Human Vibration Exposure
Whole Body and Hand-Arm Vibration

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Outline

• What is Human Vibration Exposure
• Hand Arm Vibration
• Whole Body Vibration
• Risk Assessment
• Measuring Exposure
• International Standards
• Mitigation
Every day, human beings interact with machinery. Contact with vibration is commonplace!

Unfortunately, continuous exposure to mechanical vibration can lead to physical injury...
Types of Human Vibration Exposure

Whole-body Vibration (WBV)

Hand-Arm Vibration (HAV)
Hand-Arm Vibration

Hand-Arm Vibration is caused by the transmission of vibration into the hand & arms through the palms and fingers by power tools, vibrating handles, etc.

Regular exposure can lead to what is commonly referred to as Hand-Arm Vibration Syndrome (HAVS). HAVS is a general term used to describe the physical damage to the hand, fingers, and related structures resulting from chronic exposure to excessive vibration.
Hand-Arm: US DOD Statement

In the U.S. alone, about 2.5 million workers are exposed daily to hand-arm vibration (HAV) from power tools they use on their job. Since 1918, it is documented that daily occupational exposure from many pneumatic, electric, hydraulic or gasoline powered vibrating hand-tools have been causally linked to HAVS.

HAVS is an irreversible medical condition of the fingers/hands, which causes loss of sensation and blood supply to the hands and may cause loss of fingers. Because HAVS is often misdiagnosed, it is underreported. The documented workplace prevalence of HAV in the U.S. ranges from 20-50% for certain groups of power tool users. This is believed to be a conservative estimate. Even by conservative estimates, as many as 1.25 million power tool users may be at risk for developing HAVS.


Emphasis added
Hand-Arm: Statement From the UK

Hand arm vibration is a widespread hazard, with over one million UK workers exposed to vibration over the HSE action limit $2.8\text{m/s}^2$. At present at least 300,000 workers have reported symptoms of Hand Arm Vibration Syndrome (HAVS). HSE guidance (HSG88) states that up to 10% of exposed workers will develop symptoms of blanching, based on exposure to $2.8\text{m/s}^2$ for 8 years. HAVS is the most common disease assessed by the DSS and is the most common disease reported under RIDDOR.

http://www.whitefinger.co.uk/technical.html
Hand-Arm: Exposure Limits

Vibration exposure limits have been established through European Directive 2002-/44/-EC and the American Conference of Industrial Hygienists (ACGIH). Limits for maximum exposure which are called the Threshold Limit Value (TLV) and action levels are shown below.

<table>
<thead>
<tr>
<th>ACGIH Threshold Limit Values (TLVs)</th>
<th>EU Directive 2002/44/EC Limit and Action Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Daily Exposure Duration</strong></td>
<td><strong>Daily Exposure Duration</strong></td>
</tr>
<tr>
<td>4 to less than 8 hours</td>
<td>8 hours</td>
</tr>
<tr>
<td>2 to less than 4 hours</td>
<td>6 m/s²</td>
</tr>
<tr>
<td>1 to less than 2 hours</td>
<td>8 m/s²</td>
</tr>
<tr>
<td>Less than 1 hour</td>
<td>12 m/s²</td>
</tr>
</tbody>
</table>

The ACGIH TLV is based upon the dominant axis: X, Y, or Z.
The EU Directive is based upon a vector sum of the X,Y, and Z axes.
Whole Body Vibration Exposure

Whole body vibration occurs when the entire body is supported on a vibrating structure. Typically this means sitting or standing on a machine or vehicle.

Whole body vibration can impact the ride and comfort of the driver or worker, and it can also create health risks when:

- The magnitudes of vibration are high
- The exposure duration is prolonged
- The frequency of exposure correlates to the bodies structural resonances
- The exposure includes impacts or shocks
Whole Body: Health Concerns

Whole body vibration exposure has a cumulative affect on the skeletal and muscular system of the body. It is important to know than it can cause:

- Low-back pain and back disorders
- Neck-shoulder disorders
- Digestive and circulatory disorders
- Cochleo-vestibular and reproductive effects
Whole Body: Exposure Limits

The European Union has set exposure limits in directive 2002/44/EC and the ACGIH has set limit values that follow the ISO 2631-1 standard for WBV. These "action" and "limit" values are shown below for reference.

