Chapter 13

Whole-body vibration hazard at workstations associated with the processing of mineral raw materials

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DOI: 10.54215/Noise_Control_2022_A_Digital_Monograph_Zajac_J_Kowalski_P_Whole-body

Abstract
The article presents the results of whole-body vibration (WBV) research at 30 workstations associated with the processing of mineral raw materials. Measurements of mechanical vibration acceleration were carried out at selected workstations located in the places where the person supervising the machine/equipment works. Based on the results of the measurements, daily exposures to whole-body vibration and multiplication factors of exceeding the permissible exposure limit for vibration were determined. The assessment showed that the researched workstations may be the cause of occupational risk. The risk was large at 7 workstations. At 6 workstations the daily exposure values exceeded 0.5 the threshold limit value (TLV) (medium risk); at 6 workstations did not exceed 0.5 TLV (low risk). At 11 workstations occupational risk was estimated as a negligible (daily exposure values do not exceed 0.2 TLV). Obtained research results indicate the need to carry out control measurements and WBV assessment at workstations associated with the processing of mineral raw materials.

Keywords: whole-body vibration, vibration measurements, occupational safety, mineral raw materials

1. Introduction

Mechanical vibrations acting on the whole body of a worker through the feet (when standing) or through the pelvis, back or flanks (when in a sitting or lying position) are called whole-body vibrations (WBV). Prolonged exposure to vibration can lead to permanent, irreversible lesions involving primarily the skeletal system (low back pain) and internal human organs. Whole-body vibration, even with low amplitudes, is often a nuisance to humans, causing not only discomfort but also reducing their psychomotor skills [1-4]. Based on recent data contained in the reports on the activities of the National Labour Inspectorate, it is possible to estimate that over 100.000 people in Poland are employed at workstations associated with the processing of mineral raw materials (crushing, grinding, sifting, etc.) [5]. Underestimation of the total number of people exposed to vibrations is associated with the issue of inadequate identification of exposure to whole-body vibration in workstations associated with the processing of mineral raw materials. Currently, the measurement of mechanical vibrations from machinery and equipment used in the processing of mineral raw materials is usually carried out to determine and monitor their technical condition. Evaluation of whole-body vibrations on this type of workstations is not performed at all or is carried out to a very limited extent. This is due, in large part, to the lack of recognition of the main sources of the exposure of workers to vibrations; sometimes due to the need to use custom instrumentation, as well as the limited possibilities of an additional person (apart from the operator) being at this type of workstation. So, an occupational risk assessment must be prepared by employers in accordance with directive 2002/44/EC [6] on the minimum health and safety requirements regarding the exposure of workers to the risks that arise from vibration. Underestimating the total number of people exposed to vibrations is associated with the problem of insufficient recognition of exposure to WBV at workplaces associated with the processing of mineral raw materials.

2. Testing method

The testing method used by the author is based on the simultaneous registration of time vibration acceleration signals in three directions: x, y and z. The basic value determined to assess worker's exposure to vibration is the daily exposure A(8) based on the dose of vibrations a^2t, which, it is assumed, best reflects the effect of vibration on the human body (PN-EN 14253+A1:2011) [7].

$$D_{total} = \sum_{i=1}^{n} a_i^2 \cdot t_i \; , \frac{m^2}{s^3} \tag{1}$$

where:

a_i – partial vibration acceleration, m/s^2, t_i – duration of partial acceleration, s.

The total vibration dose is determined from the measured values of directional vibration acceleration and is the value indirectly determined in the calculation of the daily exposure to vibration A(8).

The daily exposure to whole-body vibration is determined from the following relationship:

$$A_l(8)_{WB} = k_l \sqrt{\frac{1}{T_0} \sum_{i=1}^{n} a_{wli}^2 \cdot T_i}, \quad \frac{m}{s^2} \tag{2}$$

where:

a_{wli} – the frequency-weighted r.m.s value of the acceleration, determined over the time period T_i, s
l – direction x or y or z, $k_x = k_y = 1.4$ for directions x and y; $k_z = 1$ for direction z, T_0 – reference duration of 8 h (480 min = 28800 s).

