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NOISE LEVEL MEASUREMENT AND ANALYSIS IN A MANUFACTURING ENTERPRISE

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Abstract: Noise is one of the most common physical factors causing nuisance and harmful to worker health in the long term. The focus of the research was the measurement and analysis of the noise level at the screw injection moulding machine operation station intended for plastic elements' manufacturing. The occupational risk evaluation was conducted based on the observed data. The results of the study allowed for the development of precautionary and preventive measures. Furthermore, the paper features identification of the work environment factors occurring in the studied manufacturing enterprise with division to dangerous, harmful, and bothersome.
Keywords: noise, work environment factors, work safety, occupational risk

1. INTRODUCTION

The execution of each professional work features human exposure to various hazards. They are mainly determined by the impact of work environment factors specific for each discipline, occupation or given position. This specifically concerns manufacturing enterprises for which the manufacturing process itself affects the work process and is related to the occurrence of complex dependencies in the work environment (Niciejewska and Kiriliuk, 2020; Woźny, 2020). Workplaces should be adapted as well as possible for the safe execution of work to prevent any types of accidents. Often seemingly trivial shortcomings or belittling the impact of various factors on work can lead to dangerous effects for human life and health. A distracted worker can accidentally enter an incorrectly secured hazardous work zone and be exposed to a direct hazard to health or life. Another example is when a worker stays for an excessively long time in an environment of physical, biological, or chemical factors, as well as direct or indirect contact with such factors. Working with any type of machines and devices, requiring the ability to use them correctly and compliance with safety principles, is especially dangerous (Fila et al., 2020; Kielesińska, 2020; Niciejewska and Obrecht, 2020).

In subject literature, work environment factors are divided into three categories, depending on danger level and the effects caused. These include dangerous, harmful, and bothersome.

Dangerous factors, also known as injury risk factors, are characterised by a sudden impact on the human organism and they include, e.g. hazards caused by machine operation, moving or sharp elements, electrocution, etc. *Harmful factors* that can affect a human performing his or her duties in the work environment cause negative consequence for the worker's health and life during, e.g. intoxication, bodily injury and damage, other health damage, e.g. hearing loss. *Bothersome factors* occurring in the work environment can lead to lowering the worker's physical and mental fitness (e.g. long-term sitting in front of a computer), distraction, apathy, fatigue, etc. Therefore, hazards at the workplace can be divided into those resulting from the work environment determined by physical, chemical, and biological factors or from the work execution manner.

In case of a change in the given factor's degree of impact on the human organism, a factor classified as harmful can be reclassified as dangerous. On the other hand, long-term worker exposure to bothersome factors can lead, after a certain time, to the factor's reclassification as a harmful factor (Frymus and Babicz, 2017). Summarising the foregoing considerations, work environment factors can be categorised in the following manner (Uzarczyk, 2009):

- dangerous - the factors' immediate impact on the worker can cause injuries or lead to the deterioration of the worker's general well-being and health condition, or even cause death;
- harmful - the factors' impact on the human organism can lead to the deterioration of the worker's health condition or can cause health problems**.**
- bothersome - the factors constitute a group of factors that indirectly affect the worker. They do not directly cause a deterioration in the worker's health or well-being, but their effects can appear after a long time. The bothersome factors also have a negative impact on the worker's concentration capacity, thereby reducing his or her performance.

Each work environment includes factors that affect work, however the hazards caused by them only occurs when the maximum permissible concentration (MPC) and maximum permissible intensity (MPI) specified in the regulations and standards are exceeded. Identification and then minimisation or elimination of adverse work environment factors is very important, mainly for the sake of worker health and life, but also for the employers' performance of their duties specified in legal codes and acts. Along with increasing public awareness on the hazards present in work environments, legislators, organisations, and enterprises started to develop various regulations, standards and safety principles that implement strict rules on job creation. Their purpose is to ensure worker safety in a holistic manner and simultaneously reduce hazard occurrence. Furthermore, in order to eliminate the occurrence of adverse work environment factors or limit their adverse impact on worker health and life, employers are obliged to apply a series of precautionary and preventive measures (Regulation of the Minister of Economy and Labour of 5 August 2005 on occupational health and safety at work featuring exposure to noise or mechanical vibration, the Regulation of the Minister of Family, Labour and Social Policy of 12 June 2018 on the maximum permissible concentration and intensity of factors harmful to health in the work environment).

