Sound Attenuation and Test Strategies for Generator Set Installations

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The views and opinions expressed in this course shall not be considered the official position of any regulatory organization and shall not be considered to be, nor be relied upon as, a Formal Interpretation.

Participants are encouraged to refer to the entire text of all referenced documents. In addition, when in doubt, reach out to the Authority Having Jurisdiction.
Course Objectives

Sound Attenuation and Test Strategies for Generator Set Installations

This course will provide a brief overview of acoustics including methods of specification and on-site testing. The instructor will review common sound attenuation strategies for generator set installations and will include recommendations for methods employed to meet stringent noise requirements. The course will also review data commonly provided by manufacturers, how it is interpreted and how it can be best applied.

After completing this course, participants will be able to:

• Describe the fundamentals of acoustics relative to generator set installations.
• Identify appropriate strategies for specifying sound requirements and test methods.
• Recognize data provided by manufacturers that is most relevant to site noise limits.
What do you know about sound?
Sound Power vs. Sound Pressure

100 Watts

100 Decibels
Sound Power vs. Sound Pressure

Distance in meters.

- 130 dB
- 110 dB
- 104 dB
- 98 dB
dB
(Decibels)
dB (A)

(Decibels) (A-Weighted)
Perceived Sound Level (A-Weighting)
Generator Set Sound Contributors

- Un-silenced engine exhaust
  - 120-130 dB(A) @ 1m
- Radiator cooling fan
  - 100-110 dB(A) @ 1m
- Engine
  - 100 -105 dB(A) @ 1m
- Alternator
  - 80 – 90 dB(A) @ 1m
The Sum of Sound Sources

Adding decibels when the numerical difference in dB(A) between two noise levels is:

<table>
<thead>
<tr>
<th>Difference in dB(A)</th>
<th>Add this dB(A) to the higher of the two noise levels for a total:</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.0</td>
</tr>
<tr>
<td>0.1 – 0.9</td>
<td>2.5</td>
</tr>
<tr>
<td>1.0 – 2.4</td>
<td>2.0</td>
</tr>
<tr>
<td>2.4 – 4.0</td>
<td>1.5</td>
</tr>
<tr>
<td>4.1 – 6.0</td>
<td>1.0</td>
</tr>
<tr>
<td>6.1 – 10</td>
<td>0.5</td>
</tr>
<tr>
<td>&gt;10</td>
<td>0</td>
</tr>
</tbody>
</table>

100 dB(A) + 100 dB(A) = 103 dB(A)
True or False. Sound pressure level is the perceived sound level of a source measured at a defined distance from the source.
True or False. Sound pressure level is the perceived sound level of a source measured at a defined distance from the source.
How do you see owner sound level requirements defined?

How do you specify sound level requirements for manufacturers?
Installation Considerations

- Limits are almost always based on sound pressure at the property line.
- Location is the single greatest ally or enemy
- Increase distance from source to receiver
  - Sound pressure drops ~6 dB(A) at 2x distance
- High mass, absorptive barriers
- Avoid reflective surfaces
  - Perceived sound pressure increases:
    - 3dBA due to a reflective surface
    - 5dBA for two reflective surfaces
- Direct noise away from sensitive locations
  - Radiator discharge turning vanes
  - Exhaust discharge elbows
Common Specification Pitfalls

Generator set shall include critical grade muffler.
• Grades are not standardized.
• Advertised sound attenuation is dependent on application.

Generator set shall include [critical grade / level X] housing.
• Does not mandate compliance with the limit imposed on the owner.
• Enclosure/housing grades are not standardized.

Generator set shall include housing/muffler with X dB(A) reduction.
• Does not mandate compliance with the limit imposed on the owner.
• Magnitude of reduction is not relative to the raw or resulting sound levels.
Specification Pitfalls: Mufflers Grades

- Fan: 86 dB(A)
- Exhaust: 94 dB(A)
- Engine/Alternator: 80 dB(A)

95 dB(A)
Specification Pitfalls: Mufflers Grades

Fan: 86 dB(A)

Exhaust: 94 dB(A)

“Industrial-Grade” Muffler [15 dB(A)]

Exhaust: 79 dB(A)

Engine/Alternator: 80 dB(A)

88 dB(A)
Specification Pitfalls: Mufflers Grades

Fan: 86 dB(A)
Exhaust: 94 dB(A)
Engine/Alternator: 80 dB(A)

“Critical-Grade” Muffler [30 dB(A)]
Exhaust: 64 dB(A)

87 dB(A)
Enclosure “Grades”
Frequency Cut-Off Requirements

- Be cognizant of sound level AND frequency
  - Higher frequencies dissipate quickly
  - Lower frequencies carry significant distances
- Local noise limits may include maximum sound pressure levels at a given frequency.

