CONCURRENT SOUND AND VENTILATION QUALITY STUDY IN A MOVING MACHINERY CABIN

Marko Antila

VTT Industrial Systems
P.O.Box 1307, 33101 Tampere, Finland
marko.antila@vtt.fi

Veli-Jukka Ollikainen

VTT Industrial Systems
P.O.Box 1307, 33101 Tampere, Finland
veli-jukka.ollikainen@vtt.fi

ABSTRACT

The noise and air quality conditions in a moving machinery cabin are important for the machine operator. Both noise annoyance and ventilation-related issues have been addressed in earlier studies separately but not at the same time in one study. In this study both cabin sound quality related issues as well as air quality issues were addressed concurrently. First the conditions were recorded in field conditions. After that a series of laboratory experiments were conducted. These experiments included the assessment of generation of noise and pressure difference in different flow conditions as well as experiments with active noise control. The results show that an optimum for both pressure loss and generated noise in a ventilation system can be found and it can be utilized in ventilation system design. Furthermore, the active noise control results showed it to be a feasible tool in diminishing the periodic components and changing the quality of perceived noise in a moving machinery cabin.

1. INTRODUCTION

The user of moving machinery has today fairly good working conditions. Important factors in this include ergonomics, effects of vibrations, noise, and ventilation. Ergonomics and vibrations are widely addressed topics. Moving machinery cabin noise and ventilation are addressed much more rarely, especially with comfort issues on focus. Both noise annoyance and ventilation-related issues have been addressed in earlier studies separately [1], [2] but not concurrently in one study. Moreover, psychoacoustics is becoming a standard tool in assessing the product quality [3].

2. METHODS

Cabins from several moving machinery manufacturers were selected as test cases. The acoustical and ventilation properties were evaluated and measured in field conditions. Measurements were carried out to get necessary background information for laboratory study as well as to get new data.

After that the cabins were brought to laboratory and further experiments were conducted, both with complete cabins and also with their critical parts, such as sound insulation structures and ventilation. Psychoacoustically relevant noise measurements were carried out with binaural microphones, which were installed in the ears of the operator. Additionally, measurements connected directly to the physical behavior of the cabin structures, systems, and materials were done using normal microphones, intensity probes and accelerometers.

Based on results of field measurements, ventilation quality and noise issues, such as air flow properties in different ducts and with various filters, were studied further. A basic model was constructed for the flow noise. Furthermore, an advanced experiment using active noise control was done to attenuate disturbing periodic noise in cabins.

3. NOISE MEASUREMENTS IN FIELD CONDITIONS

Noise and ventilation information was obtained as background information from the field measurements. In Fig. 1 the field measured values of L_{pA} and Loudness are presented for several cases. Loudness corresponds to the sound pressure levels quite well. In this case, both Loudness and L_{pA} could be used equally good indicators of the cabin noise. In all cases this is not necessarily the case, because the methods have different frequency scaling. Ventilation is a large contributor to the noise and it can be even higher than engine-related noise.

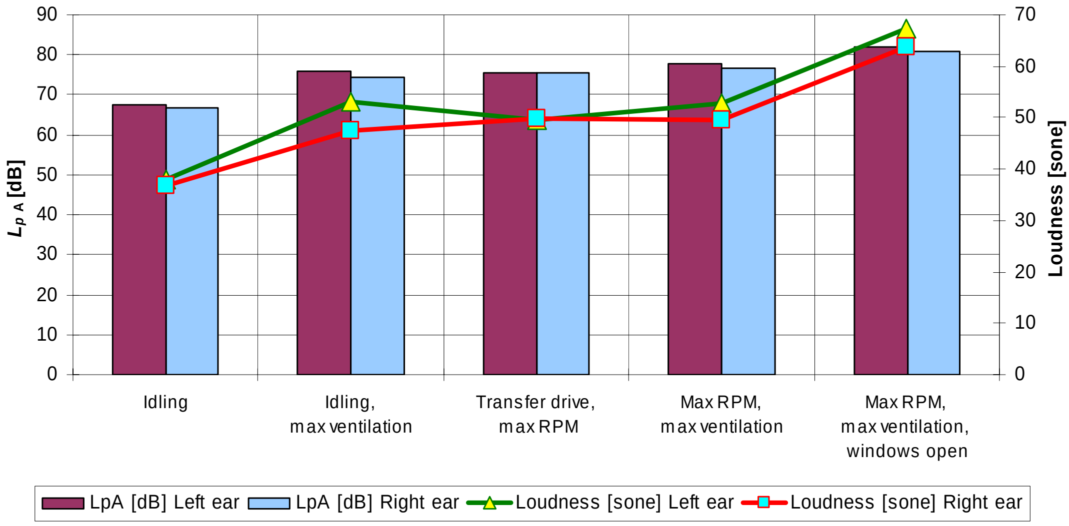

Fig. 1. Field-measured values in a cabin.