Noise is one of the physical hazards classified as a bothersome factor and possibly even a harmful factor in the long-term. According to the definition, it means the impact of sounds with various frequencies on the human organism. In the Polish Standard, noise is defined as sound of any acoustic nature, which is undesired by the given person and in the given conditions. Noise is divided into audible and inaudible for the human ear. It depends on the acoustic vibration frequency expressed in hertz (Hz). Audible noise fluctuates in the range of 20 Hz to 20,000 Hz, while inaudible noise, including infrasound fluctuates from 1 to 20 Hz, and ultrasound is above 20 kHz (PN-N-01307: 1994, PN-N-18002, PN-Z-01338:2010)

In a short time, noise can only cause discomfort for humans and have an adverse impact on their well-being and concentration. Long-term exposure to noise can have much more serious consequences including, among others, hearing impairment and even deafness. Sounds are characterised by varied biological impact on humans, depending on their frequency. For this reason, the noise level evaluation features sound designations: A – low sounds, B – medium sounds and C – high sounds, recorded as dB(A), dB(B) and dB(C) accordingly, which are in practice aimed at describing human auditory sensations (Łukjaniuk, 2019; Raczkowski, 2009).

The harmful impact of noise is accumulating over time. This means that the adverse impact of high-frequency sounds is not identifiable immediately after exposure. Seemingly harmless noise with a relatively low intensity, e.g. 75-85 dB(A), not exceeding the current standards, but with its effect lasting continuously for several or even over a dozen years, can lead to permanent and serious hearing damage and to the occurrence and development of neurotic diseases. Therefore, from the employer's perspective, it is necessary to strictly comply with the standards and regulations in force. Aside from the adverse impact of noise on the human organism, especially hearing damage, noise substantially affects the worker's performance and, in turn, the economic factors.

Noise significantly disrupts the worker's concentration. In a long-term perspective, exposure to noise causes energy loss and the resulting changes in the human central nervous system increase fatigue intensity and reduce working capacity. It hinders the execution of entrusted work in a precise and reliable manner, resulting in common errors and shortages, e.g. in manufacturing. In numerous cases, concentration loss caused by noise can lead to serious accidents, which can in turn result in worker death (Dąbrowski, 2002; Engel, 1980).

According to the rules of law, noise is characterised by three values (Regulation of the Minister of Labour and Social Policy of 12 June 2018):

- degree of noise exposure during an 8-hour daily work time;
- maximum sound level A, it is a value that cannot be exceeded;
- peak sound level C, it is related to impulse sounds, the value cannot be exceeded.

Table 1 presents the permissible values for the environment factor of noise. Table 1 demonstrates that the noise exposure in an 8-hour cycle cannot exceed 85 dB, similarly to the weekly cycle. The maximum sound level A amounts to 115 dB, while the peak sound level C - 135 dB. Noise standards for juvenile workers are 5 dB lower, while for pregnant women they are as follows: 65 dB, 110 dB, 130 dB.

The aim of the current study is to identify the noise level in a manufacturing enterprise producing parts for baby carriages. Thus, the object of the research is two screw injection moulding machine operation stations intended for plastic elements'

manufacturing. The focus is the measurement and analysis of the level of this dangerous factor. For this purpose, is used an integrating sound level meter with first-class accuracy, i.e. Sonopan SON-50 meter. The noise measurements were conducted by using the intermediate method.

