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Whole-Body and Hand-Arm Vibration in In-House Transport

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A dynamic economy contributes to the increase in the number of workers exposed to mechanical vibration caused by machines and transport equipment. As the means of transport are insufficiently recognised sources of mechanical vibrations, this article presents the results of whole-body and hand-arm vibration tests of 30 most common means of in-house transport. An analysis of vibration signals recorded at each workstation according to PN-EN 14253 and PN-EN ISO 5349 made it possible to determine the weighted values of components of directional vibration acceleration and the values of daily vibration exposure $A(8)$.

In order to assess exposure to whole-body and hand-arm vibration at the tested workstations of in-house transport, indices of vibration hazard related to admissible values, the total evaluation index (developed in a previous study at CIOP-PIB) and a three-degrees scale for assessing exposure to vibrations were used. The assessment showed that the workstations were a major hazard. Vibration hazards at all those workstations were classified as either medium or high.

Keywords: in-house transport, vibration, exposure assessment.

1. Introduction

In-house transport ensures a constant flow of raw materials and products between the various workstations, warehouses and factory divisions. A dynamic economy rapidly increases the number of devices used in the in-house transport and the number of workers exposed to vibrations generated by machinery and transport equipment. Means of transport are insufficiently recognised sources of mechanical vibrations. Research carried out at CIOP-PIB intended to identify the hazards posed by mechanical vibrations in in-house transport and indicate the ways of reducing them.

2. Methods

The methodology of researching mechanical vibrations during the in-house transport is based on registering whole-body vibration acceleration signals (in three directions: x, y, z) and hand-arm vibration acceleration signals (in three directions: x, y, z). The vibration signals recorded at each workstation are analysed according to PN-EN 14253 and PN-EN ISO 5349 to determine:

- weighted values of components of directional vibration acceleration,
- daily vibration exposure $A(8)$.
  - Exposure to whole-body vibration can be calculated from:

$$A_{WB,l}(8) = k_l \sqrt{\frac{1}{T_0} \sum_{i=1}^{n} a_{wli}^2 \cdot T_i}, \tag{1}$$

where a_{wli} – the frequency-weighted root-mean-square (rms) value of the acceleration, determined over the time period T_i, l – x, y, z, $k_x = k_y = 1.4$ for the x and y directions; $k_z = 1$ for z direction, T_0 – reference duration of 8 h (28 800 s).

  - Exposure to hand-arm vibration can be calculated from:

$$A_{HA}(8) = \sqrt{\frac{1}{T_0} \sum_{i=1}^{n} a_{hvi}^2 \cdot T_i}, \tag{2}$$

where

$$a_{hvi} = \sqrt{a_{hwxi}^2 + a_{hwyi}^2 + a_{hwzi}^2}, \tag{3}$$

a_{hvi} – total vibration value of frequency-weighted rms acceleration for the i-th operation, a_{hwxi}, a_{hwyi}, a_{hwzi} – rms acceleration values of the frequency-weighted hand-transmitted vibration for axes denoted x, y and z respectively, T_0 – reference duration of 8 h (28 800 s).

The measurement system was based on direct cooperation between piezoelectric transducers with voltage output and the analysis PULSE system (Fig. 1).

The vibration acceleration signals were analysed in the 0.5 Hz to 400 Hz frequency range (resolution 0.25 Hz) for whole-body vibration and 1 Hz to 1 600 Hz (resolution 1.0 Hz) for hand-arm vibration.

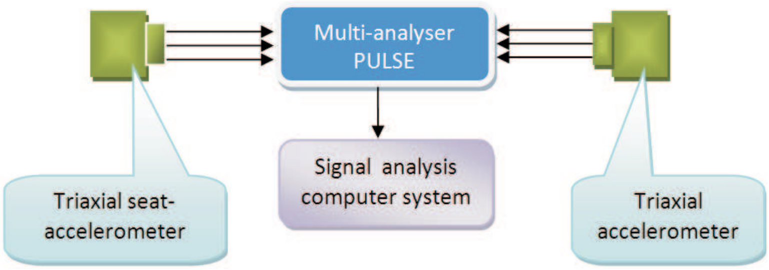

Fig. 1. Schematic representation of the system for recording and analysing vibration signals.

