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Energy Density Active Noise Control in an Earthmoving Machine Cab

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ABSTRACT

Conventional active noise control (ANC) systems attempt to minimize pressure at an error sensor (or sensors) to achieve control, and often result in a relatively small zone of control. Considering a practical application in a vehicle, this approach is acceptable provided the operator's head remains within the control zone. In the case of an earthmoving machine, an operator's head regularly moves about the cab, either because of the motion of the machine during operation or as the operator moves about to perform various tasks. By minimizing Energy Density (ED), instead of pressure, a potentially larger control zone may be achieved. Active control of the sound field within an earthmoving machine cab was attempted using the ED technique. The scope was limited to controlling the engine firing frequency tonal within the cab with the machine running, but in a static condition (engine idle). Frequency response and spatial results show the method achieved nearly global control within the cab and effectively reduced the A-weighted sound pressure level by a few decibels, despite only reducing a single low frequency tone. In this sense, active control using ED has the potential to be more suitable to earthmoving machine applications than pressure techniques.

1. INTRODUCTION

Conventional three-dimensional active noise control (ANC) minimizes pressure at an error sensor (or sensors) to achieve control. Within an enclosure or cabin, pressure minimization results in a control zone of limited size. For a single sensor application, the effective control zone may be on the order of one-tenth the wavelength with a steep sound pressure gradient[1,2]. Considering a practical application in a vehicle, this approach is acceptable provided a) the operator's head remains within the control zone, or b) the target frequency range is sufficiently low enough so that the control zone is large enough to cover the region of interest. For pressure minimization to achieve global control over a wide frequency range, multiple sensors and actuators, as well as additional signal processing power are required.

The conditions in a typical earth moving machine cab differ from those of a passenger vehicle. Because of a combination of factors, including demanding work cycles (e.g., digging dirt, moving heavy loads over rough terrain, etc.), the need to reach various machine controls, or reposition oneself for visibility reasons, an earth moving machine operator's head moves about the cabin more so than in a passenger vehicle. For these circumstances, it would be advantageous to have a control zone that covers the majority of the cab interior so the operator experiences a relatively uniform sound field.

2. BACKGROUND

It has been shown that energy density active noise control is generally more effective than traditional pressure methods in achieving global control of the field when applied to low-frequency, low-modal density acoustic fields[3,4]. An additional potential benefit of energy density is decreased sensitivity to sensor placement compared to traditional methods[3-5]. Consequently, one can generally locate the energy density sensors at practically convenient locations, without suffering significant degradation in the performance of the system by having the sensors at sub-optimal locations. This is achieved because both pressure and particle velocity are minimized when minimizing the energy density. Thus, the controller does not minimize the pressure at the expense of increasing the particle velocity, which often occurs when the modes are restructured to create a local zone of silence as a result of minimizing pressure.

Faber and Sommerfeldt demonstrated the use of Energy Density control within a mock earthmoving machine cab using synthesized and recorded machine sounds as input[4]. In both cases, the acoustic source was a speaker contained within the mock cab. A cab mounted on a machine is exposed to air-borne noise from all sides and structure-borne sources from various connections. The purpose of the work described in this paper was to explore the extent of the control zone within an actual machine cab while exposed to actual machine excitations.

3. MEASUREMENTS

A. Experimental Set Up

The active control system used for this work is similar to that described in Reference 5, and consists of:

- an energy density sensor
- control speakers (consumer quality)
- amplifiers and signal conditioners
- a DSP board and associated software running a filtered-X, feed-forward adaptive control algorithm designed to minimize energy density
- photo-tachometer monitoring a rotating component, rotating proportional to engine speed

The system is designed to minimize acoustic energy density at the sensor location. Using a feed forward technique, the system attempts to cancel any acoustic signal correlated to the reference signal (in this case, engine rpm).

A medium-sized wheel loader was selected as the test specimen, as shown in Figure 1. This machine had a noticeable engine firing frequency tonal that became particularly strong when running near rated speed due to cab resonance. For these tests, off-the-shelf components were used to provide filtering and amplification capabilities, as shown in Figure 2.

Figure 1: (a) Wheel loader used in this study. All tests were performed with the machine stationary. (b) Sensor mounted above the operator's head.

Figure 2: (a) Amplifiers and signal conditioners shown mounted on the right side of the cab. Computers and other supporting hardware were situated on the left side (not shown). (b) Consumer-quality speaker. Another speaker was mounted in a similar location on the other side of the cab.

Tests were conducted at several engine rpm settings. For each operating condition, the engine speed was held constant and time-averaged sound pressure levels were measured at points on two horizontal planes as depicted in Figure 3.

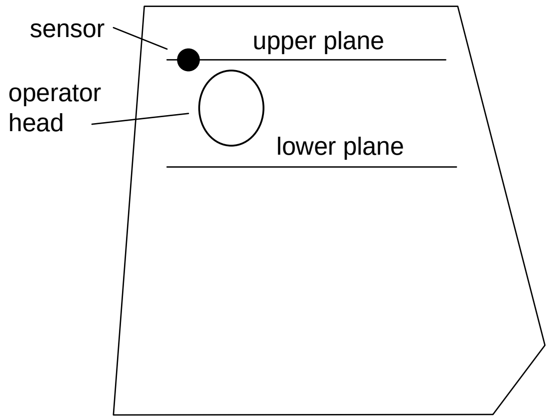

Figure 3. Measurement planes above and below the operator's head.

