Measuring the Potential for Noise and Vibration Injuries in Industrial Settings

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Presentation Overview

- Motivation - *Injury Prevention*
- Vibration
- Noise
- Summary
- Tools & Meter Demos
Why Worry About Vibration and Noise?

Problem:
- 2 to 4 Million People exposed to tool vibration in the US annually.
- 50% of people exposed develop injuries.
- Costs associated with ailments estimated to be in the 100's of millions of dollars and growing.

Resulting Injuries:
- Symptoms including:
  - Numbness
  - Tingling
  - Decreased grip strength
  - Loss of Dexterity
- Hearing Loss:
  - Loss in perception across all sound frequencies
  - High frequency sounds the most damaging

Hearing in the News
- 28 million Americans currently have some degree of hearing loss
- 78 million by 2030
Hand-Arm Vibration

Measured Tool Vibration

Acceleration in the z-direction (axial)
Effects of Hand-Arm Vibration

- Vibration-induced White Finger (VWF)
- or, Hand-Arm Vibration Syndrome (HAVS)
- or, Raynaud's Phenomenon
  - Hand-arm vibration causes damage to blood vessels and nerves in the fingers
- Reported effects
  - attacks of whitening (blanching) in one or more fingers when exposed to cold
  - tingling and loss of sensation in the fingers
  - loss of light touch
  - pain and cold sensations between periodic white finger attacks
  - loss of grip strength

Carpal Tunnel Syndrome

Median nerve is compressed at the wrist, resulting in numbness or pain
Legal Requirements

*The OSH Act of 1970*

- Each employer
  
  shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees;

  shall comply with occupational safety and health standards promulgated under this Act.

- Each employee
  
  shall comply with occupational safety and health standards and all rules, regulations, and orders issued pursuant to this Act which are applicable to his own actions and conduct.

Thresholds of Exposure

**Hand Vibration**

<table>
<thead>
<tr>
<th>Total Daily Exposure Duration</th>
<th>Dominant Frequency-Weighted Component of Acceleration Which Shall Not be Exceeded (RMS)</th>
<th>g’s</th>
</tr>
</thead>
<tbody>
<tr>
<td>m/s²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 to 8 hours</td>
<td>4</td>
<td>0.40</td>
</tr>
<tr>
<td>2 to 4 hours</td>
<td>6</td>
<td>0.61</td>
</tr>
<tr>
<td>1 to 2 hours</td>
<td>8</td>
<td>0.81</td>
</tr>
<tr>
<td>less than 1 hour</td>
<td>12</td>
<td>1.22</td>
</tr>
</tbody>
</table>

ACGIH recommendations
What is vibration?

- Vibration is quantified using acceleration measurements.
- Acceleration is a vector quantity:
  - Magnitude
  - Direction
- Magnitudes combined using the root-mean-square (RMS).
- Units = m/s² or g's
- Most jurisdictions and agencies use acceleration as a measure of vibration exposure since the degree of injury is related to the magnitude of vibration.

\[
a_{\text{Total, RMS}} = \sqrt{a_{x, RMS}^2 + a_{y, RMS}^2 + a_{z, RMS}^2}
\]

Frequency Spectrum

- Time (sec)
- Acceleration (g)
- Frequency (Hz)
- Spectral Amplitude
Hand-Arm Vibration - Filter
(ISO 5349)

\[ Wi = \text{weighting factor for a given 1/3 octave frequency} \]
\[ ai = \text{magnitude for a given 1/3 octave frequency} \]
\[ aw = \text{rated acceleration (i.e. vibration) (m/s}^2 \text{ or g’s)} \]

\[ a_w = \sqrt{\sum_{i} Wi a_i^2} \]
Hand-Arm Vibration - Exposure Time

Implications

- Hand and arm most susceptible to injury at vibration frequencies between 4 and 20 Hz.
- As frequency increases, threat of injury decreases.
- These rules apply to continuous vibration.
- Impact (shock) related vibrations are not as well understood.
- As vibration increases, total daily exposure must be reduced.
Identifying Sources and Severity of Vibration

- Utilize existing performance data and information on tools whenever possible
  - NIOSH Power Tool Database (Noise)
  - Manufacturer’s Data (Vibration and Noise)
- Take on-site measurements using vibration meters

