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Experimental determination of far field sound power due to panel and vent radiation of a portable diesel generator

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ABSTRACT

Most portable diesel generators (often referred to as gensets) produce high sound power levels. The sound generated by various internal components of the genset is transmitted to the far field by two radiation mechanisms: sound transmits through the panels of the generator enclosure as well as propagates through any openings in the enclosure. In order to determine which mechanism to control, a study was performed to quantify the contribution of the radiated sound power coming from the panels and openings. A radiation model was created from near-field acoustic intensity scans performed on the surface of the enclosure and from feed-forward active noise control performance on a single air intake vent. The empirical model was used to predict the possible far field sound power attenuation if passive treatments were applied to the enclosure and if active noise control were used on the enclosure openings. The model predicts that the overall sound power level could be reduced by 8.7 dBA with both passive and active treatments. This paper outlines the model development and predictions.

1. INTRODUCTION

Portable diesel generators (gensets) are used to produce electricity on construction sites and other remote locations. The noise produced by the genset can be a nuisance to workers and nearby residents. The primary internal components of a genset are an engine, an electric generator, and a radiator and fan. Typically, the internal components are enclosed by a metal box to reduce sound radiation. Passive acoustical treatments, such as lead and foam linings, are often applied to the inside of the box to increase its sound transmission loss. These passive treatments can be very effective on enclosures with no openings which result in acoustic leaks. However, airflow specifications of the engine and radiator require openings in the enclosure box of portable generators. The openings reduce the effective transmission loss of the box by providing a direct acoustic path to the far field. Both the sound transmission through the panels of the enclosure box and the sound propagation through openings in the box must be considered when reducing the far field radiated sound power.

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2. THE PROBLEM

A. Controlling the internal sound field

Research has been done by Boone[1] to control the internal sound field of a genset using feedforward and feedback active noise control (ANC). Reductions of the sound field outside the enclosure of 0.4-1.6 dBA were realized when using ANC inside the enclosure. Limited ANC performance was caused by poor coherence between the reference and error sensors for feedforward control and by poor autocorrelation of the error sensor for feedback control. The internal sound field of the genset is complex, contains many acoustic sources, and is difficult to control.

B. Controlling engine exhaust noise

Research has been done by Cuesta and Cabo[2] which uses ANC to control engine exhaust noise from a small, enclosed generator. The exhaust noise was controlled as it exited the enclosure through an exhaust duct. The fundamental engine tone and two harmonics were reduced by 30 dB at the error microphone. This approach was effective because it reduced the active control problem of the enclosure openings to a classical ANC duct problem.

C. Simplifying the genset problem

To simplify the control problem, the genset was treated as a box with two sound radiation mechanisms: sound transmitted via the vibrating panels of the enclosure and sound that directly propagated through openings in panels of the enclosure. Although the control of the entire sound field depends on effective control of both radiation mechanisms, each mechanism can be controlled independent of the other, that is, passive control can be applied to the panel areas while ANC can be performed in internal ducts with one end of the duct located on the surface of the enclosure.

No matter how high the transmission loss potential of the enclosure, openings for vents will reduce its effective transmission loss. Bell[3] provides the chart shown in Figure 1 as a guide. The transmission loss potential (i.e. the maximum transmission loss possible with no openings in the barrier) is plotted on the x-axis and the actual noise attenuation realized is plotted on the y-axis.

For example, the particular genset used in this work has 4% open area for air intake and exhaust vents. If the total transmission loss potential of the enclosure box was 30 dB without openings, a percent open area of 4% would reduce its transmission loss potential to approximately 13 dB. This principle is referred to as acoustic leakage and can severely degrade the performance of any barrier intended for transmission loss purposes.

Figure 1[3] shows the importance of reducing the percentage of open area of the genset. However, since openings are required for proper functioning of the generator, the acoustic leakage will be reduced by actively controlling the sound radiated from the open areas.

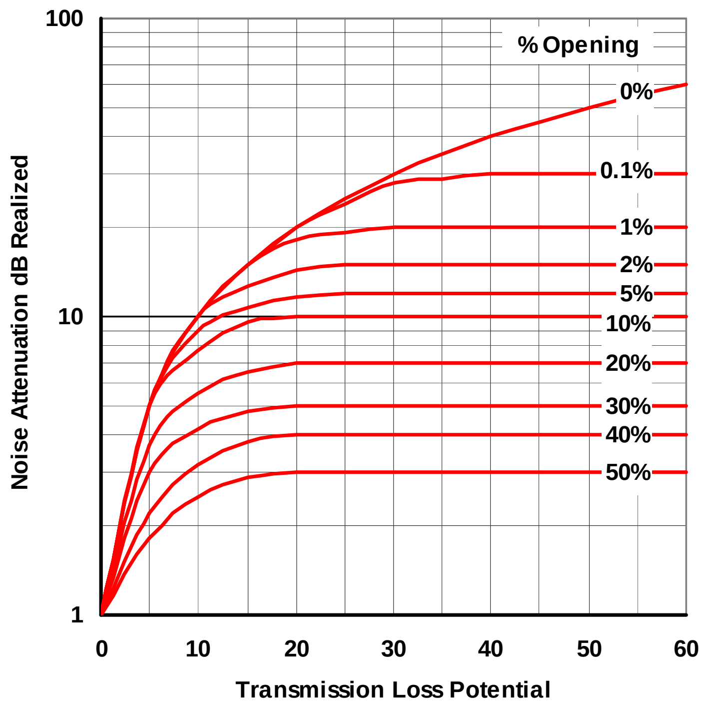

Figure 1. Chart of possible noise attenuation realized as a function of the original transmission loss potential and the percent open area of the enclosure (adapted from Bell[3]).

