Vibration Injury Network

Research Network on Detection and Prevention of Injuries due to Occupational Vibration Exposures

Guidelines for conducting laboratory measurements of the power absorbed by the hand and arm

Appendix H3D to Final Report

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1. Scope

There are indications that absorbed power may represent an alternative descriptor of human exposure to vibration, to be used in the risk assessment procedure. Although measurements of absorbed power can in principle be performed both in the laboratory and in the field, the present state of research and technical development is such that no standard procedure can be recommended for field experiments. The scope of this document is to provide general guidelines for conducting laboratory experiments aimed at the measurement of absorbed power during the exposure to hand – transmitted vibration.

2. Definitions

Absorbed power: the total energy dissipated in the unit time by the oscillating system which consists of the vibrating tool and the subject operating the tool itself. Unit: [W]

Specific absorbed power: the energy dissipated in the unit time in a unit frequency interval by the above oscillating system. Unit: [$W\ Hz^{-1}$]

Normalized absorbed power: specific absorbed power divided by the input acceleration power spectral density. Unit: [$(W\ Hz^{-1}) / ((ms^{-2})^2\ Hz^{-1})$] = [$N\ m^{-1}\ s^3$]

3. Measuring principles

Absorbed power is the real part of the scalar product of force and velocity:

$$P_{Re} = \overline{v} \cdot \overline{F} = v \cdot F \cdot \cos(f)$$

Absorbed power is maximum when the phase angle f between force and velocity is zero. No power is absorbed when $f = \pi/2$. In this latter case the system behaves in a purely elastic mode, and power is transmitted back and forth between the vibration source and the object. A measurement of absorbed power can be performed either in the time or in the frequency domain:

- In the time domain it requires the simultaneous measurement of force and velocity, at any given instant of time.
- In the frequency domain absorbed power is calculated as the real part of the complex cross spectrum of force and velocity.

4. Instrumentation and technical requirements

4.1 The signal generator should be able to produce sinusoidal, sine sweeps, random and impulsive (shock) signals, which are conditioned by a power amplifier and then fed to the shaker. Unless shock type vibration is generated, the signal from a control transducer inside the handle should, if possible, be fed back to the signal generator in a closed loop, in order to keep the vibration magnitude to within a predetermined fraction of the desired level.

4.2 The shaker should be equipped with an ad-hoc handle. The handle first resonance frequency must be specified in order to allow the determination of the effective frequency range.

4.3 The handle should enable measurement of both static grip and feed forces applied by the subject to the handle as well as dynamic forces. The grip and feed force measuring systems both work with resolutions indicated by the international standard ISO 15230. Grip and feed forces may be monitored either by the subject or by the experimenter, or both.

4.4 The handle should have an ergonomic grip, i.e. shape and size which fit the average human hand, as specified by the european standard EN 420.

4.5 One or more force transducers should be used to measure the dynamic force transmitted to the handle from the shaker, along the vibration axis. An accelerometer, located inside the handle, is used to measure acceleration,

from which velocity is calculated. Special care has to be taken to secure that no erroneous phase shift between force and acceleration channels occurs.

4.6 The multi-channel signal analyser should operate A/D conversion with a sampling frequency greater than 2.56 times the highest frequency of interest.

Frequency domain – the real-time analyser performs vectorial subtraction of the force due to the mass of the unloaded handle (i.e. mass cancellation) and integrates acceleration to velocity. This is followed by cross correlation between force and velocity signals. Finally, absorbed power should be calculated from the real part of the complex cross spectrum. Minimum resolution of 400 lines is required. The analyser also provides values of the absorbed power in one-third octave bands, as defined by EN 61260.

Time domain – force and velocity signals are expanded in a Fourier series. The scalar product of force and velocity should be calculated for each term in the series, and absorbed power is eventually calculated by adding up all the terms.

5. Experimental conditions

Experimental conditions must be defined with respect to

5.1 The vibration axis. This should be specified as indicated in the international standard ISO 5349.

5.2 The frequency range. It is usually assumed that reliable results can be obtained up to a frequency 1/3 the frequency of the first resonance of the unloaded handle. If special experimental setups and/or data analysis has allowed the extension of the effective frequency range, these should be illustrated.

5.3 The nature of the stimulus. Two quantities which should always be specified are duration and r.m.s. magnitude. Other quantities may be useful to characterize specific signals, e.g. the crest factor for random and sine+random signals, or the repetition frequency for shock and shock+random signals.

5.4 Posture. The position of the hand, forearm and arm should be described using a total of six angles. The arm should be modelled as a vector rotating around a fixed point in space (the shoulder), and its direction specified by two angles. The forearm should be modelled as a vector rotating around a point in space (the elbow), and its direction should again be specified by two angles. Finally the hand orientation should be modelled allowing rotation around the axis "across the wrist" as well as around the axis along the forearm, thus requiring two more angles.

6. Experimental procedure

6.1 The experimental set up is calibrated taking a measurement of the system loaded with known weights within the range 0 – 5 Kg.

6.2 The subject adopts the required posture.

6.3 The subject is instructed to grip and feed with the required forces.

6.4 The shaker is switched on, and the desired stimulus is applied.

6.5 The subject adjusts grip and feed forces and provides a go-ahead signal. The duration of the measurement should be adjusted to the nature of the stimulus as well as to the target of the experimental study.

6.6 In case the experiment requests that grip/feed forces are kept constant, and the subject fails to maintain the grip and feed forces within 20% of the required values, the experiment shall be aborted and restarted.

6.7 The experiment should be repeated at least three times allocating rest periods between two consecutive exposures in order to restore the same initial conditions.

6.8 The subject always wears earmuffs.

7. Data analysis and reporting of results

For each experiment the following quantities and individual parameters should be reported:

a) absorbed power as a function of frequency or time

b) normalized absorbed power

c) phase between force and velocity as a function of frequency

d) static grip force

e) static feed force

f) standard deviations for quantities a) to e)

g) acceleration power spectrum (Unit: m^2s^{-3})

h1) tolerance set on the vibration level (%) (if preset in an automatic closed loop)

h2) uncertainty in the vibration level (%) (if determined in an operator-assisted closed loop)

i) direction of vibration

j) effective frequency range and frequency of the first handle resonance

k) duration of exposure

l) posture, specified as indicated in 5.4

m) relevant anthropometric parameters of the subject (length/mass of arm, forearm, hand, fingers)

n) gender and age of the subject

o) ambient temperature

p) time at which the experiment was conducted

8. Safety

The study will be conducted according to the safety recommendations included in ISO 13090 -1. Although this ISO standard is predominantly focussed on experiments involving human exposure to whole-body vibration, some parts may, as indicated in the standard itself, also be valid for local vibration, i.e. HAV.

The experimental subjects will give informed written consent to the study, and the experimental procedures shall be approved by local Ethical Committees.

9. Bibliography

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