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

Piotr KOWALSKI, Jacek ZAJĄC

*Central Institute for Labour Protection*
*National Research Institute*
Czerniakowska 16, 00-701 Warszawa, Poland
e-mail: {pikow; jazaj}@ciop.pl

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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.

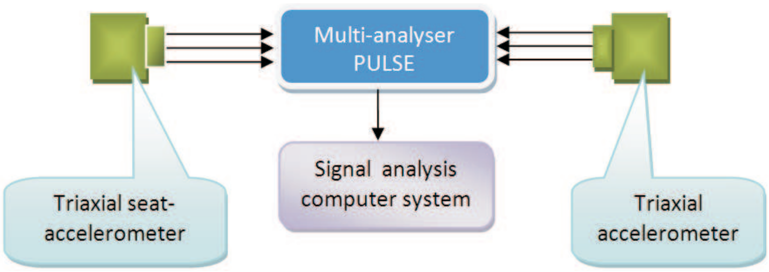


Fig. 1. Schematic representation of the system for recording and analysing vibration signals.

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 | $A_{WB}(8)_{\text{dop}} = 0.8$<br>$a_{w,\text{dop, 30 min}} = 3.2$ |
| hand-arm vibration | $A_{HA}(8)_{\text{dop}} = 2.8$<br>$a_{hv,\text{dop,30 min}} = 11.2$ |

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 |

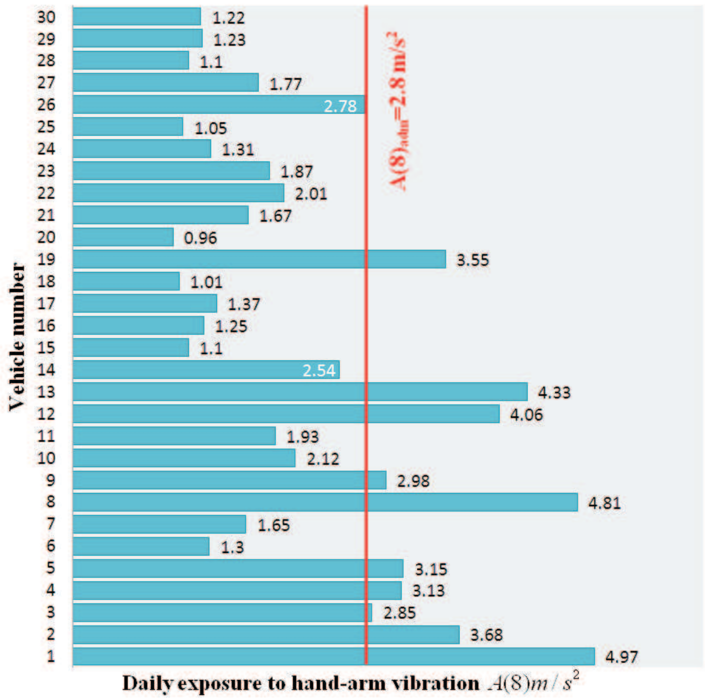


Fig. 2. Values of daily exposure to hand-arm vibration at 30 workstations.

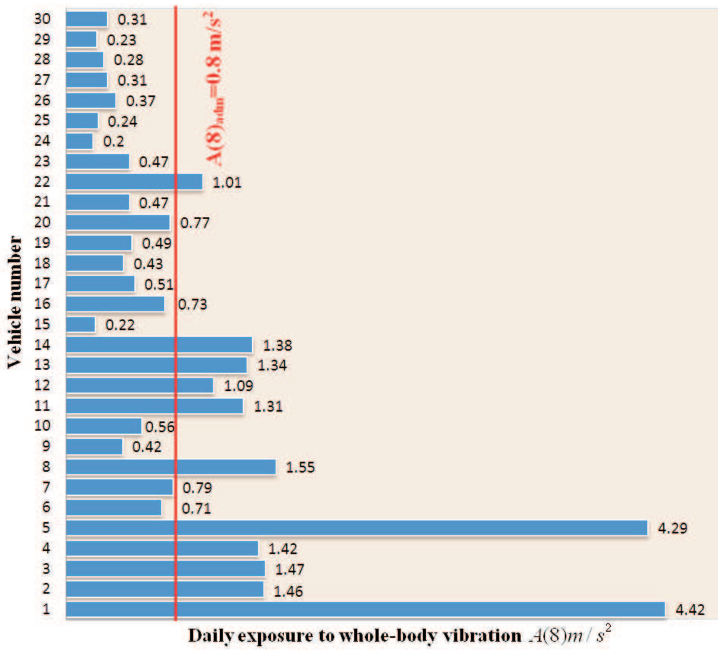


Fig. 3. Values of daily exposure to whole-body vibration at 30 workstations.

## 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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