3. SOUND POWER CONTRIBUTION OF PANEL AND VENT

A. Near-field intensity measurements

It was important to determine the sound power contribution from each radiation mechanism. This was important because it would not be necessary, for example, to passively control the sound propagating from the panels if they conributed very little to the far field sound power level. Likewise, it would not be necessary to actively control the sound radiated from the vent openings if the far field sound power was dominated by the panel radiation. In order to determine the sound power contributions, nearfield acoustic intensity scans were measured on each side of the genset.

The A-weighted overall intensity level was measured 2 cm from the surface of the enclosure on a grid consisting of 10 cm by 10 cm squares. Ten averages were taken at each point. The acoustic intensity map for each side is shown in Figure 2. It is seen from Figure 2 that the sound intensity level (re: 10^{-12} W/m^2) was highest near the vent openings in the side panels. However, these spots also have the smallest radiating areas.

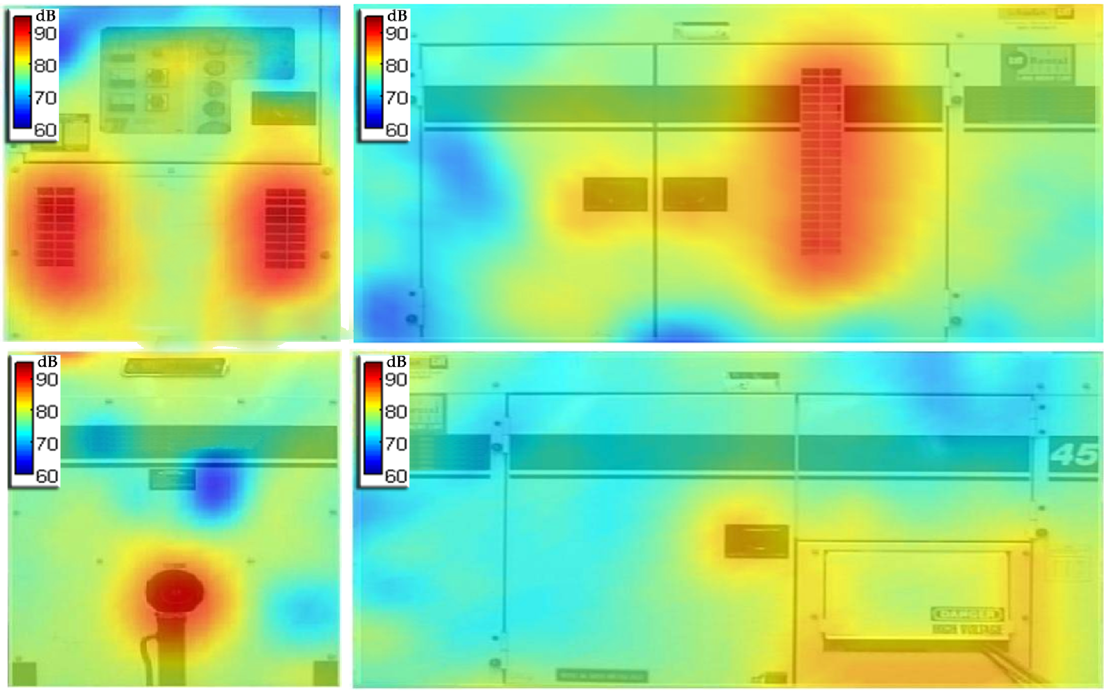

Figure 2. Nearfield intensity scans of each side of the genset: a) back, b) left side, c) front, d) right side (dB re: 10^{-12} W).

The sound power is given by:

$$L_{\Pi k} = \sum_{i=1}^{n} I_i S_i \tag{1}$$

where $L_{\Pi k}$ is the sound power level of the k^{th} panel, I_i is the intensity level of the i^{th} area, and S_i is the area of i. The total sound power is then found by summing the $L_{\Pi k}$ for the entire genset. These computations, for each side of the genset, are shown in Table 1. The intensity levels used in the table for the panel areas and the vent areas were spatially averaged intensity levels over the surface. This table will be used as a model of radiated sound power for other configurations.

Table 1. Computation table for summing the sound power for each vent and panel area.

