 + et^4 + ft^5 + gt^6 + ht^7, \quad (1)$$

where $t$ is the operating time, $a$, $b$, $c$, $d$, $e$, $f$, $g$, $h$ is the coefficients of the approximation expression.

**Table 2.** Data value of the approximation expression (testo 816-1).

| Coefficients | | | | | | | |
|---|---|---|---|---|---|---|---|
| $a$ | $b$ | $c$ | $d$ | $e$ | $f$ | $g$ | $h$ |
| $9.08\cdot10^{-11}$ | $6.55\cdot10^{-15}$ | $1.26\cdot10^{-15}$ | $-1.97\cdot10^{-17}$ | $9.31\cdot10^{-20}$ | $-6.57\cdot10^{-23}$ | $-4.90\cdot10^{-25}$ | $8.45\cdot10^{-28}$ |
| Standard error | | | | | | | |
| 0.31 | | | | | | | |
| Correlation coefficient ($R$) | | | | | | | |
| 0.99 | | | | | | | |
| Coefficient of determination ($R^2$) | | | | | | | |
| 0.97 | | | | | | | |

**Table 3.** Data value of the approximation expression (NIOSH Sound Level Meter).

| Coefficients | | | | | | | |
|---|---|---|---|---|---|---|---|
| $a$ | $b$ | $c$ | $d$ | $e$ | $f$ | $g$ | $h$ |
| $9.03\cdot10^{-12}$ | $4.30\cdot10^{-15}$ | $1.37\cdot10^{-16}$ | $2.88\cdot10^{-18}$ | $-2.80\cdot10^{-20}$ | $1.32\cdot10^{-22}$ | $-3.01\cdot10^{-25}$ | $2.61\cdot10^{-28}$ |
| Standard error | | | | | | | |
| 0.87 | | | | | | | |
| Correlation coefficient ($R$) | | | | | | | |
| 0.91 | | | | | | | |
| Coefficient of determination ($R^2$) | | | | | | | |
| 0.89 | | | | | | | |

Based on the analysis results, the accuracy of the NIOSH Sound Level Meter app appears slightly inferior to that of a specialized device, albeit remaining within the standard error margin. Consequently, the app is deemed suitable for primary use in routine workplace noise measurements and as a personal noise dose meter for workers.

### 4.3 Calculation of the risk of hearing loss

An indicator for assessing noise in the working environment is the A-weighted sound pressure level – $L_{Aeq}$, which is a measure of the time-averaged value of acoustic energy [24].

If the measurement time interval $T_o$ is divided into smaller time intervals $T_e$, then the A-weighted sound pressure level, in dB, is calculated by the formula:

$$L_{A_{eq}} = 10\log\left[1/n\sum 10^{L_{A_{eq},Te}/10}\right], \quad (2)$$

where $L_{Aeq,Te}$ is the A-weighted equivalent sound pressure level, corrected for frequency characteristics, in the time interval $T_e$, $n$ is the number of measurements.

Based on the calculations in Formula 2, we have $L_{Aeq}$ = 92.93 dB.

Next, calculate the noise exposure level (dB) during an 8-hour working day using the formula:

$$L_{ex_{8h}} = L_{A_{eq}} + 10\log\frac{T_e}{T_o}, \quad (3)$$

where $L_{Aeq}$ is the A-weighted sound pressure level; $T_e$ is the exposure time, in minutes, during the working day; $T_o$ is the control time, equal to 8 hours (480 minutes), or using a daily noise exposure calculator in a special spreadsheet.

Calculated noise exposure level (dB) during an 8-hour working day $L_{ex_{8h}} = 91.681$ dB.

The risk of hearing loss from constant noise exposure is calculated using the formula [24]:

$$R_{ex,8h} = 10^{0.1(L_{ex_{8h}} - L_{dop})}, \quad (4)$$

where $L_{ex_{8h}}$ is the noise exposure level (dB) during an 8-hour working day; $L_{dop}$ is the permissible noise level of 80 dB.

Risk level indicators:

- Low/minimal risk of hearing loss – $R_{ex,8h} < 0.5$;
- The medium risk of hearing loss is $0.5 \le R_{ex,8h} \le 1.0$;
- High risk of hearing loss – $R_{ex,8h} > 1.0$.

The risk level of hearing loss from the noise exposure of a mill operator $R_{ex,8h} = 14.727$ calculated using formula (4) is high. Therefore, it is recommended that personal hearing protection is mandatory to reduce the risk.

### 4.4 Selection of personal hearing protection equipment

Commonly used types of such protection include earmuffs and earplugs.

The type of protection should be determined individually, for which the employer should conduct an individual ergonomic assessment by selecting (fitting) different types of PPE, or use the guidelines from NIOSH and EU-OSHA [25, 26].

Based on the results of the field studies, it was found that the noise level does not exceed 95 dB(A), which means that to reduce the noise level to the maximum level of 80 dB, personal protective equipment with an insulation level of 15 dB or more should be used. Therefore, the following modern types (examples) of PPE are suggested for use:

- Earmuffs – DELTA PLUS INTERLIGHT (noise isolation according to SNR standards – 26 dB, NRR 21 dB), ISOtunes Link 2.0 (noise isolation according to SNR standards – 30 dB, NRR 25 dB) (Features – can be used as a Bluetooth headset). Disadvantages – inconvenient to use with helmets. Since helmets are a mandatory element of workwear on the territory of a mining and processing plant, this disadvantage is levelled by modifications with a helmet mount (DELTA PLUS SUZUKA 2, LINK 2.0 Helmet Mount).
- Active earplugs – ISOtunes Pro 2.0 (noise isolation according to SNR standards – 36 dB, NRR 27 dB), ISOtunes Free (noise isolation according to SNR standards – 32 dB, NRR 22 dB) (Features – can be used as a Bluetooth headset).
- Earplugs – NEO TOOLS 97-550 (noise absorption level – 33 dB), DELTA PLUS CONIC200 (noise absorption level – 37 dB).
- Custom-made earplugs – these are made individually for each worker, but they will not work well if the fit or moulding is not correct.

## 5 Conclusions

Experimental studies have established that the level of noise pollution at the mill operator's workplace in the crushing plant (mill plant) is uneven and constantly varies from min – 90.9 dB(A) to max – 94.9 dB(A), which significantly exceeds the regulatory maximum permissible level at permanent workplaces in production facilities and on the territory of enterprises of 80 dB(A).

A mathematical model of the dependence of sound level and mill operator's working time was obtained based on the results of measurements of the testo 816-1 sound level meter and a smartphone microphone using the NIOSH Sound Level Meter application. The adequacy of the model is verified by the corresponding coefficients of determination of 0.974 and 0.893, which indicates a high degree of connection of the system coefficients.

The calculated risk level of hearing loss from the noise load of the mill operator is high and equals $R_{ex,8h} = 14.727$. Therefore, it is proposed to use modern personal hearing protection equipment, namely, those made according to the individual ergonomic characteristics of the employee.

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