inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 3.8

A LOCAL ACTIVE NOISE CONTROL SYSTEM FOR LOCOMOTIVE DRIVERS

J.L. Nielsen*, A. Sæbø*, G. Ottesen, T.A. Reinen**, S. Sørsdal****

* Silence International, Gaustadalléen 21, 0349, Oslo, Norway

** SINTEF, Telecom and Informatics, 7465, Trondheim, Norway

Tel.: +47 22958672 / Fax: +47 22604427 / Email: johan.nielsen@silence.no

Keywords:
ACTIVE NOISE CONTROL, SILENT SEAT, LOCOMOTIVE, SILENT ZONE

ABSTRACT
An active noise cancellation system for drivers of diesel locomotives has been developed. The system is local and fully self-contained, and is designed as a chair headrest. Both random and tonal low frequency noise is attenuated while maintaining robust stability. Due to the very low frequency nature of the disturbing noise, balanced noise-criterion curves have been used as noise attenuation criteria for the digital controller design. External signals like communication and entertainment can be replayed on the system speakers. The system has been tested in a real situation, and was received favorably by drivers.

1 - INTRODUCTION
Noise is seriously deteriorating the work environment for drivers of some diesel locomotives, which are in use on several long-distance railway lines in Norway. As the process of replacing older engines is progressing very slowly, these locomotives will be used for quite a while yet. Recent focus among drivers, their trade union and the Norwegian State Railway (NSB) management on improving working conditions have led to a search for measures against noise problems.
The noise is predominantly low frequency engine noise, which is difficult and very costly to attenuate by passive means. The drivers seldom use hearing protection, as they detest having to wear earmuffs or earplugs all day. Therefore a non-contact active noise control system, the "Silent Zone", is under development.

Figure 1: NSB diesel locomotive.

2 - THE SILENT ZONE SYSTEM

The Silent Zone system is a silent-seat type of solution, similar to a suggested application of Olsson and May's electronic absorber [1], with microphones and loudspeakers integrated in a driver's headrest, see Fig. 2. The system is therefore local and fully self-contained, only an external power supply is necessary. Mounting is fairly easy, the system being a replacement headrest for existing chairs. Sound is picked up by microphones close to the driver's head, processed and adapted by a digital signal processor, and the resulting anti-noise produced by the speakers, see Fig. 2. The processing delay in the electronics has been minimized. Due to local sound pickup and low delay, the system is capable of attenuating both random and tonal low frequency noise. Microphone placement and incorporation of robust feedback cancellation ensure system stability.

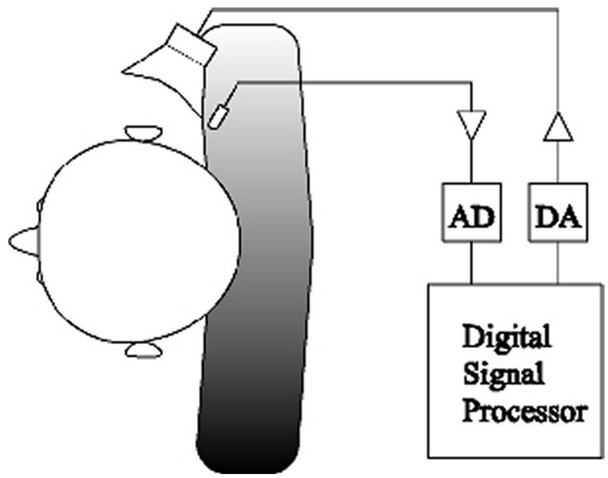

Figure 2: Silent zone system (right side only for clarity).

To be able to produce the necessary sound pressure levels for creating zones of attenuated noise at the driver's ears, loudspeaker elements of substantial size and weight have to be used. This, combined with the limited geometrical extent of the zone due to the distance attenuation of sound from the speaker, made the mechanical design of the system a major challenge. The static working position and limited necessary arc of visibility of the locomotive drivers made it possible to extend the position of the speakers on the side of the head, while staying close to the ears, see Fig. 3. The system can therefore create acceptable zones of attenuation without blocking sight lines or bothering the driver. Personal adjustment of the headrest position is crucial to place the zone of quiet correctly.

Figure 3: Mechanical design.

