

# Daily Exposure Estimation from Field Measurements of Repetitive Shock Vibration <sup>†</sup>

Frédéric Maître <sup>1</sup> and Maël Amari <sup>2,\*</sup>

<sup>1</sup> Caisse Régionale d'Assurance Maladie d'Ile-de-France (CRAMIF), 75019 Paris, France; frederic.maitre@assurance-maladie.fr

<sup>2</sup> Electromagnetism, Vibration, Optics Laboratory, Institut National de Recherche et de Sécurité (INRS), 54519 Vandoeuvre-lès-Nancy, France

\* Correspondence: mael.amari@inrs.fr; Tel.: +33-3-83-50-21-24

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**Abstract:** Some hand-held power tools generate repeated shocks of high amplitudes. The daily vibration exposure  $A(8)$  is rarely evaluated over the whole working day. The vibration total value  $a_{hv}$  emitted by a machine and the total daily duration of exposure  $T$  are usually estimated from a sample that may not be representative of the whole working task. Thus, the comparison of  $A(8)$  with regulatory limit values is difficult. The daily number of shocks can sometimes be estimated from production features (i.e., the number of manufactured parts). This article presents an  $A(8)$  evaluation method adapted to such situations. It allows for a better evaluation of the risk for non-stationary vibrations.

**Keywords:** hand-arm vibration; multiple shocks; daily vibration exposure; vibration total value; total daily duration of exposure; evaluation method

## 1. Introduction

The standard method for assessing exposure to hand-arm vibration is defined by ISO 5349-1 [1]. The daily vibration exposure  $A(8)$  of an operator must be derived from the vibration total value  $a_{hv}$  emitted by the machine and the total daily duration of exposure  $T$ . In the field, the evaluation of  $A(8)$  is often performed on a limited time period in order not to disturb the company's production.

Some hand-held tools generate shocks and transient vibrations of high amplitudes [2]. For these non-stationary signals, the vibration total value  $a_{hv}$  and the total daily exposure time  $T$  may not be representative of the worker's real exposure: irregular working task, signal splitting by the experimenter, and limited information on daily activities. The estimation of the daily vibration exposure  $A(8)$  and its comparison with the regulatory limit values are therefore difficult [3].

The aim of this article is to present a method for the estimation of the daily vibration exposure  $A(8)$  adapted to vibrations composed of repeated shocks. It only requires the calculation of the vibration dose received by the operator during the intervention and the estimation of the total number of daily shocks. Its mathematical formulation is presented. It is then illustrated on a real case of field measurement.

## 2. Materials and Methods

### 2.1. Daily Vibration Exposure

The daily vibration exposure  $A(8)$  is defined as:

$$A(8) = a_{hv} \cdot \sqrt{\frac{T}{T_0}} \left( \text{m} \cdot \text{s}^{-2} \right), \quad (1)$$



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$a_{hv}$  ( $\text{m}\cdot\text{s}^{-2}$ ) is the vibration total value emitted by the machine.  $T$  (s) is the total daily duration of exposure of the operator.  $T_0 = 8 \times 3600$  (s) is the reference duration for a working day.

The vibration total value emitted by the machine  $a_{hv}$  is defined as:

$$a_{hv} = \sqrt{a_{hw_x}^2 + a_{hw_y}^2 + a_{hw_z}^2} \left( \text{m}\cdot\text{s}^{-2} \right), \quad (2)$$

$a_{hw_{x,y,z}}$  ( $\text{m}\cdot\text{s}^{-2}$ ) is the root-mean-square value of the  $W_h$  weighted accelerations, measured in the directions  $x$ ,  $y$ , and  $z$ .

The root-mean-square value of the  $W_h$  weighted accelerations  $a_{hw_{x,y,z}}$  is defined as:

$$a_{hw_{x,y,z}} = \sqrt{\frac{1}{N} \cdot \sum_{n=1}^N |a_{hw_{x,y,z}}[n]|^2} \left( \text{m}\cdot\text{s}^{-2} \right), \quad (3)$$

$a_{hw_{x,y,z}}[n]$  ( $\text{m}\cdot\text{s}^{-2}$ ) is the  $n^{\text{th}}$  sample value of the  $W_h$  weighted acceleration.  $N = T \cdot f_s$  is the total number of samples.  $f_s$  (Hz) is the sampling frequency of the signal.