The exposure of worker's health to mechanical vibrations is assessed by comparing the determined daily exposures with exposure limit values, specified in the Regulation of the Minister of Family, Labour and Social Policy of 12 June 2018 on the maximum permissible concentration and intensity of agents harmful to health in the working environment [8]. The multiplication factor of exceeding the permissible exposure limit for whole-body vibration is determined from the formula:

$$k_{r,WB} = \frac{A(8)_{WB}}{A(8)_{WB,dop}} \tag{3}$$

where:

$A(8)_{WB}$ – determined value of daily exposure to whole-body vibration, m/s^2, $A(8)_{WB,dop}$ – permissible value of daily exposure to whole-body vibration, m/s^2.

Using the value of the multiplication factor, it is possible to evaluate whether the exposure to vibration is small, medium or large. The occupational risk is *negligible* if the multiplication factor determined for the tested workstation is less than 0.2 ($k_r < 0.2$), and *small* when the multiplication factor is in the range of $0.2 < k_r < 0.5$. The occupational risk is acceptable (medium) if the multiplication factor determined for the workstation is within the range of $0.5 < k_r < 1$. The occupational risk is unacceptable (large) if the multiplication factor determined for the workstation is greater than 1, $k_r > 1$ [9, 10].

3. Measuring instruments

The measurements of the directional components of vibration acceleration were carried out using the following set of instruments:

- Brüel & Kjær PULSE multi-analyser system type 3560C,
- 8-channel Brüel & Kjær charge amplifier type 5974,
- 3 Brüel & Kjær vibration transducers type 4338 or B&K triaxial seat accelerometer type 4322.

This set facilitates the recording of signals over the frequency range of whole-body vibration acting on the worker: 0.9 ÷ 90 Hz from the range from a few mm/s^2 to ca. 1000 m/s^2 without distortion and interference. Figure 1 presents a diagram of the measuring instrumentation set.

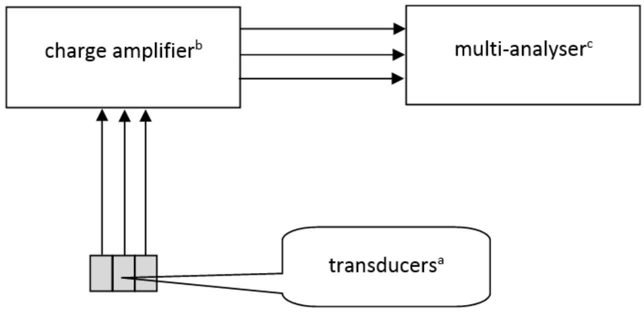

Figure 1. Diagram of the measurement set; a – 3 B&K vibration transducers type 4338 or triaxial seat accelerometer type 4322, b – 8-channel B&K charge amplifier type 5974, c – B&K PULSE multi-analyser system type 3560C

Measurements of mechanical vibration acceleration were carried out at the locations occupied by the people supervising the operation of the machinery or machine. Measurement points were located on the ground next to the machine, on the platform surrounding the device or on seats. Accelerometers were attached to the subgrade using a measuring block with a magnet, double-sided adhesive tape or a two-component glue. Three measurements were carried out at each workstation. The duration of one measurement was 5 minutes. The number and duration of the measurements was sufficient to show that the average value obtained is representative of the vibrations occurring throughout the working day. An example of the location and measurement direction orientation of the measuring points in the tested workstations is shown in Figure 2.

Figure 2. Location of measurement points and measurement directions at sample workstation (jaw crusher)

4. Test results

Daily exposure to vibration at 30 workstations associated with the processing of mineral raw materials was determined within the framework of the conducted tests, based on the recorded values of vibration acceleration. Table 1 shows the highest determined directional components of vibrations, the multiplication factors of exceeding the permissible exposure limit for WBV and evaluated the occupational risk.

Table 1. Daily exposure, the multiplication factors of exceeding the permissible exposure limit for WBV and occupational risk determined on the workstations associated with the processing of mineral raw materials