3.1. Ventilation and its noise in laboratory conditions

The operation of the ventilation was assessed in laboratory conditions by measuring the noise at different points of the pressure difference versus volume flow curve. The results in Fig. 2 show a typical phenomenon in such conditions.

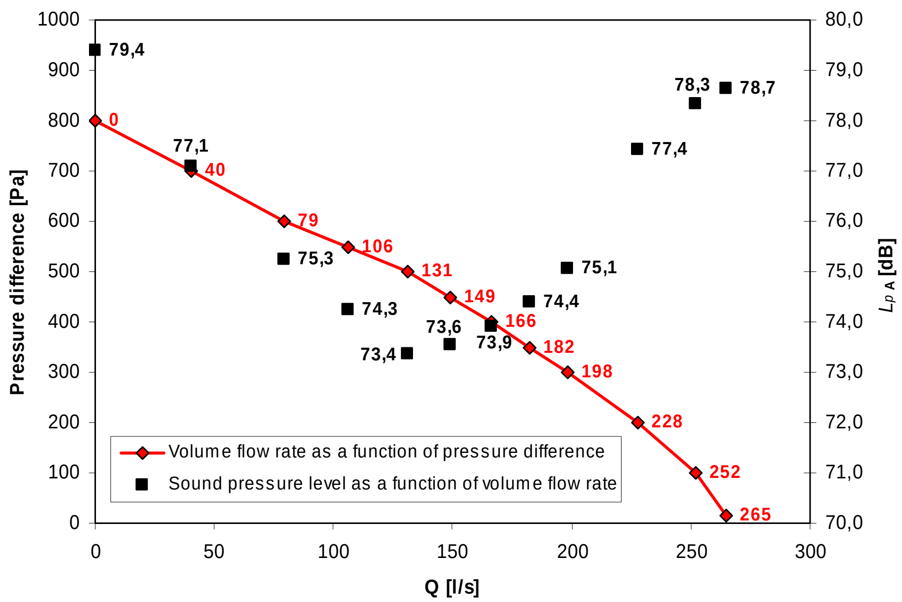

Fig. 2. Pressure difference and noise levels versus volume flow.

At low volume flow levels in high pressure-loss conditions the noise is high, and it is high again in low pressure difference - high flow condition. At certain point of the curve the optimum can be found, in this case at volume flow of 130 l/s. On the other hand, the requirement for the volume flow was only 106 l/s.

In further studies it was found out that if the pressure difference is slightly decreased to 400 Pa at volume flow of 106 l/s by reducing the pressure loss, a better local optimum, 70.2 dB(A) in noise can be achieved. This is mainly due to the lower rotational speed of the fan, because then less effort is required to move same amount of air. The pressure loss can often reduced by some, usually small re-designs of the ventilation system.

3.2. Active noise control experiments

The purpose of the active noise control experiments was to assess to feasibility of active control in attenuation of several periodic noise signals. Such signals are typically engine noise dependant, such as noise from hydraulic pump or ventilation. Periodic noise components are known to affect to annoyance in more complex way than broader-spectrum ones [4], and that was why they were selected to be attenuated and controlled by active means. Furthermore, the active reduction of periodic noise has a long time been used in car applications [5] and the control algorithms and theory for doing periodic noise attenuation is well-known [6].