## 2.2. Estimation from Field Measurements

$a_{hv_{\text{sample}}}$ ,  $T_{\text{sample}}$ , and  $A(8)_{\text{sample}}$  are the quantities related to the measurements made over a portion of the working day (measured work phase). In particular,  $T_{\text{sample}}$  is the sample duration over which  $a_{hv_{\text{sample}}}$  is calculated.

$a_{hv_{\text{estimate}}}$ ,  $T_{\text{estimate}}$ , and  $A(8)_{\text{estimate}}$  are the estimates of the unknown quantities  $a_{hv}$ ,  $T$ , and  $A(8)$  relative to the whole working day.

If the measured work phase is considered to be representative of the operator's daily task, then  $A(8)_{\text{estimate}}$  may be derived from Equation (1) as:

$$A(8)_{\text{estimate}} = a_{hv_{\text{sample}}} \cdot \sqrt{\frac{T_{\text{estimate}}}{T_0}} \left( \text{m}\cdot\text{s}^{-2} \right), \quad (4)$$

Depending on the nature of the working task, it is sometimes possible to know the numbers of shock repetitions during the measured work phase  $R_{\text{sample}}$ , and during complete working task  $R_{\text{estimate}}$ .  $A(8)_{\text{estimate}}$  is then derived from Equation (1) as:

$$A(8)_{\text{estimate}} = \sqrt{R_{\text{estimate}} \cdot \overline{A_r(8)}_{\text{sample}}} \left( \text{m}\cdot\text{s}^{-2} \right), \quad (5)$$

$\overline{A_r(8)}_{\text{sample}}$  ( $\text{m}\cdot\text{s}^{-2}$ ) represents the average vibration dose received per shock  $r$  of the sample. It is equal to the dose that would be received for each of the  $R_{\text{sample}}$  shocks of the sample if they were all identical:

$$\overline{A_r(8)}_{\text{sample}} = \frac{A(8)_{\text{sample}}}{\sqrt{R_{\text{sample}}}} \left( \text{m}\cdot\text{s}^{-2} \right), \quad (6)$$

## 2.3. Application to Vibrations Emitted by Firearms

Vibrations emitted by a Zastava M70 AB2 automatic assault rifle were measured (Figure 1). Five  $7.62 \times 39$  mm M43 rounds were fired in 35.5 s during the measurements. The ballistics expert estimates that this weapon is used for 1.5 h per day. Another piece of information is that approximately 300 rounds are fired per day both in semi-automatic and full-automatic mode. A piezoelectric accelerometer was glued to the rifle (356B20-PCB Piezotronics®). Acceleration was recorded with a R2DB front-end (DEWESOFT®).

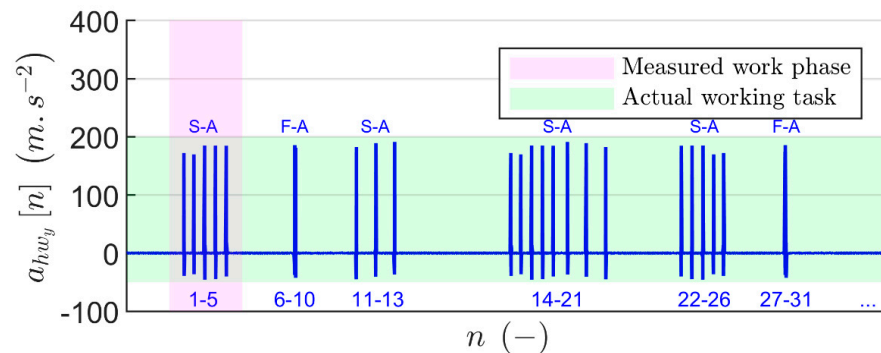


**Figure 1.** Measurement of vibrations emitted by a Zastava M70 AB2 automatic assault rifle. Top: rifle overview; bottom left: accelerometer positioning; bottom right: 7.62 × 39 mm M43 rounds.

