Human Vibration
Hand-arm Vibration

Long-term exposure can cause white-finger or dead-finger syndrome

Symptoms:
- Tingling
- Numbness
- Blanching
- Over-reaction to coldness
Whole-body Vibration

Long-term exposure can cause severe damage especially to the lumbar region of the spine

Short-term symptoms:
- Fatigue
- Headache
- Slower reactions
- Nausea
- Insomnia
Mechanical Models of the Human Body

**Whole body**
- Lung volume
- Spinal column (axial mode) (10 - 12 Hz)
- Lower arm
- Abdominal Mass (4 - 8 Hz)
- Legs (Variable from ca. 2 Hz with knees flexing to over 20 Hz with rigid posture)
- Standing person

**Shoulder girdle** (4 - 5 Hz)

**Hand-arm**
- Eyeball, intraocular structures (ca. 25 Hz)
- Head (axial mode) (20 - 30 Hz)
- Hand grip (50 - 200 Hz)

**Seated person**

**Hand-arm**
Transmission of Vibration through the Body

Acceleration Ratio

Frequency, Hz

Head
Shoulder
Thorax
Standards for Human Vibration

ISO 2631-1:1997
“Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration,
Part 1, General Requirements”.

ISO 5349-1986
“Mechanical vibration - Guidelines for the measurement and the assessment of human exposure to hand-transmitted vibration.”
Evaluation Method: Rating

Max. 1 Hour exposure allowed in this example

Rating curves
1 Hour
2 Hour
4 Hour

1/3 - octave Spectrum

Acceleration

Frequency, Hz
1 2 4 8 16 31.5
Evaluation Method: Weighting

Motion sickness

Acceleration (dB)

Whole body
x, y, z

Hand-arm
Using the Weighing Method in Practice

![Diagram showing the process of measurement, weighting, and display.](image)

**Measurement**

**Weighting**

**Display**

- $L_{eq} = 106.2\,\text{dB}$
- $L_{ls (Inst.)} = 116.5\,\text{dB}$
- $L_{lpk (MaxP.)} = 130.6\,\text{dB}$
- $L_{LFMax} = 122.6\,\text{dB}$
- Overload: 0.0 %
- Elapsed Time: 00:00:53
Measurement Directions

Whole-Body

"Handgrip" position

--- Basicentric coordinate system

Biodynamic coordinate system
Categories of Whole-Body Vibration

**Motion sickness**, in ships or vehicles with very soft suspension systems
- 0.1 to 0.63Hz

**Whole-body vibration** in vehicles or on platforms
- 1 to 80Hz

**Whole-body vibration** in buildings
- 1 to 80Hz
Whole-Body Vibration Weighting

Acceleration (dB)

Whole body

x, y
z

Combined filter

Hz
Measure in the Vertical Direction In Buildings
Hand-Arm Vibration Weighting

**Acceleration**
**dB**

8 Hz

16 Hz

Hz

-35 -30 -25 -20 -15 -10 -5 0 5 10 20 50 100 200 500 1k

0,02 0,05 0,1 0,2 0,5 1 2 5 10

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Vibration Amplitude

Vibration Level vs. Frequency

- Acceleration, $a$
- Velocity, $v = \frac{a}{2\pi f}$
- Displacement, $d = \frac{a}{2\pi f^2}$
Descriptive Parameters

Amplitude

\[ T \]

\[ a_{\text{RMS}} \]

\[ a_{\text{Peak}} \]

\[ t \]
The “Energy Equivalent” Acceleration, $a_{eq}$

**Energy Equivalent Acceleration:**

$$a_{eq}(T) = \sqrt{\frac{1}{T} \int_0^T a_{RMS}^2 \, dt}$$
Max. Peak and Crest Factor

C. F. = \frac{\text{Max. Peak}}{a_{\text{RMS}}} , \quad \text{C. F.} = \frac{\text{Max. Peak}}{a_{\text{eq}}}

T = 60 \text{ s}
m/s² or Decibels?

Acceleration
m/s²

Acceleration
dB
re. 10⁻⁶ m/s²
### m/s² or Decibels?