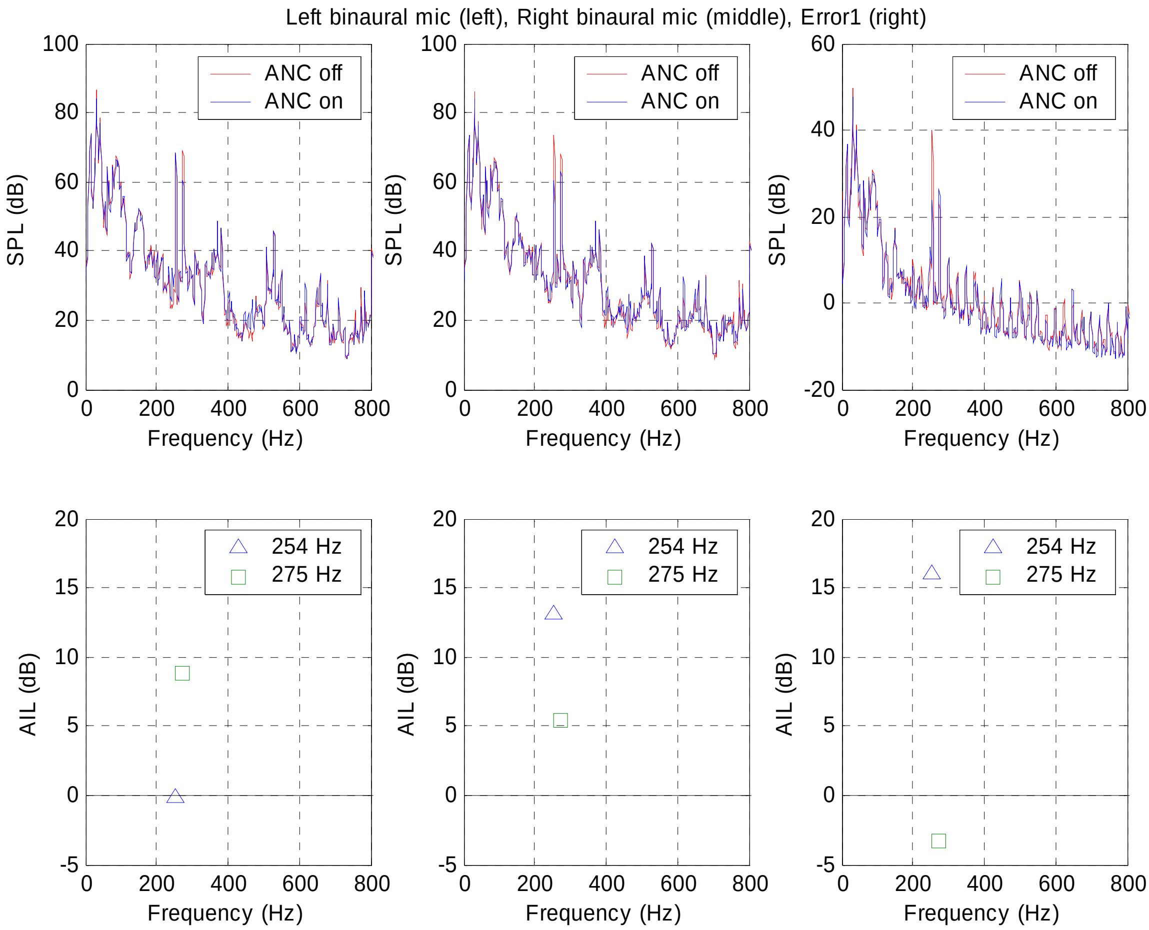

Fig. 3. Active control experiment results at 254 Hz - 275 Hz frequency pair.

To illustrate the system operation, some results are presented in Fig. 3. Figures from left to right present the SPL at left ear, right ear and a system error microphone. Upper figure row presents the narrowband spectrum and lower figure row the relative attenuations at the two frequencies, which were controlled.

The typical attenuation of the periodic noise components is around 5 - 10 dB on the operator ears. Usually the attenuation is much better at the system error microphones, as is in this case at 254 Hz, but at 275 Hz there is an exception. These anomalies are probably due to the complex vibroacoustic behavior of the cabin, which is a small, coupled enclosure.

4. RESULT ANALYSIS AND CONCLUSIONS

Study of two different but simultaneous aspects, sound and ventilation, gave a broad and detailed view of moving machinery cabin noise and ventilation inter-related issues. It became clear, that because the ventilation is one of the most important sources of noise in moving machinery cabins it is beneficial to study these two at the same time. The results achieved made it possible to further improve the cabin interior sound and ventilation quality in pre-determined and controlled manner. In addition, the results show that an optimum for both pressure loss and generated noise in a ventilation system can be found. This knowledge of optimal operating point can be utilized in ventilation system design. Based on these results, several improvements could be suggested to the current design.

Furthermore, the active noise control results showed it to be a feasible tool in diminishing the periodic components and changing the quality of perceived noise in a moving machinery cabin, thus being potential technology for the cabin acoustics improvement, similarly to active noise control in cars. On the other hand, the moving machinery cabin is a complex vibroacoustic system and it may prove challenging to construct such systems for the practical use in real machinery.

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6. REFERENCES

[1] Työkoneiden ohjaamomelun häiritsevyys ja sen vähentäminen, Hanna Järveläinen, Matti Karjalainen, Panu Maijala, Kari Saarinen, Jukka Tanttari, 1998, Otaniemi (Raportti 47)

[2] Työkoneiden ohjaamoilmastoinnin kehittäminen, Matti Lehtimäki, Ilpo Kulmala, Kimmo Heinonen, 1990, VTT Turvallisuustekniikan laboratorio, TSR raportti 88199.

[3] Psychoacoustics and Industry: Instrumentation versus Experience?, Bodden, M, Acustica united with Acta Acustica, vol. 85, no 5. p. 604 - 764607, 1999

[4] Psychoacoustics, E. Zwicker, H. Fastl, Springer, Germany, 1999 (p. 243 - 246)

[5] A Demonstration of Active Noise Reduction in a Cabin Van, Bravo, T., Cobo, P, 2001, Acta Acustica united with Acustica, Vol. 88, 493-499

[6] Active control of multiple tones in an enclosure, Sampath, A., Balachandran, B., 1999, Journal of the Acoustical Society of America, 106(1), 211-225