A COMPARATIVE EVALUATION OF HAND-ARM VIBRATION IMPACTS

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1 Introduction

As per the applicable ISO standard ISO 5349-1 [1], hand-arm vibration is typically measured with a tri-axial sensor attached to the fingers, palm, or arm. Depending on the measurement locations, applicable adapters may be inserted between the sensor and hand/arm. For hand-arm vibration measurements, the frequency weighting filter W_h is specified in ISO 5349-1, European and American guidelines [2, 3]. The frequency weighting filter W_h is comprised of three filters: high-pass, low-pass and frequency-weighting [4].

$$W_h = H_h(s) \cdot H_l(s) \cdot H_w(s) \tag{1}$$

Where H_h, H_l, and H_w are high-pass, low-pass, and frequency-weighting filters, respectively. The individual filters are defined in ISO 2631-2 [5] and can be calculated using the following equations.

$$H_h(s) = \frac{s^2}{s^2 + \frac{\omega_1}{Q_1}s + {\omega_1}^2} \tag{2}$$

$$H_l(s) = \frac{{\omega_2}^2}{s^2 + \frac{\omega_2}{Q_2}s + {\omega_2}^2} \tag{3}$$

$$H_w(s) = \frac{(s + \omega_7) \cdot {\omega_8}^2}{(s^2 + \frac{\omega_8}{Q_7}s + {\omega_8}^2)\omega_7} \tag{4}$$

Figure 1 is a plot of the frequency weighting curve W_h over the frequency range which shows the weighting network having the lowest attenuation at about 10 Hz. At frequency ranges lower than 10 Hz, an attenuation up to 30 dB can be achieved. At higher frequency ranges, the attenuation can reach down to 40 dB (at 1000 Hz). This means that most of the energy outside the "favourable" frequency band (i.e. approx. 10 Hz) is significantly attenuated due to the filtering.

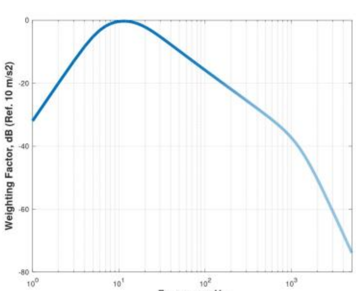

Figure 1: Frequency Weighting Curve Wh

Therefore, unless the vibration event has the dominant energy centred around 10 Hz, the vibration energy will be attenuated by the weighting curve. Consequently, the measured and calculated hand-arm vibration values, as per the ISO and other similar standards where the frequency weighting curve W_h is used, will likely be lower than the actual vibration levels as perceived by the person using the tool. In our opinion, this may be a concern because it could be leaving workers at higher vibration risks than is reported.

2 Method

In this comparative study, hand-arm vibration results between the filtered and un-filtered vibration impacts were compared in the time and frequency domains. The hand-arm vibration data was measured from the uses of two grinders, one air tool, and one hand tool. A tri-axial vibration sensor with appropriate adapters were used to measure the hand-arm vibration. The sensor was connected to a portable human vibration meter for data storage and post analysis. As per the ISO 5349-1 standard, the frequency weighting curve W_h was used for all directions. At the same time, raw (un-filtered) vibration data was sampled at about 7.2 kHz and streamed to the meter for further analysis.

Figure 2 shows the comparison of spectra from the use of one grinder. It is worth noting that a significant amount of high frequency energy was generated from this handheld grinder. Those high frequency components were attenuated by the filtering network when reporting vibration levels as per the ISO 5349-1 standard.

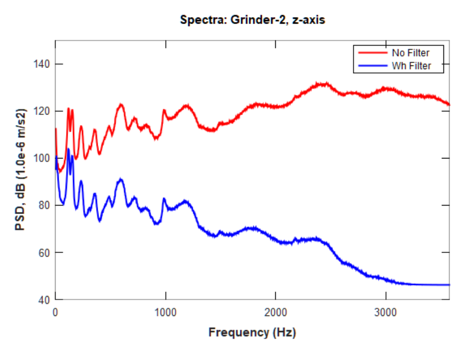

Figure 2: Spectra Comparison of Grinder #2

The frequency spectral comparison from the use of the air tool is shown in Figure 3. It can be seen that the meter "favours" the low frequency range up to approximately 50 Hz. The higher frequency components were again significantly attenuated by the filter.