<table>
<thead>
<tr>
<th>Acc.dB (re. 10⁻⁶ m/s²)</th>
<th>80</th>
<th>100</th>
<th>120</th>
<th>140</th>
<th>160</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hand-arm</strong></td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>Whole body in vehicles</strong></td>
<td><img src="image6.png" alt="Image" /></td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
<td><img src="image9.png" alt="Image" /></td>
<td><img src="image10.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>Whole body in buildings</strong></td>
<td><img src="image11.png" alt="Image" /></td>
<td><img src="image12.png" alt="Image" /></td>
<td><img src="image13.png" alt="Image" /></td>
<td><img src="image14.png" alt="Image" /></td>
<td><img src="image15.png" alt="Image" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Acc.m/s²</th>
<th>0.01</th>
<th>0.1</th>
<th>1</th>
<th>10</th>
<th>100</th>
</tr>
</thead>
</table>

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Basic Instrumentation for Weighted Measurements

Channel 1(X)

Channel 2(Y)

Channel 3(Z)
Transducer for Whole-body Vibration

Rubber disc

Tri-axial Accelerometer
Mounting the Transducer – Whole Body
Whole-body Vibration in Buildings
Directional Considerations

Weighted Acceleration Sum:

\[
WAS = \sqrt{(1.4a_x)^2 + (1.4a_y)^2 + a_z^2}
\]
Calculation of the Working Day Dose

\[
\text{Dose} = \left( \frac{t_1 + t_2 + t_3}{\tau_1 + \tau_2 + \tau_3} \right) \times 100\% 
\]

\[ t = \text{Elapsed time} \]
\[ \tau = \text{Allowed time} \]
### Example of Dose Calculation:

<table>
<thead>
<tr>
<th>Work Type</th>
<th>Elapsed Time $t$ (hours)</th>
<th>$a_{eq}$ m/s²</th>
<th>Allowed Time $\tau$ (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>0.7</td>
<td>2.5</td>
</tr>
<tr>
<td>2</td>
<td>0.5</td>
<td>1.3</td>
<td>0.9</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>0.3</td>
<td>8</td>
</tr>
</tbody>
</table>

Dose = \left( \frac{2}{2.5} + \frac{0.5}{0.9} + \frac{1}{8} \right) \times 100\% = 148\%
Approximated Exposure Evaluation

Requirement: \( a_{eq} \leq a_0 \)

\[
\begin{align*}
    a & = \begin{cases} 
        2.8 \text{ m/s}^2 & (z) \\
        2.0 \text{ m/s}^2 & (x, y) 
    \end{cases} \\
    t_0 & = 10 \text{ min} \\
    t_{allowed} & = 8 \text{ h}
\end{align*}
\]

\[
R(t) = \begin{cases} 
    a_0 & \text{if } 0 \leq t < t_0 \\
    \frac{a_0 (t - t_0)}{t_{allowed}} & \text{if } t_0 \leq t < t_{allowed} \\
    0 & \text{if } t \geq t_{allowed}
\end{cases}
\]

\[
t_{allowed} = \left( \frac{a_0}{a_{eq}} \right)^2 \times t_0 \quad \text{(1)}
\]

Dose = \( \frac{t_{elapsed}}{t_{allowed}} \times 100\% \quad \text{(2)} \)
Mounting the Transducer – Hand Arm

Accelerometers should be rigidly attached to the tool, but not interfering with normal operation.
Mounting Adaptors – Hand Arm

Hand-adaptor

Handle adaptor

Handle adaptors and hand-adaptors are used when rigid mounting to the tool is not possible.
Coordinate Systems

The hand adaptor measures in the biodynamic coordinate system

The handle adaptor measures in the basicentric coordinate system
Directional Considerations for Hand-Arm

For hand-arm vibration it is often necessary to measure in all three directions to find the worst one.
Type of Adaptor

Handle adaptor

Hand-adaptor
Cables are fixed down, often with tape, so that there is minimal cable-induced vibration in the measurement system.
Exposure Evaluation

Risk of getting vascular disorders (White finger syndrome)

Years of exposure

50th percentile
40th percentile
30th percentile
20th percentile
10th percentile

a [m/s²]
The 4-hour Energy Equivalent Acceleration, $a_{eq}\ (4)$

$$a_{eq}(4) = a_{eq}(t) \sqrt{\frac{T}{4}}$$

$\text{m/s}^2$

$$L_{eq}(4) = L_{eq(T)} + 10 \log \frac{T}{4}$$

$\text{dB}$
Exposure from Several Events

\[ a_{eq}(T) = \sqrt{\frac{a_1^2 T_1 + a_2^2 T_2 + a_3^2 T_3 + \ldots}{T_1 + T_2 + T_3 + \ldots}} \]

\[ L_{eq}(T) = 10 \log \frac{T_1 \text{ inv.log} \frac{L_1}{10} + T_2 \text{ inv.log} \frac{L_2}{10} + \ldots}{T_1 + T_2 + \ldots} \]
### Example of Exposure Calculations