Typical Tool Ratings

- Example
  - Grinder: Lab = 2.5 m/s², Field = 2 to 5 m/s²
- Interpretation:
  - RMS values
  - Vibration data weighted using ISO 5349
### Common Vibration Characteristics

<table>
<thead>
<tr>
<th>Tool</th>
<th>Vibration Magnitude</th>
<th>Maximum Exposure Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chipping hammers</td>
<td>10-40 ms(^2)</td>
<td>2-40 minutes</td>
</tr>
<tr>
<td>Sand rammers</td>
<td>25-40 ms(^2)</td>
<td>2-6 minutes</td>
</tr>
<tr>
<td>Angle grinders</td>
<td>2-35 ms(^2)</td>
<td>3 minutes-16 hours</td>
</tr>
<tr>
<td>Disc cutters</td>
<td>4-10 ms(^2)</td>
<td>40 minutes-4 hours</td>
</tr>
<tr>
<td>Disc sanders</td>
<td>10-15 ms(^2)</td>
<td>16-40 minutes</td>
</tr>
<tr>
<td>Rock drills</td>
<td>15-35 ms(^2)</td>
<td>3-16 minutes</td>
</tr>
</tbody>
</table>

The 8-hour time weighted average vibration exposure is given by:

\[
A(8) = a \times \sqrt{\frac{\text{Total}}{8}}
\]

### Low Vibration (LV) Tools

- Dual Elastomer Cushions (DEC system)—absorbs shock and vibration to reduce user fatigue.
- Kevlar reinforced Flutter Disc—strong composite disc for long life.
- Vibration level: < 2.5 m/s\(^2\)
- Sound level: 3 dB lower than conventional air hammer

<table>
<thead>
<tr>
<th>Tool</th>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snap on Air Hammer</td>
<td>Dual Elastomer Cushions (DEC system)—absorbs shock and vibration to reduce user fatigue.</td>
<td>$239 (low vibration)</td>
</tr>
<tr>
<td></td>
<td>Kevlar reinforced Flutter Disc—strong composite disc for long life.</td>
<td>$179 (conventional)</td>
</tr>
</tbody>
</table>
Reducing Vibration Transmitted to the Hand From Tools

Measurement Standards

- Hand Vibration
  - NIOSH
    - Occupational Exposure to Hand-Arm Vibration (89-106)
  - ISO/ANSI
    - Measurement and Assessment of Hand-Transmitted Vibration (ISO 5348, ISO 5349 ISO 8041, ANSI S3.34)
  - American Conference of Governmental Industrial Hygienists
    - Threshold Values for Hand-Arm Vibration (ACGIH-TLV for HAV)
Workplace Assessment – *Vibration*

- Complete assessment of exposure to vibration requires:
  - measurement of acceleration in well-defined directions,
  - Frequency content of the vibration
  - Duration of exposure.

Hand Grip force is another important factor in the exposure assessment.
- A tighter grip transfers energy (vibrations) more efficiently, causing greater damage to the user.
- This is, in part, why field measurements usually differ from lab measurements.
Workplace Assessment – Vibration

A typical vibration measurement system includes:

- vibration sensor (accelerometer),
- recording device
- frequency analyzer and frequency-weighting network
- display such as a meter, printer or recorder.

Measuring Devices

- Vibration Meter
  - Measures X, Y, and Z accelerations
  - Computes RMS frequency weighted accelerations
  - Selectable Frequency Weighting (Hand-Arm, Whole Body)

(from Larson Davis)
Sensors

- Accelerometers in different forms used for different locations on the body.

Work-Place Assessments

*Use of Vibration Meter*
Preventing Injury by Controlling Exposure

- Identify Potential Sources
- Low Vibration Tools
- Personal Protective Equipment (PPE)
- Safe Work Practices
- Employee Education

Reducing Vibration Transmitted to the Hand From Tools

Introduce a material with poor transmission characteristics
- Air Bladder
- Anti-Vibration Gloves
Safe Work Practices

- In addition to anti-vibration tools and gloves:
  - Employ a minimum hand grip consistent with safe operation of the tool or process.
  - Wear sufficient clothing, including gloves, to keep warm.
  - Avoid continuous exposure by taking rest periods.
  - Rest the tool on the work piece whenever practical.

Safe Work Practices . . .

