Passive and Active Noise Control For Next Generation Locomotive Cabs

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Noise Control for Next Generation Locomotive Cabs

- Background
- Acoustic Environment of Diesel-Electric Locomotive Cabs
- Passive Noise Control
- Active Noise Control
- Conclusions
Regulates noise limits for railroad employees in locomotive cabs:
- An 8-hour time-weighted average (TWA) limit of 90 dBA.
- **Hearing protection** required if exceeded or option for railroads to introduce operational controls

New requirements:
- Railroads must conduct in cab **noise monitoring**
- Railroads must implement a **hearing conservation program** for employees exposed to an 8-hour TWA of 85 dBA or greater
- FRA will establish **design, build and maintenance standards** for new locomotives

Primary concern is minimizing noise-induced hearing loss (NIHL) but other concerns include:
- **Fatigue, speech interference, comfort, health effects**

*U.S. Federal Railroad Administration updated 49 CFR Parts 227 and 229 - Occupational Noise Exposure for Railroad Operating Employees; Final Rule October 27, 2006*
FRA Next Generation Locomotive Cab Project

- FRA-sponsored project conducted by QinetiQ North America to research and develop the Next Generation Locomotive Cab

- Project Goals: demonstrate various safety, ergonomic, and employee health-related upgrades to locomotive cabs

- Conducted noise measurements in Alaska Railroad EMD SD70MAC locomotive

- Retrofit an EMD SD70MAC locomotive cab shell with:
  - New interior that simulates improvements in ergonomics and advanced display systems
  - Isolated floor to reduce undesirable vibrations
  - Passive noise control treatments
  - Active noise control system
Test Locomotive Cab
Noise Levels in Locomotive Cabs

- Acoustic environment in locomotive cabs is complex
Noise Levels in Locomotive Cabs

- **Noise sources**
  - Constant noise and vibration sources (prime mover, wheel/rail)
  - Short-term noise sources (train whistle, radio, special trackwork)

- **Character of the noise**
  - Significant low frequency content (typically below 200 Hz)
  - Tonal primarily due to diesel engine exhaust

- **Other factors affecting environment**
  - Open windows
  - **Radio** must be louder than other noise sources
  - Vibration of cab interior panels radiate noise
  - Aerodynamic noise
What do locomotive cabs sound like?
Noise Levels Inside Locomotive Cab

Overall Noise Level = **73 dBA**

- Significant low frequency noise below 250 Hz
- Tones correspond to cylinder firing rate of prime mover (15, 30, 45, 60 Hz, etc..)
- Engine speed = 900 RPM
- 16 cylinders
Noise Levels Inside Locomotive Cab

Overall Noise Level = 73 dBA

Low frequency noise between 100 and 250 Hz can control the overall A-weighted level.

To reduce the overall noise level (dBA) we must reduce low frequency noise!
Passive Noise Control

- What can be done to reduce interior noise levels?
- Design, build and maintenance considerations:
  - Air gaps need to be closed
  - Windows and doors need good seals
    - A one inch hole in the side of a locomotive cab can increase noise levels 20 dB or more
Passive Noise Control

- Transmission loss (TL) of cab is inherently poor at low frequencies
- Improving transmission loss of cab structure is difficult

Doubling the thickness of locomotive cab would only lower interior noise levels 6 dB at most. Actual improvements would be less.
Passive Noise Control

- Vibration damping sheets applied to inside of panels can improve TL
  - Increase the internal loss mechanisms (turns vibration into heat not sound)
  - Increase mass of panels
  - Useful as a retrofit to existing locomotives
  - Reduces “coincidence dip”

![Graph showing the effect of vibration damping sheets on transmission loss.](image)
Passive Noise Control

- The cab can be mounted on springs or rubber pads to reduce structure-borne noise caused by vibration generated at the wheel/rail interface and the prime mover
  - EMD SD70MAC “Whisper Cab” has vibration isolation but this feature has since been discontinued

- Once noise gets into the cab, it reverberates around the cab

- Increasing the acoustic absorption inside the cab will reduce reverberant noise
  - Material must be thick and porous
  - Effectiveness depends on surface area applied
  - Requires perforated sheet metal faces
Test Locomotive Cab Passive Materials