Table 1
Permissible noise intensity in the work environment

Noise exposure time	**Noise exposure level (dB)**
Eight-hour work time	85 dB
Work week	85 dB
Maximum sound level A	115 dB
Peak sound level C	135 dB

Source: (Regulation of the Minister of Labour and Social Policy of 12 June 2018)

The paper is structured as follows: following the introduction, in the second part is described the classification of work environment factors. This analysis paves the way for the third part, in which is highlighted the studied enterprise. The fourth part stresses on the results and discussion based on the research. The article closes with summary and conclusions in the field of investigation the noise level.

2. RESEARCH METHODOLOGY

The paper features the measurement and analysis of noise with consideration of the current legal regulations and standards. The scope of work covered studies in a manufacturing enterprise producing parts for baby carriages. It is a civil partnership employing less than 10 workers. The plant's infrastructure consists of a single manufacturing hall with two production machine stations, a social room and office building. The manufacturing hall features a separated area referred to as the warehouse, from which the workers take the production material, as well as a finished products storage zone. Soon, the company is planning to expand its infrastructure by building a separate warehouse for raw materials and finished products. This will also result in an increase in employment.

The study covered two screw injection moulding machine stations for plastic elements' manufacturing. The injection moulding machine is a device intended for processing of any type of plastics. The processed plastic material is fed in granulate form into the machine's dispenser, where it is then collected by the screw injector, in which it is melted and compressed. Each phase includes an injection of melted plastic to a special mould in which it solidifies and then the element is ejected from the mould. The machine operator's work includes the machine's operation and supervision (Frymus and Babicz, 2017). In addition, the worker operates auxiliary equipment intended for feeding raw material and product reception. The machine's operator in the studied enterprise is also responsible for sorting and packaging semi-products and finished products.

The studied workstation's dangerous factors include, among others, moving machine elements, working with hot moulds and material as well as electric current. Harmful factors mainly include noise, dusts, and mechanical vibration. On the other hand, bothersome factors concern strains on the musco-skeletal system, micro-climate, and lighting. In the studied enterprise, noise is mainly emitted during the (screw injector moulding) machines' operation intended for finished products' manufacturing. The

measurement of the equivalent sound level A, maximum sound level A and peak sound level C was conducted with the use of an integrating sound level meter with first-class accuracy. The measurements featured the use of a microphone windshield. The noise measurements were conducted by using the intermediate method, which is based on measuring noise in a shorter time than the worker's exposure time, and then on using specific mathematical dependencies to designate the noise values at the work stations. The measurements were conducted during a single working day. Three measurements, 15 minutes each, were conducted: the first measurement was conducted between 10:15 and 10:30, second measurement from 13:15 to 13:30, and the third measurement was conducted between 15:15 and 15:30. All three measurements were conducted during the screw injector moulding machines' operation and during social and hygienic breaks. The Sonopan SON-50 meter, constituting part of the studied enterprise's equipment, was used for this purpose. The device allows for measuring several acoustic values at the same time. The meter also indicates the measurement's time and monitors the battery charge status. It is possible to measure the effective value with the use of one of three corrective features built into the instrument: A, C, LIN, or the attached outer filter.
The SON-50 integrating sound level meter meets the requirements set out for such devices in PN-EN 61252: 2000 - Electroacoustics. Requirements for individual noise exposure meters as well as PN-EN 60804: 2002 - Integrating-averaging sound level meters.

3. DISCUSSION AND RESULTS

Table 3 presents the results of noise measurements in the studied manufacturing enterprise.

Table 3
Results of the work environment noise measurements in the studied manufacturing enterprise

	Measurement 1		**Measurement 2**		**Measurement 3**	
	During the screw injection moulding machine's operation	**During social and hygienic breaks**	**During the screw injection moulding machine's operation**	**During social and hygienic breaks**	**During the screw injection moulding machine's operation**	**During social and hygienic breaks**
Duration of measurements, min.	15	15	15	15	15	15
Individual results, dB	72.1	47.6	72.1	47.6	76.6	47.6
	71.8	48	73	48	75.4	48
	72.3	46.9	72.8	46.9	76.2	46.9
Maximum sound level A, dB	82.8	58	81.8	58	87.9	58
Peak sound level C, dB	110.8	78.9	109.4	78.9	111.8	78.0
Noise exposure level for 8 hours	71.8 (+) 2.0		72.6 (+) 2.0		75.8 (+) 2.1	