<table>
<thead>
<tr>
<th>Frequency Band (Hz)</th>
<th>Maximum Acceptable Sound Level (Decibels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>81</td>
</tr>
<tr>
<td>63</td>
<td>81</td>
</tr>
<tr>
<td>125</td>
<td>72</td>
</tr>
<tr>
<td>250</td>
<td>64</td>
</tr>
<tr>
<td>500</td>
<td>58</td>
</tr>
<tr>
<td>1,000</td>
<td>55</td>
</tr>
<tr>
<td>2,000</td>
<td>54</td>
</tr>
<tr>
<td>4,000</td>
<td>54</td>
</tr>
<tr>
<td>8,000</td>
<td>56</td>
</tr>
</tbody>
</table>

Submit sound power level data for the packaged unit operating at 100 percent load in a free field environment. The data should demonstrate compliance with the sound limitation requirements of this specification. Submit certification from the manufacturer stating that the sound emissions meet the specification. The noise generated by the diesel generator set operating at 100 percent load shall not exceed the following sound pressure levels in any of the indicated frequencies when measured in a free field at a radial distance of 22.9 feet 7 meters at 45 degrees apart in all directions.
Concept Check – Installation and Application

In order to specify a sound level requirement, the specification should include which of the following:

a) Sound pressure level
b) Distance from the source of the sound to the receiver/measurement point
c) Muffler grade
d) Enclosure type
In order to specify a sound level requirement, the specification should include which of the following:

a) Sound pressure level

b) Distance from the source of the sound to the receiver/measurement point
Data Considerations

- At what load was the data measured?
- In which configuration of the product was the data measured?
- Which units of measure are used to represent the results of the measurements?
  - Under what conditions are the given units of measure?
- Which standard or measurement methods were used to collect the data?
Sound pressure level @ 7 meters, dB(A)
See notes 1-6 listed below

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Exhaust</th>
<th>Measurement location number (note 1)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>Position average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unhoused - remote cooled</td>
<td>Infinite</td>
<td></td>
<td>94.5</td>
<td>100.2</td>
<td>98.2</td>
<td>98.9</td>
<td>95.3</td>
<td>100.5</td>
<td>100.5</td>
<td>99.2</td>
<td>98.9</td>
</tr>
<tr>
<td>Unhoused - high ambient cooling system</td>
<td>Infinite</td>
<td></td>
<td>94.6</td>
<td>101.0</td>
<td>101.0</td>
<td>100.6</td>
<td>96.4</td>
<td>101.2</td>
<td>100.0</td>
<td>102.5</td>
<td>100.2</td>
</tr>
<tr>
<td>Unhoused - enhanced high ambient cooling system</td>
<td>Infinite</td>
<td></td>
<td>96.4</td>
<td>101.9</td>
<td>101.1</td>
<td>101.4</td>
<td>99.7</td>
<td>101.8</td>
<td>103.1</td>
<td>100.9</td>
<td>101.1</td>
</tr>
</tbody>
</table>

Sound power level, dB(A)
See notes 2-4, 7 and 8 listed below

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Exhaust</th>
<th>Octave band center frequency (Hz)</th>
<th>31.5</th>
<th>63</th>
<th>125</th>
<th>250</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
<th>8000</th>
<th>16000</th>
<th>Overall sound power level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unhoused - remote cooled</td>
<td>Infinite</td>
<td></td>
<td>67.2</td>
<td>86.9</td>
<td>100.9</td>
<td>110.7</td>
<td>118.1</td>
<td>119.7</td>
<td>120.6</td>
<td>118.9</td>
<td>124.4</td>
<td>100.7</td>
<td>128.1</td>
</tr>
<tr>
<td>Unhoused - high ambient cooling system</td>
<td>Infinite</td>
<td></td>
<td>72.5</td>
<td>89.9</td>
<td>113.5</td>
<td>118.4</td>
<td>121.2</td>
<td>122.0</td>
<td>121.8</td>
<td>118.7</td>
<td>124.0</td>
<td>99.3</td>
<td>129.4</td>
</tr>
<tr>
<td>Unhoused - enhanced high ambient cooling system</td>
<td>Infinite</td>
<td></td>
<td>72.4</td>
<td>90.0</td>
<td>116.4</td>
<td>120.0</td>
<td>123.3</td>
<td>122.9</td>
<td>122.1</td>
<td>119.7</td>
<td>124.3</td>
<td>101.2</td>
<td>130.3</td>
</tr>
</tbody>
</table>