Workstation No.	Test Object		Daily exposure to vibration* (the largest directional component) *A(8)* m/s²	Multiplication factor of exceeding the permissible exposure limit for WBV $k_{r,WB}$	Occupational risk
1	Impact crusher – measurement point on a concrete ground near the impact crusher		$A_Z(8) = 0.05$	0.06	negligible
2	Jaw crusher	measurement point on a concrete ground near the control cabinet of the crusher	$A_Z(8) = 0.05$	0.06	negligible
3		measurement point on the platform made of steel plates near the crusher	$A_Z(8) = 0.17$	0.21	low
4	Jaw crusher – measurement point on a concrete ground near the control cabinet of the crusher		$A_Z(8) = 0.02$	0.03	negligible
5	Jaw crusher – measurement point on the platform made of steel plates near the crusher		$A_Z(8) = 1.55$	1.94	high
6	Jaw crusher 40-17	measurement point on the platform made of steel plates near the crusher	$A_Z(8) = 0.40$	0.50	medium
7		measurement point on the floor in the vibration-isolated operator's cab	$A_Z(8) = 0.09$	0.11	negligible
8	Cone crusher – measurement point on the platform made of steel plates near the control cabinet of the crusher		$A_Z(8) = 0.42$	0.53	medium
9	Vibrating screen SWR-1 – measurement point on the platform made of steel plates near the vibration isolator		$A_Z(8) = 0.34$	0.43	low
10	Vibrating screen SWR-3	measurement point on the platform made of steel plates near the vibration isolator	$A_Z(8) = 0.32$	0.40	low

Workstation No.	Test Object		Daily exposure to vibration* (the largest directional component) *A(8)* m/s²	Multiplication factor of exceeding the permissible exposure limit for WBV $k_{r,WB}$	Occupational risk
11		measurement point on the platform made of steel plates near the motor-reducer	$A_Z(8) = 1.23$	1.54	high
12		measurement point on the platform made of steel plates near the conveyor	$A_Z(8) = 2.46$	3.08	high
13	Rectangular screen – measurement point on a concrete ground near the screen's engine		$A_Z(8) = 0.81$	1.01	high
14	Rectangular screen – measurement point on the platform made of steel plates near the screen's engine		$A_Z(8) = 1.81$	2.26	high
15	Rectangular screen – measurement point on the platform made of steel plates near the vibration isolator		$A_Z(8) = 0.81$	101	high
16	Mobile screen Metso ST 458 – measurement point on the ground near the screen control panel		$A_Y(8) = 0.03$	0.04	negligible
17	Rectangular screen WPB-821 – measurement point on the concrete ground near the screen		$A_Z(8) = 0.16$	0.20	low
18	Finger sifter – measurement point on the concrete ground near the sifter		$A_Z(8) = 0.15$	0.19	negligible
19	Vibrating screen RHEWUM – measurement point on the platform made of steel plates near the screen		$A_Z(8) = 0.56$	0.70	medium
20	Sand separator – measurement point on the platform made of steel plates near the separator		$A_Z(8) = 0.47$	0.59	medium
21	Ball mill MK-121	measurement point on the platform made of steel plates near the mill	$A_Z(8) = 0.19$	0.24	low
22		measurement point on the concrete ground near the mill	$A_Z(8) = 0.06$	0.08	negligible
23	Vertical mill Gebr.Pfeiffer – measurement point on the concrete ground near the mill		$A_Z(8) = 0.02$	0.03	negligible
24	Vertical mill 521/37 Gebr.Pfeiffer – measurement point on the concrete ground near the mill		$A_Z(8) = 0.02$	0.03	negligible
25	Rotary dryer S-4	measurement point on the platform made of steel plates during draining the concentrate	$A_Z(8) = 0.44$	0.55	medium
26		measurement point on the platform made of steel plates during thermal drying	$A_Z(8) = 0.07$	0.09	negligible
27	Belt feeder – measurement point on the concrete ground near the belt feeder's motor-reducer		$A_Z(8) = 0.12$	0.15	negligible
28	Wheel loader Volvo L350F – measurement point on the loader's seat		$A_Y(8) = 0.73$	0.91	medium
29	Wheel loader CATERPILLAR CAT 988F – measurement point on the loader's seat		$A_Y(8) = 0.73$	0.91	medium
30	Mining dump truck Biełaz 7547 – measurement point on the truck's seat		$A_Z(8) = 0.81$	1.01	high

* Daily exposure to vibration determined over the time period $T_i = 480$ min

The determined values of daily (480 minutes) exposure to vibrations exceed the permissible values (high risk) at 7 workstations; at 6 workstations the daily exposure values exceed 0.5 TLV (medium risk), also at 6 workstations do not exceed 0.5 TLV (low risk). At 11 workplaces occupational risk due to the risk of vibration was estimated to be negligible (daily exposure values do not exceed 0.2 TLV). The uncertainty of measurement analysis is presented in the Table 2.

