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Definition and Quantification of Shock/Peak/Transient Vibration †

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Abstract: Vibration injury in the hand–arm system from hand-held machines is one of the most common occupational health injuries. Machines emitting high-frequency shock vibrations, e.g., impact wrenches have since long been identified as a special risk factor. In legislative and standard texts, the terms shock, impact, peak and transient vibration are frequently used to underline the special risks associated with these kinds of vibrations. Despite this fact, in the literature there is not a mathematically stringent definition of either shock vibration or how the amplitude of the shock is defined. In this study, we suggest algorithms for definition and quantification of these terms and apply them to machine vibrations of various kinds.

Keywords: high frequency; HAVS; VPM; VSI; VSL; transient; impact; shock; vibration; ultravibration

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1. Introduction

Vibration injury in the hand–arm system from hand-held machines is one of the most common occupational health injuries; it can cause severe and often chronic nerve and vascular injury to the operator. Machines emitting high-frequency shock vibrations, e.g., impact wrenches, bucking bars, chipping hammers, etc. have since long been identified as a special risk factor and the current standard for evaluation of risk is limited to frequencies below 1250 Hz [1–6]. This results in large occupational groups being exposed to harmful vibrations that are not regulated by any workers protection directives. The term ultravibration is used to define vibration with frequency above 1250 Hz, which is in analogy with ultrasound as frequencies above the human perception threshold. In legislative and standard texts the terms shock, impact, peak and transient vibration are frequently used to underline the special risk associated with these kinds of vibrations. Despite this fact, there is not a mathematically stringent definition of either shock vibration or how the amplitude of the shock is defined. To enhance the knowledge of medical effects and develop prevention measures from shock and ultra-vibration, it is of fundamental importance that they can be measured, defined and quantified.

This study suggests algorithms for definition of shock vibration and quantification of peak acceleration before applying them to measured vibrations from machines with different types of vibration characteristics. The algorithms used and the background behind them are explained in depth in Johannisson et al. [7].

Analysing shock requires sufficiently high upper frequency to cover the main energy content of the vibration. For a majority of hand-held machines, a frequency range of at least 10 kHz is suggested. Since the vibration signal is analysed in the time domain, it is recommended that the sample rate is at least five times the cut-off frequency of the low pass filter.

2. Materials and Methods

2.1. Quantifying the Peak/Shock Acceleration

A typical shock type vibration signal from an impact wrench low pass was filtered at 30 kHz (blue), 1250 Hz (purple) and with ISO 5349-1 weighting curve (yellow), as shown in the top graph in Figure 1; the lower graph is a zoom in on specific results. The corresponding frequency plot is seen in Figure 2.