### 3. Results

#### 3.1. Field Measurements

Figure 2 presents the weighted acceleration  $a_{hwy}[n]$  of the measured work phase. Only one axis is shown for readability reasons. An extract of the operator's daily working task is also presented in order to illustrate the differences that may exist with the sample. This part remains unknown during field measurements. Signals characteristics are presented in Table 1.



**Figure 2.** Extract from the field measurement: weighted acceleration  $a_{hwy}[n]$  and number of shots fired (S-A: semi-automatic, F-A: full-automatic).

**Table 1.** Vibration exposure characteristics: sample (measured work phase) and daily working task.

Measured Work Phase					Actual Working Task <sup>1</sup>				
$a_{hv\_sample}$ ( $m \cdot s^{-2}$ )	$T_{sample}$ (s)	$A(8)_{sample}$ ( $m \cdot s^{-2}$ )	$R_{sample}$ ( $-$ )	$\overline{A_r(8)}_{sample}$ ( $m \cdot s^{-2}$ )	$a_{hv}$ ( $m \cdot s^{-2}$ )	$T$ (s)	$A(8)$ ( $m \cdot s^{-2}$ )	$R$ ( $-$ )	$\overline{A_r(8)}$ ( $m \cdot s^{-2}$ )
2.6	35.5	0.090	5	0.040	2.1	3500.0	0.7	310	0.041

<sup>1</sup> Unknown.

#### 3.2. Daily Vibration Exposure Estimations

Table 2 shows  $A(8)_{estimate}$  values calculated from the sample depending on the available information.

**Table 2.** Daily vibration exposure estimations from sample (measured work phase) and available information.

$T_{estimate}^1$		$R_{estimate}^1$				
$a_{hv_{sample}}$ ( $m \cdot s^{-2}$ )	$T_{estimate}$ (s)	$A(8)_{estimate}$ ( $m \cdot s^{-2}$ )	$R_{estimate}$ (—)	$R_{sample}$ (—)	$A(8)_{sample}$ ( $m \cdot s^{-2}$ )	$A(8)_{estimate}$ ( $m \cdot s^{-2}$ )
2.6	5400	1.1	300	5	0.090	0.7

<sup>1</sup> Known from task information.

#### 4. Discussion

For non-stationary vibrations composed only of one or more successive shocks, Equations (1)–(3) show that  $a_{hv}$  varies with the number of points  $N$  of a signal. This is not the case for  $A(8)$ .

When only the total daily duration of exposure  $T_{estimate}$  can be determined from the daily task information, Equation (4) shows that  $A(8)_{estimate}$  depends on  $a_{hv_{sample}}$ .  $A(8)_{estimate}$  is then particularly sensitive to the sampling conditions: the machine emission, and the regularity of the firing rate throughout the day.

When the numbers of shocks of the sample  $R_{sample}$  and of the whole day  $R_{estimate}$  can be determined from task information, Equations (5) and (6) show that  $A(8)_{estimate}$  depends only on the dose  $A(8)_{sample}$ .  $A(8)_{estimate}$  is then insensitive to the consistency of the firing pace outside of the sample.

In practice, the field-measurement conditions are not always controlled.  $a_{hv_{sample}}$  varies during the day depending on the company's production (Figure 2). The assumption that the sample is representative is not always satisfied (Table 1).  $T_{estimate}$  is also difficult to determine as it represents the actual duration of exposure to vibration. It can be very different from the duration of use of the machine. The estimate of daily vibration exposure  $A(8)_{estimate}$  is then strongly biased (Table 2).

When possible, the estimation of the total number of shocks  $R_{estimate}$  is easier to perform and often more accurate than  $T_{estimate}$ . The average vibration dose received per shock during sampling  $A_r(8)_{sample}$  is often representative of the whole set of shocks (Table 1).  $A(8)_{estimate}$  is then closer to the actual daily exposure.

#### 5. Conclusions

The estimation method for the daily exposure to vibration  $A(8)$ , which takes into account the number of shock repetitions, is often more reliable than the usual one. It also facilitates the implementation of technical prevention solutions by linking the operator's exposure to production rather than to his work pace. It should be preferred for assessing the risk created by repeated shocks at the workplace.

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