The orientation of the coordinate system is compatible with the requirements of PN-EN ISO 5349 and PN-EN 14253. Vibration acceleration signals were registered in conditions typical for a workstation (only a few vehicles did not have a load). At each driver-operator workstation there were 2 measuring points: on the seat (for whole-body vibration measurements) and on the steering wheel or the steering lever (for hand-arm vibration measurements).

3. The results of measurements and calculations

On the basis on an analysis of the vibration signals recorded at each workstation it was determined that

- rms acceleration values of the frequency-weighted hand-transmitted vibration for the axes denoted x, y and z, respectively: a_{hwx}, a_{hwy}, a_{hwz};
- total value of frequency-weighted rms acceleration for hand–arm vibration (also known as the vector sum or the frequency-weighted acceleration sum);
- daily hand-arm vibration exposure $A_{HA}(8)$;
- whole-body frequency-weighted rms acceleration value of the vibration: a_{wx}, a_{wy}, a_{wz};
- daily whole-body vibration exposure $A_{WB}(8)$.

Values of daily exposure were compared with admissible values defined in the relevant regulations (Table 1 and vertical lines in Figs. 2 and 3).

Table 1. Admissible values for whole-body and hand-arm vibration.

Exposure	Admissible value, (m/s^2)
whole-body vibration	$A_{WB}(8)_{\mathrm{dop}} = 0.8$ $a_{w,\mathrm{dop},\ 30\,\mathrm{min}} = 3.2$
hand-arm vibration	$A_{HA}(8)_{\mathrm{dop}} = 2.8$ $a_{hv,\mathrm{dop},30\,\mathrm{min}} = 11.2$

Table 2 and Figs. 2–3 illustrate the determined values of daily whole-body and hand-arm vibration exposure at the 30 workstations that were tested.

The analysis of the results showed that

- the highest exposure to hand-arm vibration was found for vehicle no. 1 ($A_{HA}(8) = 4.97$ m/s^2), the lowest in vehicle no. 20 ($A(8)_{HA} = 0.96$ m/s^2);
- admissible exposure to hand-arm vibration was exceeded for 10 vehicles;
- admissible exposure to hand-arm vibration was lowest for vehicle no. 1;
- the highest exposure to whole-body vibration was found for vehicle no. 1 ($A_{WB}(8) = 4.42$ m/s^2), the lowest value in vehicle no. 24 ($A_{WB}(8) = 0.20$ m/s^2);
- admissible exposure to whole-body vibration was exceeded for 11 vehicles;
- exposure to whole-body vibration was lowest for vehicle no. 1.

Table 2. Daily exposure and admissible duration of exposure to hand-arm and whole-body vibration determined for selected vehicles in in-house transport.