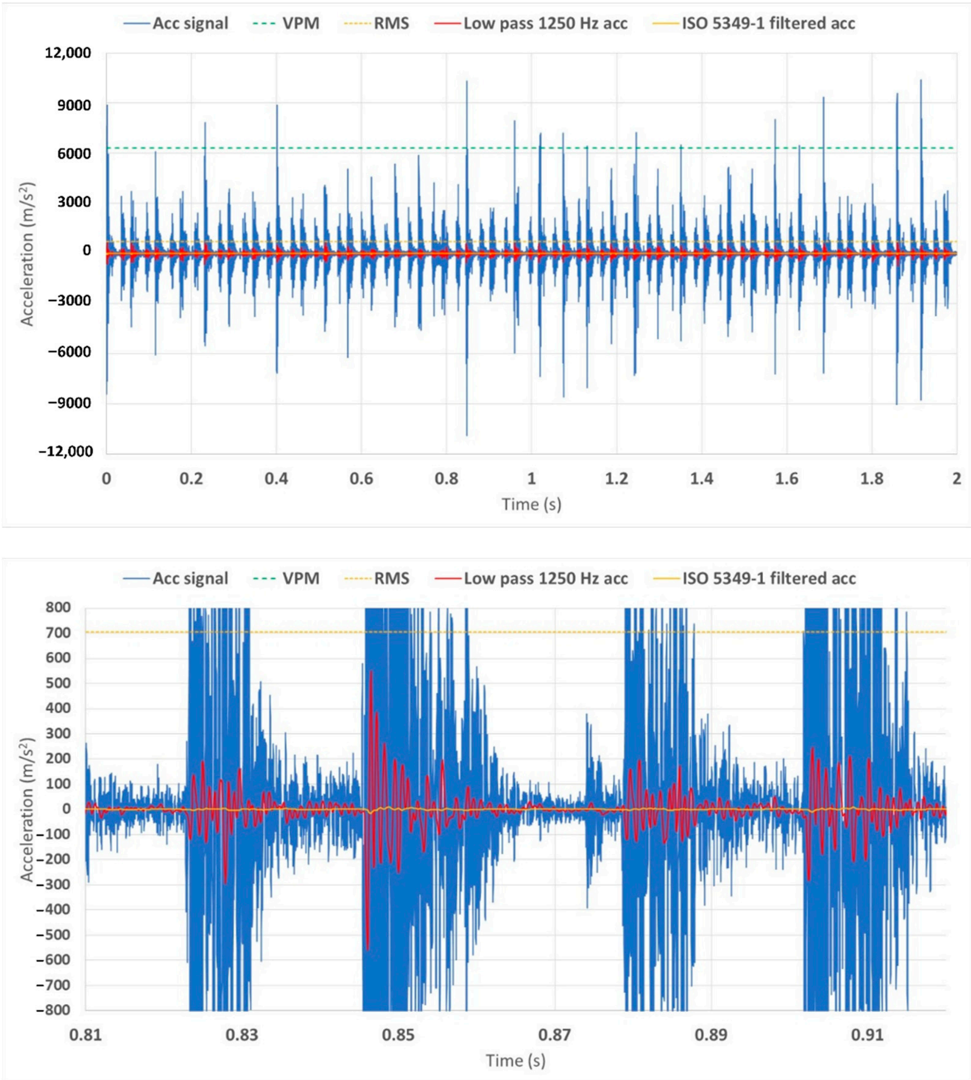

Figure 1. Acceleration from $\frac{3}{4}''$ pneumatic impact wrench, (**top**), and zoom, (**bottom**).

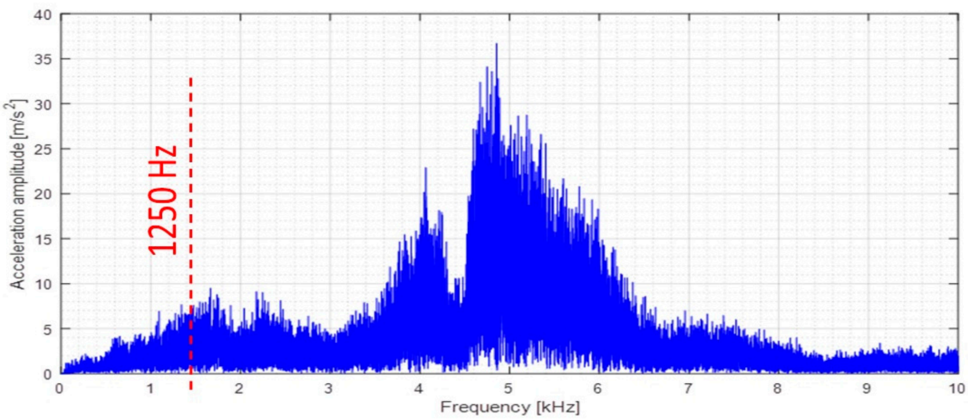

Figure 2. Acceleration frequency plot from $\frac{3}{4}''$ pneumatic impact wrench.

What could be seen is that the peak amplitude varied substantially from each impact cycle of the wrench. It could also be seen that the main frequency content was between 3 and

7 kHz; low pass filtering occurred at 1250 Hz and with ISO 5349-1 weighting, reducing the amplitude to a very large extent. It could also be seen that the RMS value underestimated the peak values significantly.

To quantify the average peak amplitude, it was suggested to define the term Vibration Peak Magnitude (VPM) [7] (in Chapter 3.6.2 in Ref. [7], the former term VSL was used.) for a sampled signal a_n, with N data points by:

$$VPM(a_n) = \sqrt{\frac{\sum_{n=1}^{N} a_n^6}{\sum_{n=1}^{N} a_n^4}} \tag{1}$$

The VPM value is a weighted average of the peaks that obtains a representative peak acceleration in m/s^2. The VPM value for the impact wrench is indicated by the green dashed line in Figure 1.

2.2. Defining Shock Vibration

The suggestion was to define the term Vibration Shock Index (VSI) [7] (Chapter 3.6.2) as:

$$VSI = \frac{VPM}{RMS} \times \sqrt{2/3} \tag{2}$$

The VSI value is a dimensionless number that indicated to what extent a given signal consisted of shocks. It was defined as the ratio of the VPM and the RMS values, multiplied by the factor $\sqrt{2/3}$. With this definition, the VSI is defined as 1 for harmonic signals and increases when the shock content increases.

3. Results

Table 1 shows the values VSI, VPM, RMS and 1250 Hz lowpass filtered RMS to examples of machines with various types of vibration.

Table 1. Typical values from different machine types.

Machine	VSI	VPM [m/s^2]	RMS [m/s^2]	RMS Lowpass 1250 Hz [m/s^2]
Angle grinder	2.1	721	344	21
Impact wrench	11.4	7840	690	78
Nail gun	48.7	1520	31	16
Reciprocating saw	6.2	1170	188	50

4. Discussion

The VPM represents an effective estimate of the characteristic peak acceleration, while the VSI can be used for evaluating the degree of shock content. It is also of fundamental importance that if shock vibrations are to be evaluated, they are measured at frequencies high enough to cover at least a major part of the signal energy. Applying a low pass filter at 1250 Hz or ISO 5349-1 weighting vastly reduces the peak amplitude. As a compromise between the complexity of measurement equipment and covering the high-frequency content, it is suggested to measure at least up to 10 kHz and sampling at 50 kHz.

If there is a need of separating shock vibration from continuous, a suggestion is to define shock vibration as machines with a VSI exceeding the value of 8, which is believed to be in line with the general opinion. In general, a higher VSI indicates a higher importance of the shocks relative to the continuous content, though this needs to be further investigated as more data becomes available.

Enabling the possibility to quantify and define shock vibration will have a plurality of benefits, such as:

- Enhancing research on health effects, especially epidemiological studies;
- Enabling machine users to restrict the high-frequency content and develop demand specifications at procurement;
- Creating incentives for machine producers to reduce high-frequency vibration emission;
- Creating incentives for development of mitigation measures on existing tools;
- Promoting the development of personal protection equipment.

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