<table>
<thead>
<tr>
<th>Standard</th>
<th>Limit Values (likely health risk)</th>
<th>Action Values (caution)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACGIH</td>
<td>A(8) = 0.9 m/s²</td>
<td>A(8) = 0.5 m/s²</td>
</tr>
<tr>
<td>ISO 2631-1</td>
<td>VDV = 17 m/s^{1.75}</td>
<td>VDV = 8.5 m/s^{1.75}</td>
</tr>
<tr>
<td>EU Directive</td>
<td>A(8) = 1.15 m/s²</td>
<td>A(8) = 0.5 m/s²</td>
</tr>
<tr>
<td>2002/44/EC</td>
<td>VDV = 21 m/s^{1.75}</td>
<td>VDV = 9.1 m/s^{1.75}</td>
</tr>
</tbody>
</table>
Human Vibration - Scope and Economic Impact

- Affected Industries: Foundries, Shipbuilding, Oil/Gas, Logging/Forestry, Mining, Transportation, Defense, Metalworking

- Currently one of the top three most compensated injuries in some countries (examples include UK and Italy)
Typical at-risk Job Descriptions

- Forestry workers
- Stone drillers, stone cutters and chippers
- Quarry drillers
- Aircraft engine workers
- Farmers
- Sheet metal workers
- Polishers
- Oil Rig workers
- Grinders
- Molders
- Maintenance and Janitorial workers
- Welders
- Riveters
- Dental technicians
- Orthopedists
- Sewing machine operators
- Chainsaw operators
- Construction workers
- Pedestal grinder operators
- Auto / truck / bus mechanics and other users of impact power tools
- Shipyard workers
- Railway workers
Human Vibration: What To Do

A. Risk assessment: Identify areas of concern
B. Determine or measure exposure
C. Mitigate exposure & control the risk
1. Identify areas of concern…
   A. Regular use of power tools (HA)
   B. A report of carpal tunnel or HAVS (HA)
   C. Workers report tingling or “pins and needles” feeling (HA)
   D. Driving off-road or on rough surfaces (WB)
   E. Operating a vehicle subject to “shocks” (WB)
   F. Do you adopt poor posture during operations (WB)
   G. Do manufactures warn of risk from vibration (Both)
Human Vibration: Measure & Mitigate

2. Determine exposure
   A. Measure
   B. Model

3. Control the risk
   A. Limit exposure time
   B. Lower vibration levels
   C. Add Vibration isolation via gloves, special seats, etc.
Human Vibration : Modeling Exposure

- Modeling method for HA vibration
- Determine tool handle vibration using OEM product data
HVM200 is:

- Small, portable meter
- Wi-Fi connected (optional)
- Used with triaxial accelerometers
- Designed to measure hand-arm & whole body vibration
- Control & view data from a free app (Android & Apple)
- Calculate metrics per International Standards
- 2nd Generation Meter
Hand-Arm Measurement Components

- HVM200
- Cable
- Accelerometer
- Adapter
- Software
# Hand-arm Measurement Accessories

<table>
<thead>
<tr>
<th>Adapter Type</th>
<th>Handle Adapter</th>
<th>“T” Adapter</th>
<th>Clamp Adapter</th>
<th>Palm Adapter</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cable</strong></td>
<td><img src="CBL217-01_incl.png" alt="Image" /></td>
<td><img src="CBL217-01_incl.png" alt="Image" /></td>
<td><img src="CBL217-05.png" alt="Image" /></td>
<td><img src="CBL216.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>Sensor</strong></td>
<td>SEN040F</td>
<td>SEN040F</td>
<td>SEN040F</td>
<td>SEN026</td>
</tr>
<tr>
<td></td>
<td>$S = 0.1 \text{ mV/(m/s}^2)$</td>
<td>$S = 0.1 \text{ mV/(m/s}^2)$</td>
<td>$S = 0.1 \text{ mV/(m/s}^2)$</td>
<td>$S = 1 \text{ mV/(m/s}^2)$</td>
</tr>
<tr>
<td></td>
<td>1.0$^1$ to 49k m/s$^2$</td>
<td>1.0$^1$ to 49k m/s$^2$</td>
<td>1.0$^1$ to 49k m/s$^2$</td>
<td>0.1$^1$ to 4.9k m/s$^2$</td>
</tr>
<tr>
<td><strong>Adapter</strong></td>
<td><img src="ADP081A.png" alt="Image" /></td>
<td><img src="ADP080A.png" alt="Image" /></td>
<td><img src="ADP082A.png" alt="Image" /></td>
<td><img src="ADP063.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>Typical Use</strong></td>
<td>Accelerometer held to the side of the hand</td>
<td>Accelerometer held between fingers</td>
<td>Clamp to handle of a machine</td>
<td>Measure at the palm under a glove</td>
</tr>
</tbody>
</table>