Vehicle No.	Vehicle	Daily exposure to hand-arm vibration $A_{HA}(8)$ [m/s^2]	Admissible duration of exposure to hand-arm vibration t_{HA} [min]	Daily exposure to whole-body vibration $A_{WB}(8)$ [m/s^2]	Admissible duration of exposure to whole-body vibration t_{WB} [min]
1	Battery-electric truck A	4.97	121	$A(8)_Z = 4.42$	6
2	Battery-electric truck B	3.68	221	$A(8)_Z = 1.46$	57
3	Battery-electric truck C	2.85	370	$A(8)_Z = 1.47$	55
4	Battery-electric truck D	3.13	307	$A(8)_Z = 1.42$	60
5	Lift truck A	3.15	302	$A(8)_Z = 4.29$	7
6	Lift truck B	1.30	480	$A(8)_X = 0.71$	241
7	Lift truck C	1.65	480	$A(8)_Z = 0.79$	190
8	Lift truck D	4.81	129	$A(8)_Z = 1.55$	50
9	Lift truck E	2.98	337	$A(8)_Y = 0.42$	480
10	Forklift truck A	2.12	480	$A(8)_Y = 0.56$	387
11	Forklift truck B	1.93	480	$A(8)_Z = 1.31$	70
12	Forklift truck C	4.06	182	$A(8)_Z = 1.09$	101
13	Forklift truck D	4.33	160	$A(8)_Z = 1.34$	67
14	Forklift truck E	2.54	466	$A(8)_Z = 1.38$	63
15	High lift truck	1.10	480	$A(8)_X = 0.22$	480
16	Tractor	1.25	480	$A(8)_Z = 0.73$	223
17	Track loader A	1.37	480	$A(8)_Z = 0.51$	455
18	Track loader B	1.01	480	$A(8)_Y = 0.43$	480
19	Track loader C	3.55	238	$A(8)_Y = 0.49$	480
20	Track loader D	0.96	480	$A(8)_X = 0.77$	204
21	Excavator	1.67	480	$A(8)_Y = 0.47$	480
22	Excavator – loader	2.01	480	$A(8)_Z = 1.01$	117
23	Gantry A	1.87	480	$A(8)_Z = 0.47$	480
24	Gantry B	1.31	480	$A(8)_Z = 0.20$	480
25	Gantry C	1.05	480	$A(8)_Z = 0.24$	480
26	Gantry D	2.78	389	$A(8)_X = 0.37$	480
27	Gantry E	1.77	480	$A(8)_Z = 0.31$	480
28	Gantry F	1.10	480	$A(8)_Z = 0.28$	480
29	Gantry G	1.23	480	$A(8)_Z = 0.23$	480
30	Locomotive	1.22	480	$A(8)_Z = 0.31$	480

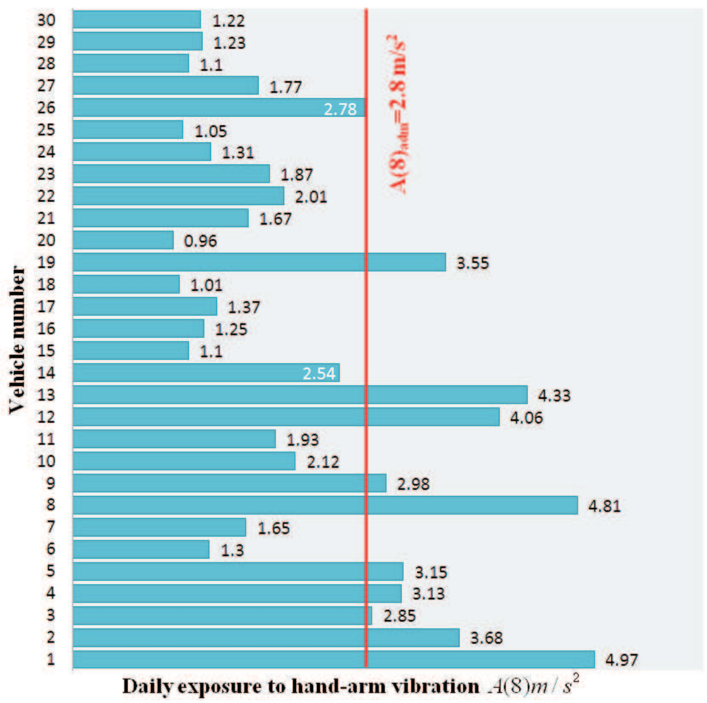

Fig. 2. Values of daily exposure to hand-arm vibration at 30 workstations.