Exhaust sound power level, dB(A)
See note 2 and 9 listed below

<table>
<thead>
<tr>
<th>Open exhaust (no muffler) @ rated load</th>
<th>Octave band center frequency (Hz)</th>
<th>31.5</th>
<th>63</th>
<th>125</th>
<th>250</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
<th>8000</th>
<th>16000</th>
<th>Overall power level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>71.0</td>
<td>101.1</td>
<td>110.2</td>
<td>123.0</td>
<td>124.9</td>
<td>124.6</td>
<td>124.6</td>
<td>125.2</td>
<td>123.7</td>
<td>104.1</td>
<td>132.2</td>
</tr>
</tbody>
</table>

Note:
1. Position 1 faces the generator front per ISO 8528-10. The positions proceed around the generator set in a counter-clockwise direction in 45° increments. All positions are at 7 m (23 ft) from the surface of the generator set and 1.2 m (4 ft) from floor level.
2. Sound levels are subject to instrumentation, measurement, installation and manufacturing variability.
3. Data based on full rated load. Sound data with remote-cooled generator sets are based on rated loads without cooling fan noise.
4. Sound data for generator set with infinite exhaust do not include exhaust noise.
5. Sound pressure levels are measured per ANSI S1.13 and ANSI S12.18, as applicable.
6. Reference sound pressure is 20 μPa.
7. Sound power levels per ISO 3744 and ISO 8528-10, as applicable.
8. Reference power = 1 pw (10^-12 W).
9. Exhaust sound power levels are per ISO 6798, as applicable.
### Sound pressure level @ 7 meters, dB(A)

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Exhaust</th>
<th>Measurement location number (note 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Unhoused - remote cooled</td>
<td>Infinite</td>
<td>94.5</td>
</tr>
<tr>
<td>Unhoused - high ambient cooling system</td>
<td>Infinite</td>
<td>94.6</td>
</tr>
<tr>
<td>Unhoused - enhanced high ambient cooling system</td>
<td>Infinite</td>
<td>96.4</td>
</tr>
</tbody>
</table>

**Note:**

1. Position 1 faces the generator front per ISO 8528-10. The positions proceed around the generator set in a counter-clockwise direction in 45° increments. All positions are at 7 m (23 ft) from the surface of the generator set and 1.2 m (48 in) from floor level.

Sound pressure level in dB(A) at given distance (7 meters) from source at noted position.

Average of 8 position measurements at given distance (7 meters).
<table>
<thead>
<tr>
<th>Configuration</th>
<th>Exhaust</th>
<th>31.5</th>
<th>63</th>
<th>125</th>
<th>250</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
<th>8000</th>
<th>16000</th>
<th>Overall sound power level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unhoused - remote cooled</td>
<td>Infinite</td>
<td>67.2</td>
<td>86.9</td>
<td>106.9</td>
<td>110.7</td>
<td>118.1</td>
<td>119.7</td>
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<td>128.1</td>
</tr>
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<td>Unhoused - high ambient cooling system</td>
<td>Infinite</td>
<td>72.5</td>
<td>89.9</td>
<td>113.5</td>
<td>118.4</td>
<td>121.2</td>
<td>122.0</td>
<td>121.8</td>
<td>118.7</td>
<td>124.0</td>
<td>99.3</td>
<td>129.4</td>
</tr>
<tr>
<td>Unhoused - enhanced high ambient cooling system</td>
<td>Infinite</td>
<td>72.4</td>
<td>90.0</td>
<td>116.4</td>
<td>120.0</td>
<td>123.3</td>
<td>122.9</td>
<td>122.1</td>
<td>119.7</td>
<td>124.3</td>
<td>101.2</td>
<td>130.3</td>
</tr>
</tbody>
</table>

Sound power level in dB(A) at noted frequency.