$^1$When using Wh frequency weighting
Whole Body – Measurement Components

HVM200 & Mobile App

G4 – HVM Software for Analysis & Reporting

SEN027 – Seat pad which includes triaxial accelerometer & cable
Every object has a resonant frequency in somewhat the same sense that a pendulum has a natural frequency. When an object is vibrated at its resonance frequency, it will vibrate at a maximum amplitude which is larger than the amplitude of the original vibration.
Resonant Frequencies of the Human Body

The frequency range of 0.5 Hz to 80 Hz is significant in terms of the body's response

- In the human body, individual body members and organs have their own resonant frequencies and do not vibrate as a single mass, with its own natural frequency.
- This causes amplification or attenuation of input vibrations by certain parts of the body due to their own resonant frequencies.
- The most effective exciting frequency for vertical vibration lies between 4 and 8 Hz.
  - Vibrations between 2.5 and 5 Hz generate strong resonance in the vertebra of the neck and lumbar region with amplification of up to 240%.
  - Between 4 and 6 Hz resonance are set up in the trunk with amplification of up to 200%.
  - Vibrations between 20 and 30 Hz set up the strongest resonance between the head and shoulders with amplification of up to 350%.
**Hand-Arm: Frequency Weightings**

<table>
<thead>
<tr>
<th>Weighting</th>
<th>Description</th>
<th>Definition</th>
<th>Reference (f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W_h$</td>
<td>Hand arm vibration (all)</td>
<td>ISO 8041</td>
<td>500 rad/s (79.6 Hz)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ISO 5349-1</td>
<td></td>
</tr>
</tbody>
</table>
## Whole Body: Frequency Weighting

<table>
<thead>
<tr>
<th>Application</th>
<th>Weight</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole body</td>
<td>Wb</td>
<td>z-axis vertical vibration</td>
</tr>
<tr>
<td>Whole body</td>
<td>Wc</td>
<td>x-axis, seat back</td>
</tr>
<tr>
<td>Whole body</td>
<td>Wd</td>
<td>x-axis &amp; y-axis, seat surface</td>
</tr>
<tr>
<td>Whole body</td>
<td>We</td>
<td>rotational seat surface</td>
</tr>
<tr>
<td>Whole body</td>
<td>Wf</td>
<td>Motion sickness (vertical)</td>
</tr>
<tr>
<td>Whole body</td>
<td>Wj</td>
<td>vertical recumbent</td>
</tr>
<tr>
<td>Whole body</td>
<td>Wk</td>
<td>z-axis, seat surface</td>
</tr>
<tr>
<td>Whole body</td>
<td>Wm</td>
<td>Vibration in buildings</td>
</tr>
</tbody>
</table>

- **Recumbent position**
- **Ischial tuberosities**
- **Roll (r_z)**
- **Pitch (r_y)**
Human Vibration – Measurement Process

1. Develop a test plan objective
   – Measure tool / vehicle typical vibration level
   – Measure the worker’s exposure for a shift or portion of a shift
2. Select the appropriate accelerometer and/or adapter
3. Setup the instrument or recall a ‘Set Up’ file
4. Start the measurement and log the data over the desired time frame
5. The metrics and time data can be monitored on your mobile device
6. Connect the meter to you PC and download the data / metrics
7. Review the data and edit out any anomalies
8. Recalculate metrics as needed
9. Conduct ‘what if ‘ studies
10. Generate a report
## Human Vibration – Data Analysis