- Refrain from using faulty tools.
- Maintain properly sharpened cutting tools.
- Consult a doctor at the first sign of vibration disease and ask about the possibility of changing to an assignment with less exposure.
- Perform periodic audiograms to monitor changes in worker hearing levels.
Employee Education

- Identify and avoid potentially harmful situations.
- Implement safe practices and LV technology.
- Workers use only tools with which they have experience, or on which they have been trained.
- Operators “let the tool do the work” by using the smallest amount of grip force possible (while still maintaining control of the tool).
- Frequent breaks while using vibrating tools.
- Alternate tasks to reduce maximum exposure times.

Hearing Damage and Prevention
What Constitutes Hearing Loss?

- Hearing loss is measured in decibels hearing level (dBHL).
- A person who can hear sounds across a range of frequencies at 0 to 20 dBHL is considered to have normal hearing.
- The thresholds for the different types of hearing loss are as follows:
  - **Mild** 25-39 dBHL
  - **Moderate** 40-68 dBHL
  - **Severe** 70-94 dBHL
- Deaf people, who cannot hear sounds quieter than 95 dB, usually communicate using sign language and lip reading.

The Consequences of Long-Term Exposure

![Graph showing the progression of NIPTS for 90 and 100 dB(A) from data in ISO-1999, 1990]
Hearing Impairment Mechanism

Think of the cochlea as "a piano, with 15,000 keys rather than 88"

Hearing Damage

Symptoms

- Hearing loss usually develops over a period of several years.
- What you might notice is a ringing or other sound in your ear (called tinnitus), which could be the result of long-term exposure to noise.
- Hearing test will detect and quantify ear damage.
- Hearing damage specialists are called otologists.
Percent of People With Tinnitus

Non-Noise Exposed Worker

Noise Exposed Workers

Types of Noise

- Continuous
- Impulse
Types of noise . . .

- **Impact/Impulse Noise.**
  - Defined by OSHA as a sound with a rise time of not more than 35 ms to peak intensity and.
  - A duration of not more than 500 msec to the time when the level is 20 dB below the peak.
  - Impulses recurring at intervals of less than 0.5 s are considered continuous noise.

Quantifying Sound

- **Sound Pressure (SP)**
  - Measurement of air pressure (waves) as noise is emitted.
  - Reported in Pa (Pascal = 1 Newton/square meter)
- **Sound Pressure Level (SPL)**
  - A relative measure of sound/noise.
  - Reported in dBs

\[
\text{dB(SPL)} = 20 \log(\frac{\text{SP}}{\text{SP}_{\text{ref}}})
\]

\[(\text{SP}_{\text{ref}} = 20 \mu\text{Pa})\]
### SP and SPL Relationship

<table>
<thead>
<tr>
<th>SP (Pa)</th>
<th>SPL (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0005</td>
<td>28.0</td>
</tr>
<tr>
<td>0.001</td>
<td>34.0</td>
</tr>
<tr>
<td>0.002</td>
<td>40.0</td>
</tr>
<tr>
<td>0.1</td>
<td>74.0</td>
</tr>
<tr>
<td>0.2</td>
<td>80.0</td>
</tr>
<tr>
<td>0.4</td>
<td>86.0</td>
</tr>
</tbody>
</table>

A doubling of the Sound Pressure is equivalent to a 6 dB increase in sound pressure level.

### Physics of Sound

- Sound pressure is inversely proportional to distance from source.
- Sound pressure is reduced by half, as distance is doubled.
- Sound Pressure Level decreases 6 dB as distance is doubled.

<table>
<thead>
<tr>
<th>Distance From Source</th>
<th>% Sound Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>A) 1m</td>
<td>100%</td>
</tr>
<tr>
<td>B) 2m</td>
<td>50%</td>
</tr>
<tr>
<td>C) 4m</td>
<td>25%</td>
</tr>
</tbody>
</table>
Sound Weighting Scales

- The A-contour filters approximates the ear at low sound levels. It is very useful for eliminating inaudible low frequencies.
- The intermediate B-contour is for medium loud sounds. It is rarely used.
- The C-contour approximates the ear at very high sound levels (traffic noise surveys in noisy areas).