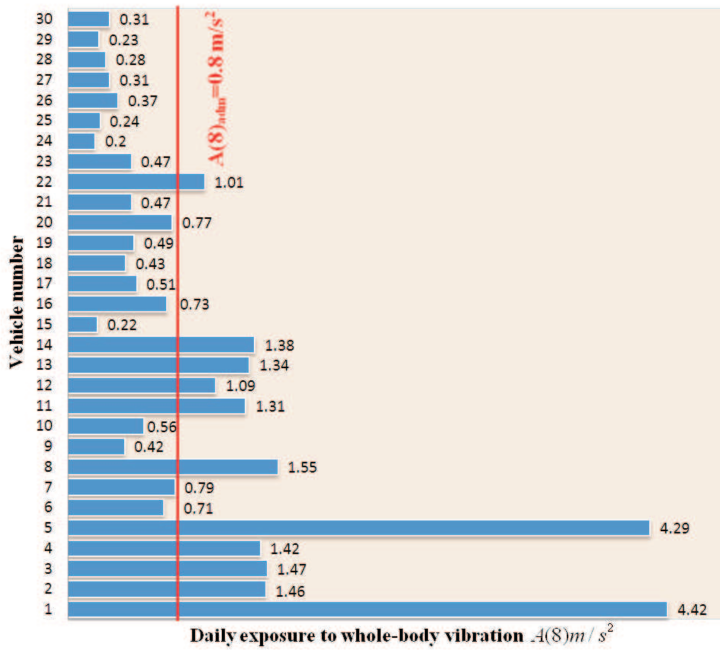

Fig. 3. Values of daily exposure to whole-body vibration at 30 workstations.

4. Assessment of exposure to mechanical vibrations at workstations

To determine the exposure to mechanical vibrations in in-house transport, the following three ratios were used:

- coefficient of the limit value for exposure to hand-arm vibration

$$k_{r,HA} = \frac{A_{HA}(8)}{A_{HA}(8)_{\text{dop}}}; \tag{4}$$

- coefficient of the limit value for exposure to whole-body vibration

$$k_{r,WB} = \frac{A_{WB}(8)}{A_{WB}(8)_{\text{dop}}}; \tag{5}$$

- index of simultaneous exposure to hand-arm and whole-body vibration (developed in an earlier study at CIOP-PIB):

$$K_D = \log\left(10^{K^2_{D_{HA}}} + 10^{K^2_{D_{WB}}} + C\right), \tag{6}$$

where

$K_{D_{WB}} = \dfrac{D_{WB}}{D_{WB,\text{adm}}}$ – admissible dose coefficient of whole-body vibration,

$K_{D_{HA}} = \dfrac{D_{HA}}{D_{HA,\text{adm}}}$ – admissible dose coefficient of hand-arm vibration,

C – correction coefficient = 1.

and a three-degree scale for assessing exposure to vibrations.

Table 3 compares the values of the determined ratios for the 30 tested workstations. Assessment of risk $R(k_r)$ was determined with $k_{r,HA}$ and $k_{r,WB}$, and also with the index K_D, thus obtaining $R(K_D)$.

Assessment of exposure with $k_{r,HA}$ and $k_{r,WB}$ showed that

- risk was high at 13 workstations (vehicles no. 1, 2, 3, 4, 5, 8, 9, 11, 12, 13, 14, 19, 22), where
  - exposure to whole-body vibration was crucial at 3 workstations (no. 11, 14, 22),
  - exposure to hand-arm vibration was crucial at 2 workstations (no. 9, 19),
  - high exposure to both hand-arm and whole-body vibration crucial at 8 workstations (no. 1, 2, 3, 4, 5, 8, 12, 13);
- risk was medium at 11 workstations (no. 6, 7, 10, 16, 17, 18, 20, 21, 23, 26, 27);
- risk was low at 6 workstations (no. 15, 24, 25, 28, 29, 30).

Taking into account simultaneous influence of hand-arm and whole-body vibration, and K_D, it was concluded that

- risk was high at 16 workstations (no. 1, 2, 3, 4, 5, 7, 8, 9, 11, 12, 13, 14, 19, 20, 22, 26),

- risk was medium at 14 workstations (no. 6, 10, 15, 16, 17, 18, 21, 23, 24, 25, 27, 28, 29, 30),
- there were no workstations with low risk.

Table 3. Values of the ratios and assessment of exposure to vibration.