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Overall Data</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Start Date and Time</strong></td>
<td>2016-Mar-16 10:35:53</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Run Time (hh:mm:ss)</strong></td>
<td>00:07:17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>x</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>y</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>z</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>a_{rms}</strong></td>
<td>2.8191</td>
<td>3.3041</td>
<td>2.3110</td>
<td></td>
<td>4.9199</td>
<td>m/s²</td>
</tr>
<tr>
<td><strong>MTVV</strong></td>
<td>5.1096</td>
<td>9.5952</td>
<td>5.0448</td>
<td></td>
<td>10.2055</td>
<td>m/s²</td>
</tr>
<tr>
<td><strong>a_{peak}</strong></td>
<td>37.1649</td>
<td>42.7567</td>
<td>29.0204</td>
<td></td>
<td>50.8912</td>
<td>m/s²</td>
</tr>
<tr>
<td><strong>a_{min}</strong></td>
<td>0.3410</td>
<td>0.4064</td>
<td>0.4246</td>
<td></td>
<td>0.6876</td>
<td>m/s²</td>
</tr>
<tr>
<td><strong>A(1)</strong></td>
<td>0.9822</td>
<td>1.1512</td>
<td>0.8052</td>
<td></td>
<td>1.7141</td>
<td>m/s²</td>
</tr>
<tr>
<td><strong>A(2)</strong></td>
<td>0.6945</td>
<td>0.8140</td>
<td>0.5694</td>
<td></td>
<td>1.2121</td>
<td>m/s²</td>
</tr>
<tr>
<td><strong>A(4)</strong></td>
<td>0.4911</td>
<td>0.5756</td>
<td>0.4026</td>
<td></td>
<td>0.8571</td>
<td>m/s²</td>
</tr>
<tr>
<td><strong>A(8)</strong></td>
<td>0.3473</td>
<td>0.4070</td>
<td>0.2847</td>
<td></td>
<td>0.6060</td>
<td>m/s²</td>
</tr>
<tr>
<td><strong>A(8) Exp.</strong></td>
<td>&gt;24</td>
<td>18.320</td>
<td>&gt;24</td>
<td></td>
<td>8.263</td>
<td>Hours</td>
</tr>
<tr>
<td><strong>Exposure Points</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6</td>
</tr>
</tbody>
</table>
Human Vibration: Mitigation

Mitigation strategies can focus on the two key parameters:
- Vibration magnitude
- Exposure time

Vibration magnitude countermeasures:
- Tool or vehicle selection and purchasing policies
- Understanding accessory effects
- Substitute other work methods
- Reduce grip force
- Adding vibration isolation i.e. gloves, wraps, suspension seats, standing pads
- Protection from the cold
- Manage vehicle speeds allowed and improve road surface
- Regular vehicle maintenance

Exposure time countermeasures:
- Limit operation time: i.e. job rotation
- Design tasks to minimize travel time
Example – Daily Exposure “What If” Analysis

“What If” the worker only operated this tool 4 hrs per day? Would that be put him at a safe limit?

\[ A(8) = a_{rms} \sqrt{\frac{T}{T_o}} \]

\[ A(8) = 4.9 \sqrt{\frac{4}{8}} \]

\[ A(8) = 3.46 \text{ m/s}^2 \]

\[ a_{rms} = \text{Measured Level} \]

\[ T = \text{Daily Exposure Duration} \]

\[ T_o = \text{Reference Duration (8hrs)} \]

Maximum allowable level for 8hr avg. exposure:

EU Directive: 5 m/s² (combined)
ACGIH TLV: 4 m/s² (dominant axis: x, y or z)
Human Vibration: Resources

- EU has legal limits for exposure
- US DOD Videos
  - https://www.youtube.com/playlist?list=PL1ZlaGPL5SwCYTjzyzX0fQKYbsKowv11A
- ACGIH Threshold Limit Values (TLVs)
- OSHA Technical Manual
- Tool Databases
  - NIOSH http://wwwn.cdc.gov/niosh-sound-vibration/
  - HAVTEC http://www.operc.com/havtec/
  - UMEA http://www.vibration.db.umu.se/HavSok.aspx?lang=en