Sound Level Benchmarks

<table>
<thead>
<tr>
<th>dBA Level</th>
<th>Approx. Equivalent</th>
<th>Maximum Unprotected Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Faintest sound heard by human ear.</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Whisper, quiet library</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>Normal conversation</td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>Lawn mower, shop tools, truck traffic</td>
<td>8hrs/day</td>
</tr>
<tr>
<td>100</td>
<td>Chainsaw, pneumatic drill, snowmobile</td>
<td>2hrs/day</td>
</tr>
<tr>
<td>115</td>
<td>Sandblasting, rock concert, car horn</td>
<td>15min/day</td>
</tr>
<tr>
<td>140</td>
<td>Gun shot, jet engine – even brief exposure cause pain</td>
<td>Must always have ear protection</td>
</tr>
</tbody>
</table>

23 June 2006                                     Measuring Vibration and Noise
Legal Requirements for on-the-Job Exposure

• Habitual exposure to noise above 85 dB will cause a gradual hearing loss in a significant number of individuals, and louder noises will accelerate this damage.

• For unprotected ears, the allowed exposure time decreases by one-half for each 5 dB increase in the average noise level. For instance, exposure is limited to 8 hours at 90 dB, 4 hours at 95 dB, and 2 hours at 100 dB.

• The highest permissible noise exposure for the unprotected ear is 115 dB for 15 minutes/day.

• Any noise above 140 dB is not permitted.

OSHA Noise Regulations

• Hearing Conservation Program
  • At or above 85 dBA for 8 or more hours, but less than 90 dB.
  • Employer is required to provide hearing protection and training
  • Provide annual audiometric exams
  • Conduct exposure monitoring

• Noise Control Program
  • At or above 90 dBA for 8 or more hours per day.
  • Required use of hearing protection with training
  • Provide annual audiometric exams
  • Equal energy concept
OSHA Noise Regulations . . .

Thresholds of Exposure

Permissible Exposure Limits for Occupational Noise

<table>
<thead>
<tr>
<th>Sound Pressure Level dB(A)</th>
<th>Duration Time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>32</td>
</tr>
<tr>
<td>90</td>
<td>8.0</td>
</tr>
<tr>
<td>95</td>
<td>4.0</td>
</tr>
<tr>
<td>100</td>
<td>2.0</td>
</tr>
<tr>
<td>105</td>
<td>1.0</td>
</tr>
<tr>
<td>110</td>
<td>0.5</td>
</tr>
<tr>
<td>115</td>
<td>0.25</td>
</tr>
<tr>
<td>120</td>
<td>0.125</td>
</tr>
<tr>
<td>125</td>
<td>0.063</td>
</tr>
<tr>
<td>130</td>
<td>0.031</td>
</tr>
<tr>
<td>140</td>
<td>never</td>
</tr>
</tbody>
</table>

OSHA Requirements
Relevant Standards and Publications

- **Noise**
  - OSHA
    - 1910.95 (Occupational Noise Exposure)
    - 1904.10 (Recording Hearing Loss)
    - 1926.101 (Hearing Protection)
  - NIOSH
    - Occupational Noise Exposure (Publication No. 98-126)
  - Other Federal Standards
    - DOD: Instruction 6055.12
    - Coast Guard: Circular 12-82
    - Others ....

Workplace Assessment – *Noise Measurement*

<table>
<thead>
<tr>
<th>Type of Measurement</th>
<th>Device</th>
<th>Result</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal noise exposure</td>
<td>1) Dosimeter</td>
<td>Dose or equivalent sound level</td>
<td>Most accurate for personal noise exposures</td>
</tr>
<tr>
<td></td>
<td>2) Integrating</td>
<td>Equivalent sound level</td>
<td>If the worker is mobile, it may be difficult to determine a personal exposure, unless work can be easily divided into defined activities.</td>
</tr>
<tr>
<td></td>
<td>Sound Level Meter (ISLM)</td>
<td>dB(A) – sound level using the A-filter</td>
<td>If noise levels vary considerably, it is difficult to determine average exposure. Only useful when work can be easily divided into defined activities and noise levels are relatively stable all the time.</td>
</tr>
<tr>
<td>Noise levels generated by a particular source</td>
<td>1) SLM</td>
<td>dB(A)</td>
<td>Measurement should be taken 1 to 3 meters from source (not directly at the source).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Equivalent sound level dB(A)</td>
<td>Particularly useful if noise is highly variable; it can measure equivalent sound level over a short period of time (1 minute).</td>
</tr>
<tr>
<td>Noise survey</td>
<td>1) SLM</td>
<td>dB(A)</td>
<td>To produce noise map of an area; take measurements on a grid pattern.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Equivalent sound level dB(A)</td>
<td>For highly variable noise</td>
</tr>
<tr>
<td>Impulse noise</td>
<td>1) Impulse SLM</td>
<td>Peak pressure dB(A)</td>
<td>To measure the peak of each impulse.</td>
</tr>
</tbody>
</table>
Typical Dosimeters, ISLM’s, & SML’s

