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STRUCTURE-BORNE SOUND CONTRIBUTION INTO EARTH-MOVING MACHINE CABS

Nickolay Ivanov[1], David Copley[2], Natalia Tyurina[1]

[1]Baltic State Technical University, St. Petersburg, 190005, Russia
[2]Caterpillar Inc., Peoria, IL 61629, USA
noise@mail.rcom.ru

Abstract

The interior sound field of an earth-moving machine cab is formed by air-borne and structure-borne sound contributions. Structure-borne sound is generated by cab panels, which are in turn influenced by vibrations transmitted through cab mounts. These vibrations may originate from the internal combustion engine (i.c.e.) and other sources. Significant sound reduction in cabs may be obtained in machines where effective mounts (vibration isolators) are installed. Similarly, for some machines, higher levels of vibration are noticed at some frequencies, suggesting areas for improvement. Stricter noise emission requirements for earth-moving machines in many countries have initiated further investigations into noise and vibration reduction methods. A special experimental study was carried out in order to separate the air-borne contribution from the total sound field in an earthmoving machine cab, thereby estimating the structure-borne noise contribution. A transfer function for structure-borne noise for the studied cab is presented.

1. INTRODUCTION

Cab noise reduction in earth-moving machines is carried out by considering several fields. The primary air-borne noise control measures are increase of surface mass of can panels, acoustical sealing of openings and apertures, application of sound absorptive materials. Structure-borne noise in a cab may be reduced by increasing of cab vibration isolators' efficiency, or by applying damping treatments to metal cab elements. During the last decade significant noise reduction has been obtained in earth-moving machine cabs. Nowadays average cab noise is in the range 67-75 dBA. Further noise reduction may be achieved when the noise generation processes in machines are studied in greater details. It is important to separate the contributions of structure-borne and air-borne sound. There is no reliable prediction method to separate structure-borne and air-borne sounds in a cab. This paper summarizes the results of an experimental study of the influence of cab subsystem vibration on the cab interior sound field.

2. THE METHODOLOGY OF THE EXPERIMENTAL STUDY

2.1 Airborne noise shield

The principle idea of the method is an experimental separation of structure-borne and air-borne noise contribution to the total sound field inside a cab. In order to accomplish this, a special noise barrier was placed on a hydraulic excavator. The multisided shielding structure was made from 1 mm metal panels covered by 20 mm sound absorbing material. Three panels of the cab (the rear and two side cab panels) located near the enclosure and engine compartment were covered by the shielding elements, which were connected to each other by screws. The shields were well sealed at the edges and contained no openings as is shown in Figure. 1. This shielding structure reduced the propagation of air-borne noise emitted by the engine, hydraulic system, exhaust and intake into the cab.

Figure 1. Setting up of the noise control means.

2.2. Measurement procedure

Two series of measurements were carried out. The goal of the first series was to estimate the noise shield’s insertion loss. This was accomplished with the engine off with an artificial noise source located in the engine compartment. The second series of measurements were carried out to measure the vibration velocity levels of the cab panels while the engine was on. Sound pressure levels (SPLs) and A-weighted sound pressure levels were measured in each series of measurements at two microphone positions inside the cab with and without the noise shield installed.

3. DETERMINATION OF NOISE SHIELD INSERTION LOSS

The shield insertion loss was estimated as a difference between averaged SPL (or A-weighted SPL) in the cab measured with attached shielding structure and when it was removed. The estimated insertion loss is presented in Table 1 and in Fig. 2.