Overall sound power level – weighted sum of sound power level across measured frequencies.
Sound power level in dB(A) at noted frequency.

Overall sound power level – weighted sum of sound power level across measured frequencies.
Note:

1. Position 1 faces the generator front per ISO 8528-10. The positions proceed around the generator set in a counter-clockwise direction in 45° increments. All positions are at 7 m (23 ft) from the surface of the generator set and 1.2 m (48 in) from floor level.

2. Sound levels are subject to instrumentation, measurement, installation and manufacturing variability.

3. Data based on full rated load. Sound data with remote-cooled generator sets are based on rated loads without cooling fan noise.

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7. Sound power levels per ISO 3744 and ISO 8528-10, as applicable.

8. Reference power = 1 pw ($10^{-12}$W).

9. Exhaust sound power levels are per ISO 6798, as applicable.
Concept Check – Interpreting Data

When reviewing sound data provided by a manufacturer, it is key to note which of the following:

a) Generator Set Load
b) Distance from Source to Point of Measurement
c) Test Method
d) Units of Measure (Power vs. Pressure)
e) All of the Above
When reviewing sound data provided by a manufacturer, it is key to note which of the following:

a) Generator Set Load  
b) Distance from Source to Point of Measurement  
c) Test Method  
d) Units of Measure (Power vs. Pressure)  
e) All of the Above
Testing Considerations

- At what load can the generator set be tested?
- Are there any other contributors to sound at the site? (load bank, ambient noise)
- Who is performing the measurements?
- When are the measurements being performed?
- What type of measurement equipment will be used to perform the validation testing?
Testing with Ambient Noise

If the ambient noise at the site is more than 10 dB(A) greater than the generator set, validating sound performance on site will present a challenge.

<table>
<thead>
<tr>
<th>Adding decibels</th>
<th>When the numerical difference in dB(A) between two noise levels is:</th>
<th>Add this dB(A) to the higher of the two noise levels for a total:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>0.1 – 0.9</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>1.0 – 2.4</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>2.4 – 4.0</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>4.1 – 6.0</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>6.1 – 10</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>&gt;10</td>
<td>0</td>
</tr>
</tbody>
</table>

3.0, 2.5, 2.0, 1.5, 1.0, 0.5
Exhaust System Considerations

- Insulate:
  - Muffler(s)
  - Exhaust Piping
  - Flexible Bellows*

- Do Not Insulate:
  - Turbocharger(s)
  - Exhaust Manifold(s)
Silencer Application Impact

- Specifying an oversized silencer may lead to:
  - Additional (excessive) exhaust system restriction
  - Additional space claim for generator set(s)
  - Additional project cost
  - Limited change in overall sound
Impact of Exhaust Aftertreatment

- Exhaust aftertreatment (SCR, DPF, DOC, etc.) may have inherent sound attenuation properties.
- Exhaust aftertreatment may reduce available engine exhaust restriction.
- Additional engine exhaust sound attenuation may not be necessary – consult generator set manufacturer to verify product performance.
When looking at sound data, make sure to ask yourself…

• Were the generators tested at the same load/power node?
• Was the data collected in a comparable configuration? (e.g. with or without a set mounted radiator)
• Are the units of measurement the same? (A-weighted Sound Pressure Level [SPLA] or A-weighted Sound Power Level [SPWLA])
• Were Sound Pressure Level measurements taken at the same distance?
• Was the same standard or measurement method used for the noise measurements?
• How reliable is the data?
• Were the measurements conducted at Precision-or Engineering-Grade test facilities?
Course Summary

Sound Attenuation and Test Strategies for Generator Set Installations
• Describe the fundamentals of acoustics relative to generator set installations.
• Identify appropriate strategies for specifying sound requirements and test methods.
• Recognize data provided by manufacturers that is most relevant to site noise limits.

Specify:
• Overall sound pressure level limits in dB(A) at a given distance (typically based on the property line).
• Test method and conditions used to validate performance on site (if applicable).

Avoid specifying:
• Sound reduction levels. (reduction from what?)
• Muffler and enclosure grades. (not consistent from one manufacturer to another)
Q&A

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- WA, OR, AK: Tom Tomlinson ([tom.tomlinson@cummins.com](mailto:tom.tomlinson@cummins.com))
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