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Double Panel Structure for Active Control of Noise Transmission

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Passive noise reduction means are commonly used to reduce noise in the industry but, unfortunately, their effectiveness is poor in the low frequency range. By applying active structural acoustic control to the enclosure walls significant improvement of the insulating properties in this frequency range can be achieved. In this paper a model of double panel structure with ASAC is presented. The structure consists of two aluminium plates separated by an air gap. Two inertial magnetoelectric actuators and two piezoceramic MFC sensors were used for controlling the structure. A multichannel FxLMS algorithm with virtual error microphone technique is used as a control algorithm. The signal of a virtual error microphone is extrapolated basing on signals from MFC sensors. Performance of this actively controlled structure for tonal signals at selected frequencies is presented in the article. During the study, a double panel structure was mounted on one wall of sound insulating enclosure located in an acoustic chamber. During the measurements local and global reduction of noise test signal was investigated.

Keywords: noise; sound insulating enclosure; active structural acoustic control; virtual microphone.

1. Introduction

Exposure to excessive noise in a working environment (Koradecka, 2010; Crocker, 1998) can be harmful to hearing causing permanent hearing loss (Hansen, 2005). Sound insulating enclosures widely used in industry for noise reduction have poor effectiveness in low frequency range. This can be improved by increasing mass and dimensions of the enclosure, which is unacceptable in many applications. Reduction of noise transmitted through enclosure walls can be also obtained by actively controlling of vibrations of enclosure components. In the so called active structural acoustic control (ASAC) (Pietrzko, 2009; Wrona, Pawełczyk, 2016; Carneal, Fuller, 2004) different control algorithms have been used, including the well known LMS algorithm and its modifications (Hansen *et al.*, 2012; Kuo, Morgan, 1995), as well as neural networks (Morzyński *et al.*, 2016). In the ASAC various types of signal sensors, including microphones, MFC, or PVDF sensors can be used. Usually, MFC piezoelectric patches or magnetoelectric inertial actuators have been used as control actuators. In the recent studies ASAC of single (Wrona, Pawełczyk, 2013; Mazur, Pawełczyk, 2013) and double (Pietrzko, 2009; Wrona, Pawełczyk, 2016; Carneal, Fuller, 2004; Jakob, Möser, 2003a; 2003b; Hansen *et al.*, 2012; Pietrzko, Mao, 2008; Ho, Berkhoff, 2014) panel structures with panels made from different materials like aluminium (Mazur, Pawełczyk, 2013), steel (Wrona, Pawełczyk, 2016), or glass (Jakob, Möser, 2003a; 2003b; Pietrzko, Mao, 2008; Morzyński *et al.*, 2016) have been described.

In this article construction and performance in laboratory conditions of a double panel structure with ASAC are described. The control strategy of the structure is based on the FxLMS algorithm (Hansen *et al.*, 2012; Kuo, Morgan, 1995) and virtual error microphone technique.

2. The double panel structure

The basic scheme of the investigated double panels structure as well as some of its construction details are presented in Figs. 1 and 2. This structure consists of two aluminum 2 mm thick plates mounted on a rigid frame (Fig. 1b). The panels of the structure are separated by a construction frame, which is 25 mm deep, and clamped by mounting frame to the steel plate forming one of the sound insulating enclosure walls.