<table>
<thead>
<tr>
<th>Work Type</th>
<th>$a_n$ m/s²</th>
<th>Effective time Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.6</td>
<td>0.7</td>
</tr>
<tr>
<td>2</td>
<td>10.3</td>
<td>0.5</td>
</tr>
<tr>
<td>3</td>
<td>2.5</td>
<td>1.0</td>
</tr>
</tbody>
</table>

$$a_{eq}(T) = \sqrt{\frac{5.6^2 \times 0.7 + 10.3^2 \times 0.5 + 2.5^2 \times 1.0}{0.7 + 0.5 + 1.0}} = 6.1 \text{ m/s}^2$$

$$a_{eq}(4) = 6.1 \times \sqrt{\frac{2.2}{4}} = 4.5 \text{ m/s}^2$$

$$a_{eq}(8) = 6.1 \times \sqrt{\frac{2.2}{8}} = 3.2 \text{ m/s}^2$$
Frequency Analysis – 1/3 Octave

Note: Different signals to the analyzers
Frequency Analysis – FFT

Note: Different signals to the analyzers
Level Analysis

Level dB

Time
Statistical Analysis

Level distribution

% vs. Level (dB)

Cumulative distribution

% vs. Level (dB)

$L_{90} = 103$ dB

$L_{10} = 128$ dB
Example: Wheel-loader

Level dB

- Health
- Proficiency

Allowed time
Hours

0.5
1.5
2
5
10
24

105
110
115
120
125
130
135
140

115

Shaded area represents the allowed time.
Example: Wheel-loader

1/3 Octave Spectrum

- dB
- m/s²
- Z-direction

- 120
- 1
- 110
- 0,315
- 100
- 0,1
- 90

- 1,0
- 2,5
- 6,3
- 16
- 40
- 63
- 100

- Hz

Suspension
Example: Helicopter

FFT Spectrum

Main rotor blades
Main rotor
Tail blades
Tail shaft
etc.

0 10 20 30 40 50 60 70 80 90 100 Hz

80 90 100 110 120 130 dB

5.25 10.5 22 33 43 53 64 71 75 86 97
Example: Chipping Hammer

Very high peak acceleration levels are found at the handle of the chipping hammer. Even higher levels are found at the chisel (and the operator often uses his other hand to control the chisel).
Chipping Hammer Vibration

1/3 - Octave Acceleration

- Tool body resonance
- Left Hand Resonance
- Blow frequency
- Subharmonic

Frequency (Hz)

4  16  63  250  1k  4k  16k  63k Hz

Acceleration (m/s²)

130  140  150  160  165  170  175  180

Decibel (dB)
Example: Chain Saw

[Diagram of a person using a chain saw with annotations indicating distances and directions: 600 mm from the ground line, 25 mm, 80 mm from the centre line of the log, f, v, s, and f labels.]
Chain Saw

Weighted 1/3-octave Spectrum

- **Engine**
- **Teeth 4h**
- **Engine 2h**

Legend:
- **Idling**
- **Sawing**
- **Racing**

Parameters:
- **dB**
- **m/s²**

Frequency Bands:
- 8 Hz
- 16 Hz
- 31 Hz
- 63 Hz
- 125 Hz
- 250 Hz
- 500 Hz
- 1k Hz

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Example: Grinders

![Graph showing oscillation frequency and weighted 1/3-octave spectrum for grinders.](image)

- **Y**, **X**, and **Z** axes are labeled, indicating directions of measurement.

The graph illustrates:
- **Oscillation frequency** with markers for 2^{th}, 4^{th}, and 8^{th} harmonics.
- **Random distortion products** below the 2^{th} harmonic.
- **Weighted 1/3-octave Spectrum** showing dB values.

Legend:
- **dB**: Decibels
- **m/s^2**: Meters per second squared

Frequency ranges:
- 4 Hz, 16 Hz, 63 Hz, 250 Hz, 1 kHz, 4 kHz
Conclusion

Central Issue:
Avoid breaking occupational health legislation at lowest cost

Monitoring and Risk assessment checklist:
- Is there a problem?
- How big is the problem?
- What causes the problem?
- How do we reduce the problem?
- How do we prevent the problem?

Vibration + Time = Vibration Exposure

Vibration Exposure + Time = Tissue Damage

Vibration exposure is measured according to national and international standards for Hand-Arm Vibration and Whole-Body Vibration.