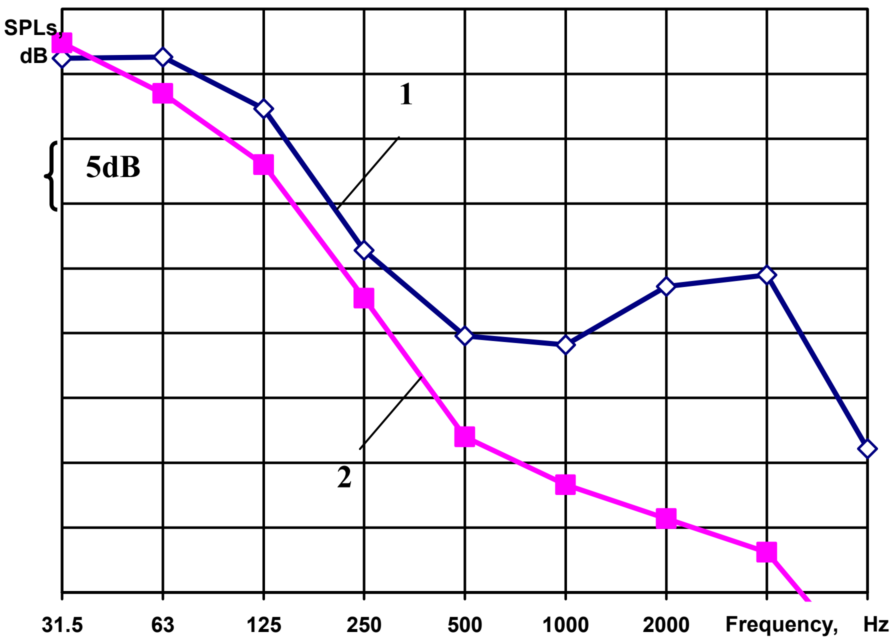

Figure 2. Efficiency of noise control means.
1 – SPLs without noise control means;
2 – SPLs when noise control means are attached.

The airborne noise shield provides noise reduction in the wide frequency range (63-8000 Hz). Insertion loss is about 3-8 dB in the low frequency range and about 11-21 dB in the high frequency range. The A-weighted insertion loss is 8 dBA. It is concluded that the application of an elaborated shielding structure provides significant air-borne noise reduction in the cab.

Table 1. Average insertion loss of elaborated noise control means

Insertion Loss, dB, in octave frequency bands, Hz									dBA
31,5	63	125	250	500	1000	2000	4000	8000	
-1,2	2,8	4,3	3,7	7,8	10,8	17,9	21,4	17,2	8,3

4. SEPARATION OF AIR-BORNE NOISE CONTRIBUTION IN CAB USING THE NOISE SHIELD

The difference of sound pressure levels measured in cab with and without the shield is presented in Table 2 (engine rpm=1500).

Table 2. Difference in cab noise levels measured
with and without the airborne noise shield (engine rpm=1500)

Insertion Loss, dB, in octave frequency bands, Hz									dBA
31,5	63	125	250	500	1000	2000	4000	8000	
8,0	0,8	2,4	2,5	6,8	10,3	15,3	20,6	15,5	5,6

A comparison of data presented in Table 1 and Table 2 shows that the noise shield is still efficient even if the machine engine is on. Significant noise reduction (8 dB at 31.5 Hz) may be explained by the air volume excitation at this frequency band. The reduction of insertion loss by 1-2 dB in the frequency range from 63 Hz to 250 Hz may be explained by the structure-borne noise influence in this frequency range. Insertion loss reaches 7-20 dB in the frequency range of 500-8000 Hz and is due to the absence of vibration effect on cab noise generation mechanisms in this frequency range.

Thus, the main conclusion of this experiment is the dominant structure-borne noise influence on the total cab noise is in the 63 Hz octave frequency band, with comparable contributions of the air-borne and structure-borne noise in the frequency range of 125-250 Hz.

5. STRUCTURE-BORNE NOISE AND AIR-BORNE CONTRIBUTION SEPARATION

Structure-borne cab noise is emitted by vibrating cab elements (ceilings, windows, doors, etc.). The relative contribution of a given panel to the interior sound field depends on its vibration velocity level, the panel area and the coefficient of sound radiation. To simplify the problem, it is assumed that the areas of all panels and coefficients of sound radiation by metal and glass surfaces of the cab are similar. In this case the structure-borne cab sound pressure levels depend on the vibratory velocity level only. Analysis of vibratory velocity levels measured at cab panels shows that trends of vibration distribution at all panels are similar (deviation is about ± 3dB). This allows us to summarize the levels using an energy summation principle in order to obtain the average cab vibratory levels. The measured average vibration levels in octave frequency bands are called the vibration criterion at cab panels (Table 3). The developed vibration criterion may be used for approximate prediction of structure-borne noise in a cab.

It is assumed that sound pressure levels measured in a cab when the noise shield is installed represent only structure-borne noise. In this case, air-borne noise is negligible. One exception shall be made for frequency band of 31.5 Hz where experimental results are significantly influenced by oscillations of the air volume.