B. Results

A-weighted sound pressure levels were measured during normal operation (control off) and during active control. The differences at nine points for each plane are shown in Figure 4. Figure 5 shows the 1/3 octave spectrum near the operator's head.

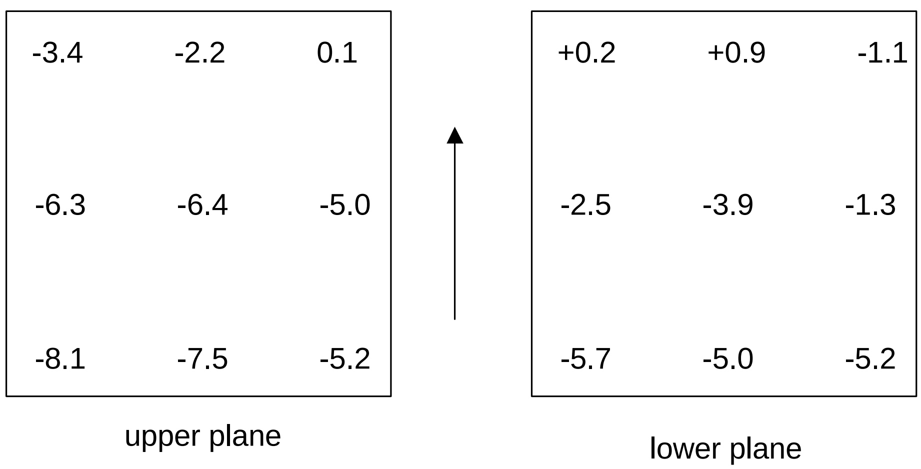

Figure 4. A-weighted sound pressure level differences obtained near rated speed of the wheel loader. Negative values indicate attenuation with the control system operating. The arrow indicates the forward direction of the cab.

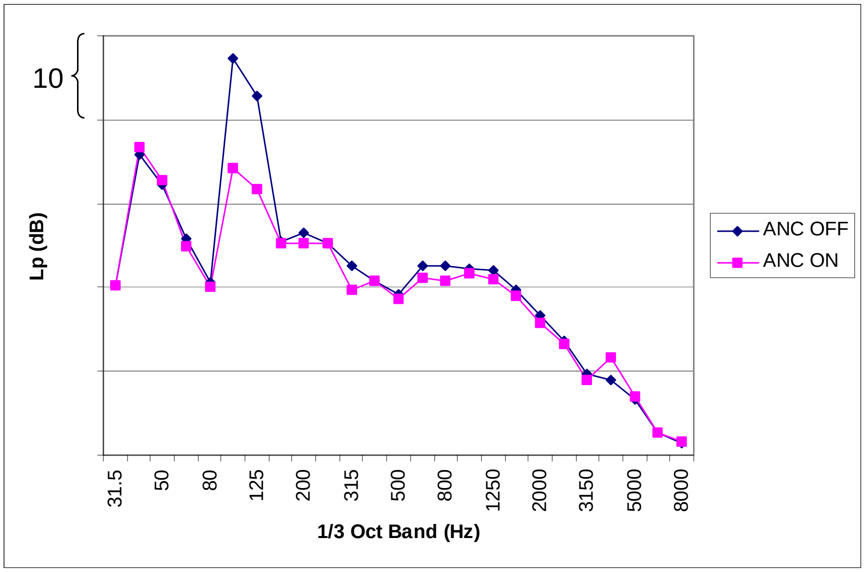

Figure 5. Sound level spectrum near the operator's head with active control off and on with the engine near rated speed.

4. DISCUSSION

As seen in Figure 4, good spatial control was achieved on both measurement planes. At two points near the front windshield the sound field increased slightly with the control system operating. Loosely interpolating between points, and considering typical movements about the cab, these results suggest that the operator would experience 3 to 6 dB reduction in A-weighted sound level. Figure 5 shows a peak in the 100Hz – 125Hz range dominating the spectrum when the engine runs at rated speed. This is attributed to the engine firing frequency aligned with a cab resonance. Had the peak not been as prominent (as found at other engine speeds) the A-weighted reduction would not have been as large.

While harder to quantify, the aural difference was also very noticeable. With the engine tone absent, the sound inside the cab was more pleasing in quality. As one moved about the cab, the sound field was fairly uniform, whereas without control there were definite loud and quiet zones due to the cab resonance.

Results at high idle were similar. Results at lower engine speeds did not yield as much attenuation partly because the engine tone was not as dominant, and partly because the speakers were not as capable at the lower frequencies.

5. CONCLUSIONS

This study demonstrated the use of energy density active noise control on an actual earthmoving machine. While the scope was limited to static conditions, the ability to attain global control throughout the cab using a single sensor suggests the energy density method may have at least one advantage over conventional pressure methods in this application.

ACKNOWLEDGEMENTS

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