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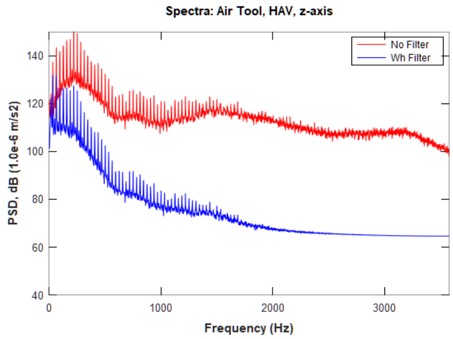

Figure 3: Spectra Comparison of an Air Tool

The comparisons of other spectra (grinder #1 and the hand tool) show similar favoritism by filter W_h.

3 Discussions

Table 1 shows the measured and calculated overall vibration energies.

Table 1: Comparison of Vibration Energies

Activity	Filtered Energy (m/s2)	Unfiltered Energy (m/s2)	Energy Ratio
Grinder – 1	0.4	3.6	12%
Grinder - 2	1.6	123.2	1%
Air Tool	11.5	96.7	12%
Hand Tool	12.8	105.4	12%

From Table 1 it can be seen that the meter measured/calculated vibration energy levels consisting of approximately 12% of the total vibration energy levels for 3 of the 4 test activities. For grinder #2, the reported energy is only 1% of the total energy.

The above analysis shows the meter measured/reported energy levels are typically lower than the total energy levels contained in the raw vibration data because of the frequency weighting curve W_h. In particular, the reported levels appear even more suppressed when the vibration energy is contained in the high frequency ranges.

To test if other parameters may be sensitive to the different types of vibration activities, statistical parameters such as Skewness, Kurtosis, Crest Factor, and Vibration Dose Value (VDV) were calculated for the above test cases. The Table below shows the calculated values for the selected parameters.

Table 2: Comparison of Additional Parameters

	Kurtosis	VDV
Grinder – 1 (Stationary)	256	196
Grinder -2 (Handheld)	3	4093
Air Tool	11	2507
Hand Tool	2308	10624

The purpose of using these values is to characterize the "peakness" of the vibration data. The VDVs show much higher values when compared against other types of vibration data that are more or less stationary and have central frequencies in the lower ranges, compatible with the frequency weighting curve W_h.

4 Conclusions

The attenuation characteristics of the frequency weighting curve W_h was investigated. The weighting curve has a favourable narrow frequency band around 10 Hz. As a result of the unique frequency response of the weighting curve, the majority of energies contained outside the favourable frequency band are attenuated. Therefore, the measured and reported vibration levels are typically lower than the vibration impacts without the filter. It is our opinion, that it may be worthwhile to look into some additional parameters in order to characterize the hand-arm vibration impacts.

References

[1] ISO 5349-1:2001, Mechanical vibration - Measurement and evaluation of human exposure to hand-transmitted vibration -- Part 1: General requirements.

[2] EU Advisory Committee on Safety and Health at Work, Guide to Good Practice on Hand-Arm Vibration, 2006.

[3] American Conference of Governmental Industrial Hygienist (ACGIH), TLVs and BEIs, 2019.

[4] A. N. Rimell, N. J. Mansfield, Design of Digital Filters for Frequency Weightings Required for Risk Assessments of Workers Exposed to Vibration, Industrial Health 2007, 45, 512-519.

[5] ISO 2631-2: Mechanical Vibration and Shock – Evaluation of Human Exposure to Whole Body Vibration, Part 2 - Vibration in Buildings (1 Hz to 80 Hz). US General Service Administration Public Building Service, Sound Matters: How to Achieve Acoustic Comfort in the Contemporary Office, December 2011.