Dose Badges
Sound Measurement Protocol

a. Emphasize that the employee should continue to work in a routine manner.

b. Explain to each employee being sampled the purpose of the dosimeter, and emphasize that the dosimeter is not a speech recording device.

c. When the dosimeter is positioned (generally in the shirt pocket or at the waist), clip the microphone to the employee's shirt collar at the shoulder, close to the ear.

d. Position and secure any excess microphone cable to avoid snagging or inconveniencing the employee.

e. Check the dosimeter periodically to ensure that the microphone is oriented properly.

f. Note sound level meter readings during different phases of the work performed by the employee during the shift. Take enough readings to identify work cycles. For statistical reasons, more readings should be taken when noise levels fluctuate widely.

g. Record the information required on the OSHA-92.
Hearing Protection

- **What Are Hearing Protectors?**
  - Earplugs are small inserts that fit into the outer ear canal.
    - They must be snugly sealed so the entire circumference of the ear canal is blocked.
    - An improperly fitted, dirty or worn-out plug may not seal and can irritate the ear canal.
  - Earmuffs fit over the entire outer ear to form an air seal so the entire circumference of the ear canal is blocked.
    - They will not seal around eyeglasses or long hair, and the adjustable headband tension must be sufficient to hold earmuffs firmly around the ear.

How Effective Are They?

- Properly fitted earplugs or muffs reduce noise 15 to 30 dB.
- The better earplugs and muffs are approximately equal in sound reductions.
- Earplugs are better for low frequency noise.
- Earmuffs are better for high frequency noise.
- Simultaneous use of earplugs and muffs usually adds 10 to 15 dB more protection than either used alone. Combined use should be considered when noise exceeds 105 dB.
Ear Muffs

Typical Ratings

- 29 dB NRR from certified US laboratory ANSI S3.19-1974
- 34 dB SNR as tested by certified European laboratory to CE EN-352-1
- Superb full spectrum and low frequency attenuation
- Extra wide ear cushions for highest comfort
- Soft padded headband with low force on head
- Steel headband tolerates temperature extremes
- Solid construction
- Suggested resale is $16.60

Detailed Earmuff Data

HB-650: ANSI S3-19-1974

<table>
<thead>
<tr>
<th>Frequency, Hz</th>
<th>125</th>
<th>250</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>3150</th>
<th>4000</th>
<th>6000</th>
<th>8000</th>
<th>H</th>
<th>M</th>
<th>L</th>
<th>NRR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Attenuation, dB</td>
<td>22.1</td>
<td>27.9</td>
<td>34.9</td>
<td>35.8</td>
<td>37.3</td>
<td>41.4</td>
<td>42.3</td>
<td>41.6</td>
<td>41.2</td>
<td>37</td>
<td>33</td>
<td>27</td>
<td>29</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>2.9</td>
<td>2.8</td>
<td>3.4</td>
<td>2.0</td>
<td>2.5</td>
<td>2.7</td>
<td>2.8</td>
<td>3.1</td>
<td>3.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Ear Plugs and Canal Caps**

- **Why Can’t I just Stuff My Ears with Cotton?**
  - Ordinary cotton balls or tissue paper are very poor protectors
  - Reduces noise only by approximately 7 dB.

---

**The NIOSH Noise Program**

- Assess workplace factors and existing knowledge
- Conduct and evaluate intervention efforts
- Educate, disseminate information and evaluate efforts
Worker Perceptions

Safety Tools

- “Why didn’t someone show me these years ago?”

- “This thing really works.”

- “My co-workers and kids are now going to have to learn new curse words from someone else.”
In Summary . . .

- Safe use of tools can only be achieved with a multi-dimensional approach
  - Workplace assessments including measurements
  - Proper choice and use of tools
  - Protective gear
  - Education, training.
- New tool technologies help make worker protection achievable without loss of productivity.

Thank You!

Questions?

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