Table 3. Vibration criterion of the cab

Vibratory velocity levels, dB, in octave frequency bands, Hz						
31,5	63	125	250	500	1000	2000
83	86	74	76	64	48	43

The cab transfer function is the dependent upon the structure-borne sound pressure levels inside the cab (vibration criterion) on the vibratory velocity levels at cab panels. Example of developed transfer function is presented in Fig. 1.

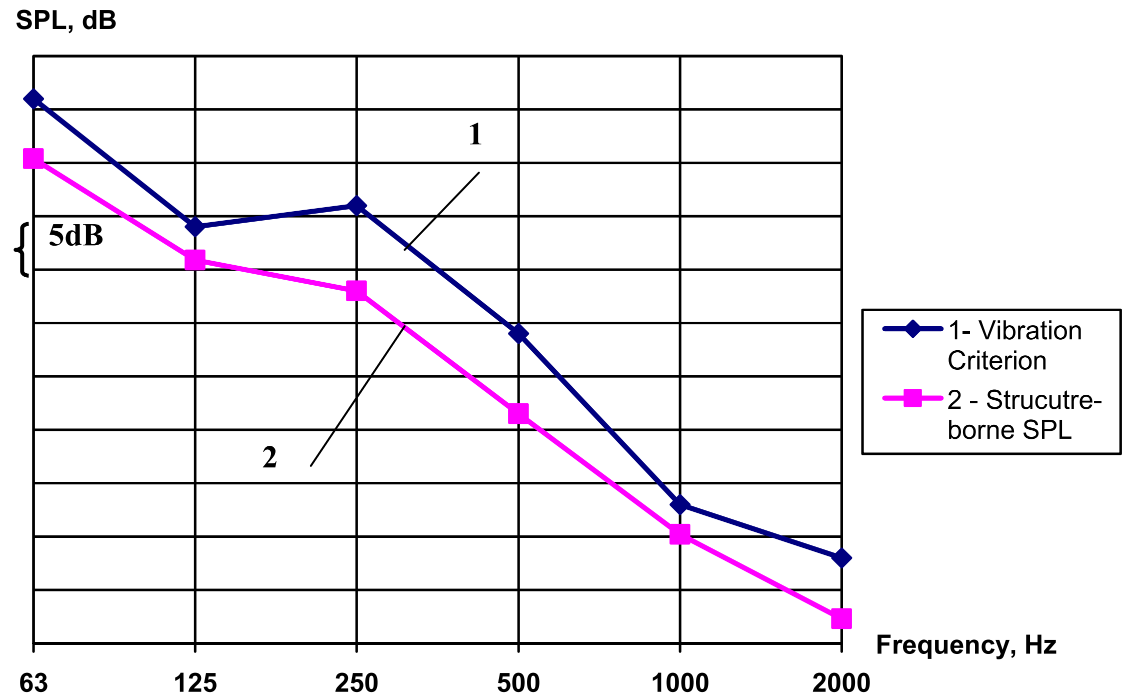

Figure 3.Transfer function representing the effect of cab panels' vibration level on the structure-borne sound pressure level in the cab
1 – vibration criterion (average cab panels' vibratory velocity levels)
2 – averaged sound pressure levels (SPL) in cab (rpm=1500).

The average cab panel vibration level for the 63 Hz octave band is 6 dB above its structure-borne contribution to the cab sound pressure level. Similarly, the difference in vibration criterion and sound pressure level for the 125 Hz octave band is 3 dB and at 250 Hz 10 dB.

These results may be used in practice as follows: if a given cab panel vibration level is measured in the fashion described, then its approximate structure-borne sound contribution may be estimated by using the elaborated transfer function.

6. CONCLUSIONS

An elaborate noise shield provides reduction of the air-borne cab noise by 3-21 dB in the frequency range of 125-8000 Hz and allows structure-borne noise separation. Structure-borne noise significantly influences total cab noise in the octave frequency band with a geometrical mean frequency of 63 Hz and has comparable contributions with the air-borne noise in the frequency range of 125-250 Hz. An approximate transfer function representing the effect of the cab elements' vibration level on structure-borne cab noise is found.

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