	Panel Area (m^2)	Panel Intensity Level (dBA)	Panel Intensity (W/m^2)	Panel Power (W)	Vent Area (m^2)	Vent Intensity Level (dBA)	Vent Intensity (W/m^2)	Vent Power (W)	Total Power (W)
Right side	2.40	75	3.16E-05	7.59E-05	0.000	91.3	1.35E-03	0.00E+00	7.59E-05
Left side	2.35	75	3.16E-05	7.43E-05	0.062	91.3	1.35E-03	8.36E-05	1.58E-04
Back	1.06	75	3.16E-05	3.35E-05	0.052	91.3	1.35E-03	7.01E-05	1.04E-04
Front	1.11	75	3.16E-05	3.51E-05	0.000	91.3	1.35E-03	0.00E+00	3.51E-05
Top	1.54	75	3.16E-05	4.87E-05	0.268	91.3	1.35E-03	3.62E-04	4.10E-04

The total sound power was found by adding the sound powers for each side of the genset (the rightmost column in Table 1). The total sound power was found to be 0.783 mW (88.94 dBA; all intensity dB levels re: 10^{-12} W/m^2).

The sound power contribution of the vents was 0.515 mW (87.12 dBA), nearly twice the sound power contribution of the panels at 0.268 mW (84.27 dBA). It was determined in this application that actively controlling the vents would be the first priority, followed by applying passive transmission loss treatments to the enclosure. Further details are given in section four of this paper.

B. Sound power verification measurements

An outdoor sound power measurement was conducted to verify the results of the model shown in Table 1. A six microphone hemisphere measurement was conducted according to ISO 4872 Alternative B. This standard uses six microphones placed on a 4 m radius hemisphere. The measured far field sound power level was 88.97 dBA. This agrees with the model with less than 1% error.

4. USING THE MODEL TO PREDICT RESULTS

A. Passive transmission loss pads

Passive transmission loss pads were used to increase the transmission loss of the panels. The pads consist of a heavy vinyl layer with a quilted layer on one side. Holes were cut in the pads to fit over the vent openings. The applied transmission loss pads are shown in Figure 3.

The sound power was measured with the transmission loss pads in place. In this configuration, the sound power was found to be 87.82 dBA (88.97 dBA without pads). This result was then matched using the model in Table 1 by reducing the panel intensity level by 5 dBA, from 75 dBA to 70 dBA. In this way, the effect of the transmission loss panels could be accounted for in the model.

Figure 3. Transmission loss pads applied to the genset. The pads were custom made to fit the vent openings in the panels.

B. ANC in a vent opening

Feedforward active noise control (ANC) was performed in one of the two vent openings on the back panel of the genset. An external duct was used for ease of experimentation. In a production model, the duct would be built into the interior of the generator enclosure. The reference microphone was placed inside the generator near the vent opening, while the error microphone was placed at the end of the duct. The duct configuration is shown in Figure 4.

Figure 4. Photograph of the experimental ANC duct, located over one of the two vent openings on the back side of the genset.

Feedforward ANC in the duct provided 14 dBA of overall attenuation at the error microphone. This reduced the overall vent intensity level from 91.3 dBA to 77.3 dBA. This change in vent intensity level was used in the model shown in Table 1. For ANC performed in one vent opening on the backside of the genset, the model predicted a total sound power of 0.749 mW (88.75 dBA). The actual measured sound power for this configuration was 0.743 mW (88.71 dBA).

C. Predicted results

The model was used to predict the radiated sound power for six configurations of active and passive treatments. Four of the configurations were then verified using the 6 microphone, 4 m radius sound power measurement technique. The model results agreed closely with the measured results in the first four configurations. The last two configurations were only predicted with the model. The sound power from each treatment configuration was then compared to the sound power with no treatment at all. The results are shown in Table 2.

Table 2. Results for six treatment configurations. The first four configurations were verified through sound power measurements. The last column shows how much attenuation the treatment provides above no treatment at all.

	Sound Power		
Treatment	Predicted (dBA)	Measured (dBA)	Treatment attenuation (dBA)
None	88.94	88.97	n/a
ANC in one intake duct (14 dBA reduction)	88.75	88.71	0.19
Transmission loss pads (5 dBA reduction)	87.78	87.82	1.16
Transmission loss pads and ANC in one intake duct	87.53	87.67	1.41
ANC in all ducts	84.59	n/a	**4.34**
Transmission loss pads and ANC in all ducts	80.22	n/a	**8.72**

It was predicted that employing ANC on all four vent openings would reduce the overall sound power level by 4.3 dBA. In addition, using the transmission loss panels with ANC in all four vent openings would reduce the overall sound power level by 8.7 dBA.

CONCLUSIONS

A study was performed to quantify the contribution of the radiated sound power coming from the panels and openings of a portable diesel generator. A radiation model was created from near-field acoustic intensity scans performed on the surface of the enclosure and from feed-forward active noise control performance on a single air intake vent. The empirical model was used to predict the possible far field sound power attenuation if passive treatments were applied to the enclosure and if active noise control were used on the enclosure openings. Measured results agree closely with the model predictions for four treatments. The model predicts that the overall sound power level could be reduced by 4.3 dBA with ANC in all ducts or by 8.7 dBA with both passive and active treatments. The quantification of the sound power from the radiating sound sources was a critical step in reducing the noise of a portable diesel generator.

ACKNOWLEDGEMENTS

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