Vehicle No.	Vehicle	$k_{r,HA}$	$k_{r,WB}$	K_D	Risk	
					$R(k_r)$	$R(K_D)$
1	Battery-electric truck A	1.78	5.53	30.53	high	high
2	Battery-electric truck B	1.31	1.83	3.34	high	high
3	Battery-electric truck C	1.02	1.84	3.38	high	high
4	Battery-electric truck D	1.12	1.78	3.16	high	high
5	Lift truck A	1.13	5.36	28.76	high	high
6	Lift truck B	0.46	0.89	0.94	medium	medium
7	Lift truck C	0.59	0.99	1.10	medium	high
8	Lift truck D	1.72	1.94	3.82	high	high
9	Lift truck E	1.06	0.53	1.22	high	high
10	Forklift truck A	0.76	0.70	0.89	medium	medium
11	Forklift truck B	0.69	1.64	2.68	high	high
12	Forklift truck C	1.45	1.36	2.30	high	high
13	Forklift truck D	1.55	1.68	2.95	high	high
14	Forklift truck E	0.91	1.73	2.98	high	high
15	High lift truck	0.39	0.28	0.56	low	medium
16	Tractor	0.45	0.91	0.97	medium	medium
17	Track loader A	0.49	0.64	0.72	medium	medium
18	Track loader B	0.36	0.54	0.63	medium	medium
19	Track loader C	1.27	0.61	1.64	high	high
20	Track loader D	0.34	0.96	1.03	medium	high
21	Excavator	0.60	0.59	0.74	medium	medium
22	Excavator - loader	0.72	1.26	1.64	high	high
23	Gantry A	0.67	0.59	0.78	medium	medium
24	Gantry B, Q=5t	0.47	0.25	0.58	low	medium
25	Gantry C, *Q=5t,*	0.38	0.30	0.56	low	medium
26	Gantry D	0.99	0.46	1.09	medium	high
27	Gantry E	0.63	0.39	0.69	medium	medium
28	Gantry F, 12.5/3.2 Mp	0.39	0.35	0.57	low	medium
29	Gantry G, 10/3.2 t	0.44	0.29	0.58	low	medium
30	Locomotive	0.44	0.39	0.60	low	medium

5. Conclusions

The assessment presented in this paper showed that the analysed workstations may cause a major hazard. Exposure was low at 6 workstations. If exposure to simultaneous hand-arm and whole-body vibration was considered, vibration hazard at all workstations was either medium or high. It is therefore necessary to take measures to reduce vibration at these workstations and to closely monitor the working conditions and working hours. The tentatively analysed frequency characteristics of recorded vibration signals will be used, e.g., to assess the effectiveness of technical solutions used to minimize exposure to vibration in the in-house transport.

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References

1. Augustyńska D., Kowalski P. (2006), *Strategy of protection against mechanical vibrations according to the new legislation – European and national* [in Polish: *Strategia ochrony pracowników przed drganiami mechanicznymi według nowych przepisów prawnych – europejskich i krajowych*], Bezpieczeństwo Pracy, **5**, 416, 8–10.
2. Directive 2002/44/WE 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), (Sixteenth individual directive within the meaning of Article 16(1) of Directive 89/391/EEC), OJ L177, 06.07.2002.
3. Engel Z., Kowalski P. (2008), *Investigations of the influence of simultaneous vibroacoustic exposures on the operator*, Journal of Theoretical and Applied Mechanics, **4**, 46.
4. Engel Z., Kowalski P. (2001), *Vibration exposure assessment using indices* [in Polish: *Ocena ekspozycji drganiowej przy zastosowaniu wskaźników*], Mechanics 83, Kraków University of Technology, Kraków.
5. Griffin M.J. (1990), *Handbook of human vibration*, Academic Press, Harcourt Brace Jovanovich, London.
6. Harazin B. (2006), *Estimation of occupational risks and health risks related to hand-arm vibration* [in Polish: *Szacowanie ryzyka zawodowego i ryzyka zdrowotnego związanego z działaniem miejscowych wibracji*], Bezpieczeństwo Pracy, **6**, 417, 8–11.
7. Świderski S. (2002), Industry transportation, **2**.