3 - CRITERIA, ADJUSTMENT AND PERFORMANCE

Low frequency noise exposure can, in addition to general annoyance and lowering of pleasantness, lead to degraded work performance because cognitive demands are less well coped with [2]. Permissible

noise levels in work environments are expressed in dBA, both governmental regulations and also NSB's requirements adapted to locomotives in particular. While probably being an adequate descriptor for risk of hearing loss, dBA is quite clearly useless for measuring other effects of low frequency noise exposure, like audibility, annoyance, stress, intelligibility of communication signals, etc. This realization led to a search for better measures, and the balanced noise-criterion (NCB) curves [3] have initially been adopted as criteria for noise attenuation, and thereby as basis for adjustment of the digital controller. Laboratory tests have demonstrated that this correctly leads to attenuation of the noise components that the locomotive drivers find particularly annoying in the long term, and preliminary tests in real conditions have further confirmed this hypothesis.
In active control of noise a common problem is so-called spillover, or amplification of noise just outside the frequency band where the system produces attenuation. Using the NCB curves as criterion spillover is taken into account when estimating the effect of the system. In addition to noise attenuation other concerns are important as well, like system stability and robustness, loudspeaker performance, protection against system overload due to pressure pulses (for instance when entering tunnels at high speeds), etc. The design and operation of the digital controller is therefore a multi-criterion optimization problem. System measurement, filter design and real-time system control software has therefore been developed.
An example of system performance, expressed as difference in noise levels measured on locomotive noise replayed in a laboratory, is shown in Fig. 4. The NCB-curve criterion applied to locomotive noise has led to focussing attenuation on very low frequencies.

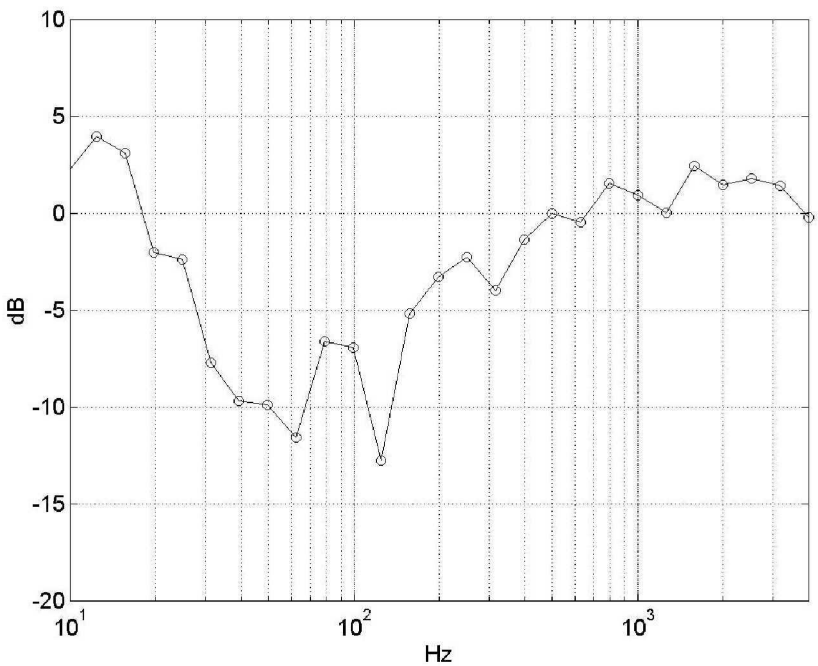

Figure 4: An example of change in locomotive noise levels when applying the silent zone system.

4 - COMMUNICATION AND ENTERTAINMENT

Information-carrying signals, like communication, alarms and entertainment, are not influenced appreciably by the Silent Zone system due to their spectrum. They can, on the other hand, be replayed on the system loudspeakers without disturbing the active noise control effect. This has several advantages. Without the active noise control the low frequency noise effectively masks higher frequency signals like speech. The noise canceling system therefore enables highly intelligible communication and entertainment at substantially lower sound levels. Also, entertainment signals will tend to mask the higher frequencies of the locomotive noise, which the noise canceling system cannot attenuate, thereby creating a more pleasant overall sound environment. It should be noted that the entertainment program is automatically muted if communication is activated.
Suitable signal conditioning like equalization and cross-filtering is necessary to produce a pleasant auditory display for such external signals. So far only crude filtering has been implemented. However, the placement of loudspeakers close to the driver's head opens up interesting possibilities in utilizing modern 3D-audio techniques in presentation of entertainment and communication signals. The substantial

challenge of out-of-the-head localization and front-to-back confusion remains to be solved in a robust manner.

5 - SUBJECTIVE REACTIONS

The Silent Zone system has been tested both in laboratory and locomotive environments, also in real working conditions while pulling trains on long-distance lines. The noise attenuation effect of the system has been received favorably by drivers. The reduction in overall noise loudness is not large, due to focussing of the attenuation at very low frequencies, but it is clear that the most bothersome components of the noise is being substantially reduced. Also the effect of being able to reduce the level of communication and entertainment signals has been commented on as a relief.

ACKNOWLEDGEMENTS

The authors thank professor Asbjørn Krokstad at the Norwegian University of Science and Technology for help and discussions, Peter Molthe at Silence International, Jarle Svean and Odd K. Pettersen at SINTEF for organization and project management, Asle Nordbotten and staff at NSB for enthusiastic cooperation, Thorbjørn Drage and staff at INVENTAS for design, and SND for financial support.

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