Unfinished Cab

Damping Panels and Absorption

Finished Cab with Perforated Sheet Metal Faces
- Damping panels and absorption improve noise reduction up to 10 dB
- No real benefits below 250 Hz
Active Noise Control Background

- How can we reduce low frequency noise?
- Active noise control!
  - **Unwanted sound** is the prime mover exhaust noise
  - **Reference microphones/sensors** measure the unwanted sound
  - **Active control system** calculates signal to cancel the noise
  - **Control speaker** reproduces the sound $180^\circ$ out of phase
  - **Error microphones** measure the result and adjust the control system
Active Noise Control Background

- Key elements to active noise control
  - Control speaker needs to reproduce sound precisely in time to be 180° out of phase
    - Repetitive/tonal sounds are easiest to cancel

- Noise reduction is a function of the listeners proximity to the control speaker and the wavelengths of unwanted sound
  - Active control is more effective at low frequencies than high frequencies

- Active noise control can be either:
  - “global”- effective throughout the cab
  - “local” - effective only in specific areas near the control speaker
    - Global reduction is generally achieved only at specific frequencies which are acoustic modes of the cab

- The goal of the demonstration was to achieve localized noise reduction near the engineer’s ears
ANC System Demonstration Setup

- Diesel engine noise simulated by subwoofer loudspeaker positioned outside of locomotive cab
- Reference microphone located outside of cab near source
Active Noise Control Equipment

- Feed-forward active noise control system
  - EZANC II active noise controller manufactured by Causal Systems
    - Up to 10 reference and error signals
      - microphones, accelerometers, tachometer
    - Up to 10 control outputs (control speakers)
ANC System Demonstration

- Control source loudspeaker located above the engineer’s seat
- Speaker must be compact yet generate a lot of low frequency sound
ANC System Demonstration

- Error microphones mounted to engineer’s seat headrest (final location recessed into seat)
ANC System Demonstration Results

- The ANC demonstration focused on reducing the level of several tones simultaneously.

- With the ANC system on, a strong noticeable quiet zone around the head of the train conductor was achieved.

- The level of all tones were successfully reduced by 20-30 dB.
Active Noise Control Performance in Cab

Locomotive Cab
Active Noise Cancellation Performance

Sound Pressure Level (dB re: 20 mPa)

ANC OFF
ANC ON

Frequency (Hz) 1.6 Hz Bandwidth
Other results typical of ANC systems

- These proof-of-principle tests represent idealized performance
- Examples of other ANC systems in operating cabs:
  - Noise reduction of 5 to 15 dB at low frequencies (tones between 60 Hz to 140 Hz) in a Class 1 locomotive cab has been attained by Cooper-Standard
  - Noise reduction of 3 to 4 dBA in an electric locomotive cab (which has more difficult to cancel high-frequency tones) has been achieved by SNCF (French National Railway)
  - Noise reduction up to 12 dB (at frequencies up to 150 Hz) have been achieved with a hybrid active/passive noise control system installed on the locomotive exhaust (FRA/Paul Remington)
### Summary of Noise Control Treatments and Estimated Performance

<table>
<thead>
<tr>
<th>Noise Control Treatment</th>
<th>Estimated Noise Reduction</th>
<th>Effective 1/3 O.B. Frequency Range</th>
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</thead>
<tbody>
<tr>
<td>Rubber isolating pads</td>
<td>3 dB</td>
<td>4 Hz – 100 Hz</td>
</tr>
<tr>
<td>Vibration damping panels</td>
<td>3 dB</td>
<td>200 Hz – 10,000 Hz</td>
</tr>
<tr>
<td>Acoustical absorption on ceilings and walls</td>
<td>5 dB</td>
<td>250 Hz – 500 Hz</td>
</tr>
<tr>
<td>Acoustical absorption on ceilings and walls</td>
<td>10 dB</td>
<td>5,000 Hz – 10,000 Hz</td>
</tr>
<tr>
<td>Active Noise Control</td>
<td>7 dB</td>
<td>31.5 Hz – 200 Hz</td>
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Conclusions

- FRA Final Rule on Occupational Noise Exposure for Locomotive Engineers brings awareness and action to improving the locomotive cab environment.

- Acoustic environment in locomotive cabs has significant low-frequency, tonal sound from prime mover.

- Passive noise control effective at high frequencies.

- Active noise control needed for low frequencies which are critical to the overall acoustic environment in the cab.
Thank You

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