Source: own study

The obtained results of noise measurement in the studied enterprise must be rated very highly because all values are within the current maximum permissible intensity limits for the work environment. The noise exposure level during an 8-hour work time did not exceed the permissible value, i.e. 85 dB, in any of the measurements conducted. The maximum sound level A is also within the current standard limits, i.e. it did not exceed 115 dB. The peak sound level C is similar, and its values are below 135 dB. It is a very positive phenomenon, because noise is one of the main reasons of occupational hearing impairments, especially among manufacturing workers.

The obtained results varied slightly during the machines' operation, whereas the results obtained during sanitary and hygienic breaks were at a similar level. The individual results were highest in the last measurement conducted during the machines' operation. The maximum sound level A during the machines' operation was 5.1 dB lower in the first measurement than in the third measurement. The peak sound level C was lowest in the second measurement conducted at 13:15-13:30 and was 2.4 dB lower than the highest result obtained in the third measurements.

The next stage of the study, following the noise measurement in the selected manufacturing enterprise, includes analysis and an occupational risk evaluation. Occupational risk determines the worker's exposure to noise in the following categories: high, average, low.

The noise risk evaluation was conducted by using the methodology based on the algorithm specified in PN-N-18002 "Occupational health & safety management systems. General guidelines for occupational risk evaluation", which is presented in Figure 1.

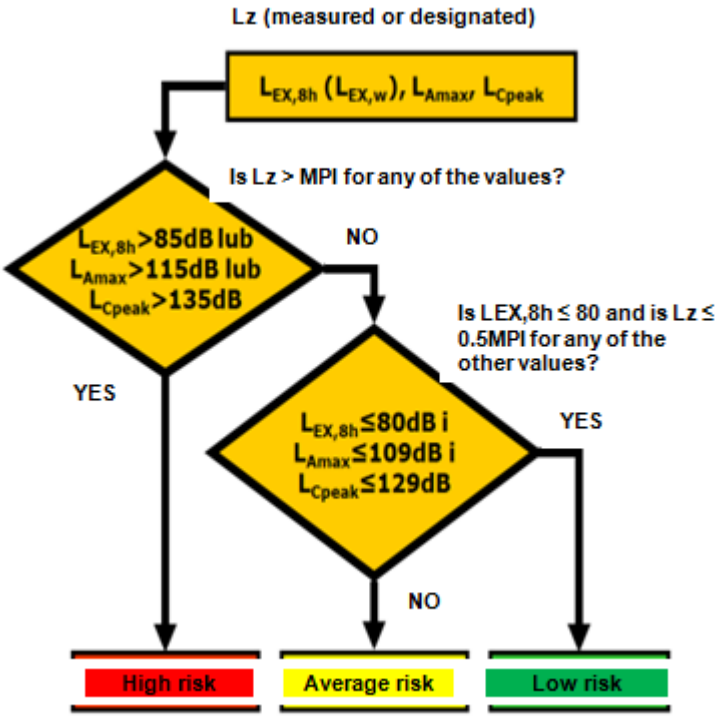

Figure 1. Algorithm for occupational risk evaluation for noise acc. to PN-N-18002 "Occupational health & safety management systems. General guidelines for occupational risk evaluation"

Source: (Romanowska- Słomka 2010; Uzarczyk 2006)

When analysing the noise measurement results in the studied enterprise in relation to the presented occupational risk evaluation algorithm for noise, it is possible to state that:

- in case of high risk: $L_{EX,8h}$ = 75.8 dB, result L_z (measured value) < 85 dB- condition met; L_{Amax}= 87.9 dB, result L_z < 115 dB - condition not met and L_{Cpeak}= 111.8, result L_z < 135 dB - condition not met. Therefore, the noise exposure risk is not high;
- in case of average risk: $L_{EX,8h}$ = 75.8 dB, result 80 dB≤L_z < 85 dB- condition not met; L_{Amax}= 87.9 dB, result 109 dB≤L_z< 115 dB - condition not met and L_{Cpeak}= 111.8, result 129 dB≤ L_z < 135 dB - condition not met. Therefore, the noise exposure risk is not average;
- in case of low risk: $L_{EX,8h}$ = 75.8 dB, result L_z < 80 dB- condition met; L_{Amax}= 87,9 dB, result L_z< 109 dB - condition met and L_{Cpeak}= 111.8, result L_z < 129 dB - condition met. Therefore, the noise exposure risk is low.

4. SUMMARY AND CONCLUSIONS

When summarising the consideration on the noise level measurement and analysis in the studied manufacturing enterprise, it can be structured conclusions and recommendations for improving the company environment.

Firstly, due to the specificity of the discipline in which the enterprise operates, the studied work environment features dangerous, harmful, and bothersome factors. Considering the conducted noise measurements, the factor is currently classified as bothersome. The measurements are conducted by the employer on a regular basis and there is currently no basis for classifying noise as a harmful factor. The obtained values are within the current maximum permissible intensity limits for the work environment. The noise exposure level during an 8-hour work time did not exceed the permissible value, i.e. 85 dB, in any of the measurements conducted, while the highest value amounts to 75.8 dB. The maximum sound level A, which reached the highest value of 87.9 dB in three subsequent measurements, is also within the current standard limits, i.e. it did not exceed 115 dB. The peak sound level C, measured at 111.8 dB, is also below the limit value, i.e. 135 dB. The noise source at the studied workstation is emitted from the machines' operation, i.e. it is a mechanical source, and the noise exposure is continuous.

Secondly, when analysing the obtained noise levels in terms of noise-related occupational risk evaluation, it is assumed that the risk is currently low. Due to the above, it is an acceptable risk and there is no need to apply additional control mechanisms. Therefore, the employer should continue applying the existing precautionary and preventive measures, which include personal protection means, such as hearing protection, training on compliance with the safety work principles or breaks.

Thirdly, considering that the company is planning to expand its infrastructure, including also the purchase of new manufacturing machines and increasing employment, noise may not only be a bothersome factor that is currently causing discomfort at work and reduced work performance, but also become a harmful factor. An increased number of manufacturing devices and workstations can also cause increased measurable noise values. In such case, they may not be within the current standard limits and may cause an increase in occupational risk. Such progress may warrant the necessity of applying new control mechanisms, including collective noise protection means. It is worth considering the following measures:

- labelling workstations at which the noise levels exceed the maximum permissible intensity with safety signs;
- separation of safety zones with such stations;
- grouping sound sources depending on the emitted sound's acoustic pressure;
- insulating and sound-proofing enclosures as well as other technical solutions.

Due to the above, the conducted analyses will constitute a basis for further research in this regard. The next noise level measurements in the company are planned for November 2021.

Even though the noise measurements are within the agreed standard limits and the occupational risk is acceptable, long-term exposure to this level of noise can cause deafness. At L_{Amax}= 87.9 dB, the risk amounts from 5% to 14% in a period of 15 years. It can also cause a shift in the hearing threshold (increased threshold). A positive aspect is the fact that a worker at the studied workstation is not dealing with impulsive and intermittent noise which has more harmful effects on health, but with noise with continuous acoustic energy during observations (continuous noise).

Finally, the studied enterprise did not feature any accident related to work environment factors within the last 10 years. The conducted study on the factors occurring in the work environment demonstrates that the employer makes every effort to best adapt other work environment factors to the nature of the work performed and make them comfortable for workers. This allows for minimising the risk of worker distraction and concentration loss at the workstation.

The aim of this milestone research is fulfilled, and it can be taken as a basis for further research in this regard. In summation, this paper shall be taken to stand as a basic up-to-date study for further investigation of the noise level measurement and analysis discussed.

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