Table 2. Spreadsheet model showing the uncertainty budget

Source of uncertainty	Value, m/s^2	Probability distribution	Divisor	Standard uncertainty, m/s^2
Calibration of the measurement instruments	0.021	Normal	1	0.021
Calibration of the measurement set	0.002	Normal	$\sqrt{3}$	0.001
Resolution of the measuring instruments	0.028	Rectangular	$\sqrt{3}$	0.016
Location of measurement points and directions	0.010	Normal	1	0.010
Combined standard uncertainty		Assumed normal		0.03
Expanded uncertainty		Assumed normal (k = 2)		0.06

5. Summary and conclusions

The results of whole-body vibration tests at workstations associated with the processing of mineral raw materials indicate the possibility of exceeding the permissible exposure limit values for this type of workstations. In order to enable employers to take action to reduce the exposure to vibration, it is necessary to access the information and materials on the current state of the exposure of workers and the possibilities and methods for reducing vibration.

In the case of workstations associated with the processing of mineral raw materials, one of the most important elements affecting the proper implementation of measurements and the related estimation of daily exposure to vibration is the proper location of the measuring points. The mechanical vibration from machinery and equipment used in the processing of mineral raw materials is transferred to humans most often through seats, floors and platforms. In many cases, such identification of sources is sufficient to assess worker exposure to vibration. However, the situation changes radically, when it is necessary to limit their emissions. The actual elements of the machines do not produce the vibrations directly, but only transmit them to the worker's body; they are secondary sources of vibration. To effectively reduce or eliminate vibration, it is first necessary to identify the primary sources of vibration. The obtained results of tests indicate the need for measurement and evaluation of whole-body vibration at workstations associated with the processing of mineral raw materials.

Acknowledgements

This paper has been based on the results of a research task carried out within the scope of the fourth stage of the National Programme "Improvement of safety and working conditions" partly supported in 2017-2019 – within the scope of state services – by the Ministry of Labour and Social Policy. The Central Institute for Labour Protection – National Research Institute is the Programme's main coordinator.

References

[1] Engel Z. Ochrona środowiska przed drganiami i hałasem [Protecting the Environment against Vibration and Noise]. Warsaw: PWN; 2001.

[2] Engel Z, Kowalski P. Evaluation indices of exposure to vibration. Machine Dynamics Problems. 2000;24(3):21-33.

[3] Engel Z, Zawieska WM. Hałas i drgania w procesach pracy: źródła, ocena, zagrożenia [Noise and vibration in work processes. Sources, assessment, threat]. Warsaw: CIOP-PIB. 2010.

[4] Griffin MJ. Effects of Vibration on People. In: Crocker MJ, Ed. Handbook of Noise and Vibration Control. New Yersey: John Wiley & Sons, Inc., Hoboken; 2008. p. 343-354.

[5] Hickiewicz I. Sprawozdanie z działalności Państwowej Inspekcji Pracy w 2013 roku [Report on the activities of the National Labor Inspectorate 2013]. Warsaw; 2014.

[6] Directive 2002/44 / EC of the European Parliament and of the Council of 25 June 2002 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration) (16th individual Directive within the meaning of Article 16 (1) Directive 89/391 / EEC).

[7] PN-EN 14253+A1:2011. Drgania mechaniczne – Pomiar i obliczanie zawodowej ekspozycji na drgania o ogólnym działaniu na organizm człowieka dla potrzeb ochrony zdrowia – Wytyczne praktyczne [Mechanical vibration – Measurement and evaluation of occupational exposure to whole-body vibration with reference to health – Practical guidance].

[8] Rozporządzenie Ministra Rodziny, Pracy i Polityki Społecznej z dnia 12 czerwca 2018 r. w sprawie najwyższych dopuszczalnych stężeń i natężeń czynników szkodliwych dla zdrowia w środowisku pracy [Regulation of the Minister of Family, Labour and Social Policy of 12th June 2018 on the maximum permissible concentration and intensity of agents harmful to health in the working environment]. Journal of Laws of 2018, item 1286.

[9] Kowalski P, Zając J. Assessment of exposure to mechanical vibrations of employees of in-house transport for the purpose of prevention. National Programme "Improvement of safety and working conditions" (2008-2010) [Ocena narażenia na drgania mechaniczne pracowników transportu wewnątrzzakładowego w celu profilaktyki. Program Wieloletni pn. „Poprawa bezpieczeństwa i warunków pracy” (2008-2010)].

[10] Kowalski P, Zając J. Whole – body and hand – arm vibration in in-house transport. Archives of Acoustics. 2010;35(2):183-190.