--- Goal ---
Better tools and work practices
Thank You

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Support Slides

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## Accelerometer Selection

<table>
<thead>
<tr>
<th>Application</th>
<th>Accel</th>
<th>Description (with HVM200)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand-arm (rotating)</td>
<td>SEN041F</td>
<td>0.09 to 4.9k m/s² miniature triaxial 1 mV/(m/s²), 2 to 4k Hz, 1st order LP filter ¼-28 4-pin connector (use with CBL217-xx)</td>
</tr>
<tr>
<td>Hand-arm (Impulsive)</td>
<td>SEN040F</td>
<td>0.9 to 49k m/s² miniature triaxial 0.1 mV/(m/s²), 2 to 4k Hz, 1st order LP filter ¼-28 4-pin connector (use with CBL217-xx)</td>
</tr>
<tr>
<td>Hand-arm (Gloves)</td>
<td>SEN026</td>
<td>0.09 to 4.9k m/s² miniature triaxial, low-profile, 1 mV/(m/s²), 1 to 9k Hz, mini 4-pin connector. Use with ADP063 &amp; CBL216</td>
</tr>
<tr>
<td>Whole body</td>
<td>SEN027</td>
<td>0.01 to 98 m/s² seatpad with triaxial sensor, 10 mV/(m/s²), 0.5 to 1k Hz, mini 4-pin connector</td>
</tr>
<tr>
<td>General Vibration</td>
<td>SEN020</td>
<td>0.9 to 14.7k m/s² triaxial, 0.1 mV/(m/s²) 0.5 Hz to 5 kHz, 1st order LP filter ¼-28 4-pin connector (use with CBL217-xx)</td>
</tr>
</tbody>
</table>
# Hand-arm Adapter & Weighting Selection

<table>
<thead>
<tr>
<th>Adapter</th>
<th>Sensor</th>
<th>When to use</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADP063</td>
<td>SEN026</td>
<td>For measurement in the palm and under a glove</td>
</tr>
<tr>
<td>ADP080A</td>
<td>SEN040F SEN041F</td>
<td>For measurement between the fingers</td>
</tr>
<tr>
<td>ADP081A</td>
<td>SEN040F SEN041F</td>
<td>For measurements at the side of the hand</td>
</tr>
<tr>
<td>ADP082A</td>
<td>SEN040F SEN041F</td>
<td>For attaching accelerometer directly to a handle</td>
</tr>
</tbody>
</table>

Use Wh weighting for all hand-arm measurements
HVM200 Selection Guide

Selection & Configuration Guide
Human Vibration Configuration Guide (HVM200)

Hand-Arm Vibration

Whole Body Vibration

General Vibration

Optional Accessories

Included Accessories

13 October 2015
## Frequency Weightings – Whole Body

<table>
<thead>
<tr>
<th>Weighting</th>
<th>Description</th>
<th>Definition</th>
<th>Reference (f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W_b$</td>
<td>z-axis vertical vibration</td>
<td>ISO 8041</td>
<td>100 rad/s (15.9 Hz)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ISO 2631-4</td>
<td></td>
</tr>
<tr>
<td>$W_c$</td>
<td>x-axis, seat back</td>
<td>ISO 8041</td>
<td>100 rad/s (15.9 Hz)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ISO 2631-1</td>
<td></td>
</tr>
<tr>
<td>$W_d$</td>
<td>x-axis, seat surface</td>
<td>ISO 8041</td>
<td>100 rad/s (15.9 Hz)</td>
</tr>
<tr>
<td></td>
<td>y-axis, seat surface</td>
<td>ISO 2631-1</td>
<td></td>
</tr>
<tr>
<td>$W_e$</td>
<td>rotational seat surface</td>
<td>ISO 8041</td>
<td>100 rad/s (15.9 Hz)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ISO 2631-1</td>
<td></td>
</tr>
<tr>
<td>$W_f$</td>
<td>Motion sickness (vertical)</td>
<td>ISO 8041</td>
<td>2.5 rad/s (0.398 Hz)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ISO 2631-1</td>
<td></td>
</tr>
<tr>
<td>$W_j$</td>
<td>vertical recumbent</td>
<td>ISO 8041</td>
<td>100 rad/s (15.9 Hz)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ISO 2631-1</td>
<td></td>
</tr>
<tr>
<td>$W_k$</td>
<td>z-axis, seat surface</td>
<td>ISO 8041</td>
<td>100 rad/s (15.9 Hz)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ISO 2631-1</td>
<td></td>
</tr>
<tr>
<td>$W_m$</td>
<td>Vibration in buildings</td>
<td>ISO 8041</td>
<td>100 rad/s (15.9 Hz)</td>
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<tr>
<td></td>
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<td>ISO 2631-2</td>
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