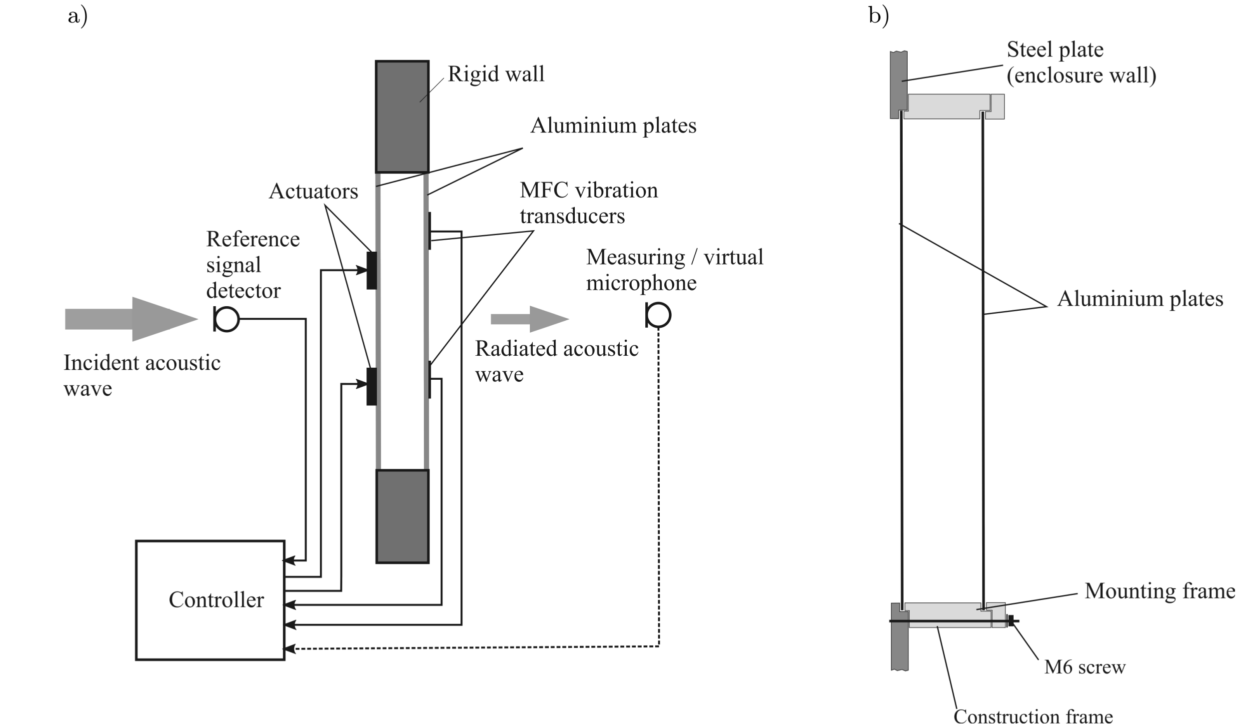

Fig. 1. Scheme (a) and construction details (b) of a double panel structure with ASAC.

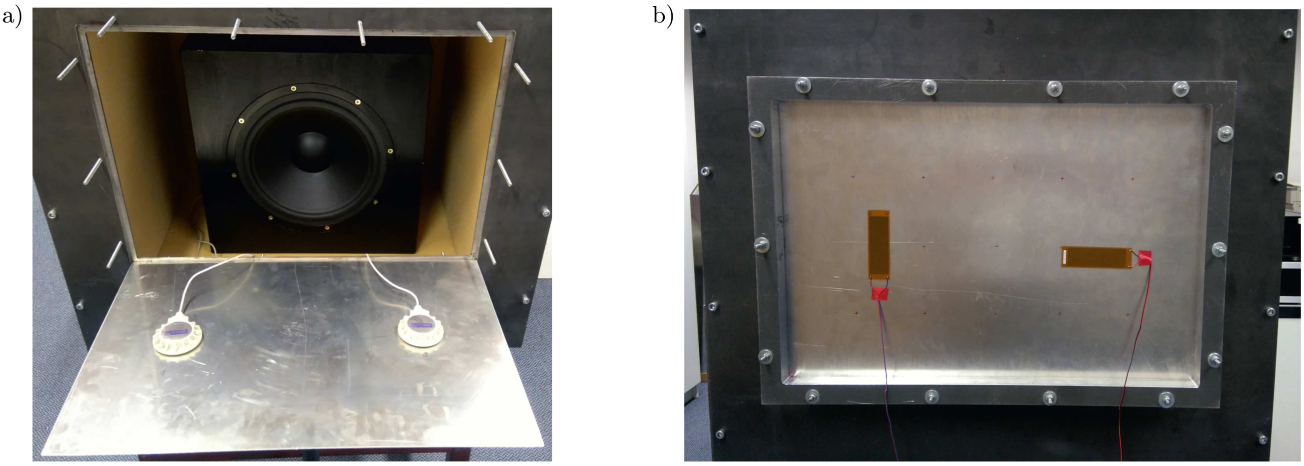

Fig. 2. Double panel structure with ASAC: the incident panel with inertial actuators (a) and the external panel with MFC error sensors (b).

On the incident panel (a panel on the noise source side, enclosure's inner side) of the structure two or three (depending on the experiment) inertial magnetoelectic actuators of the Monacor EX-1 type were mounted (but only two of them were used for controlling vibrations of the structure). On the radiating panel (a panel on the enclosure's outer side) of the structure two piezoceramic MFC 8528-P2 type transducers produced by Smart Materials were glued (Fig. 2b). They were used as error signal sensors.

The diagram of the implemented control algorithm is presented in Fig 3. This algorithm is a multichannel FxLMS algorithm with virtual error microphone technique. The ASAC of panel structures performs better when microphone is used as an error sensor. But the use of an outer microphone in practical solutions in many cases will be inconvenient. In the implemented virtual error microphone technique a signal from the virtual error microphone is extrapolated basing on the error signals from MFC sensors. The use of a virtual error microphone requires determination of the transfer function of extrapolation filters $\widehat{A}_i(z)$ which are the estimates of the transfer functions between the MFC error sensors and virtual error microphone placed at the observation point, $A_n(z)$. That is why the first stage of the implemented algorithm is to identify the transfer functions of $\widehat{A}_i(z)$ filters. Parts of the ASAC system involved in this stage are shown in Fig. 3 in grey. For

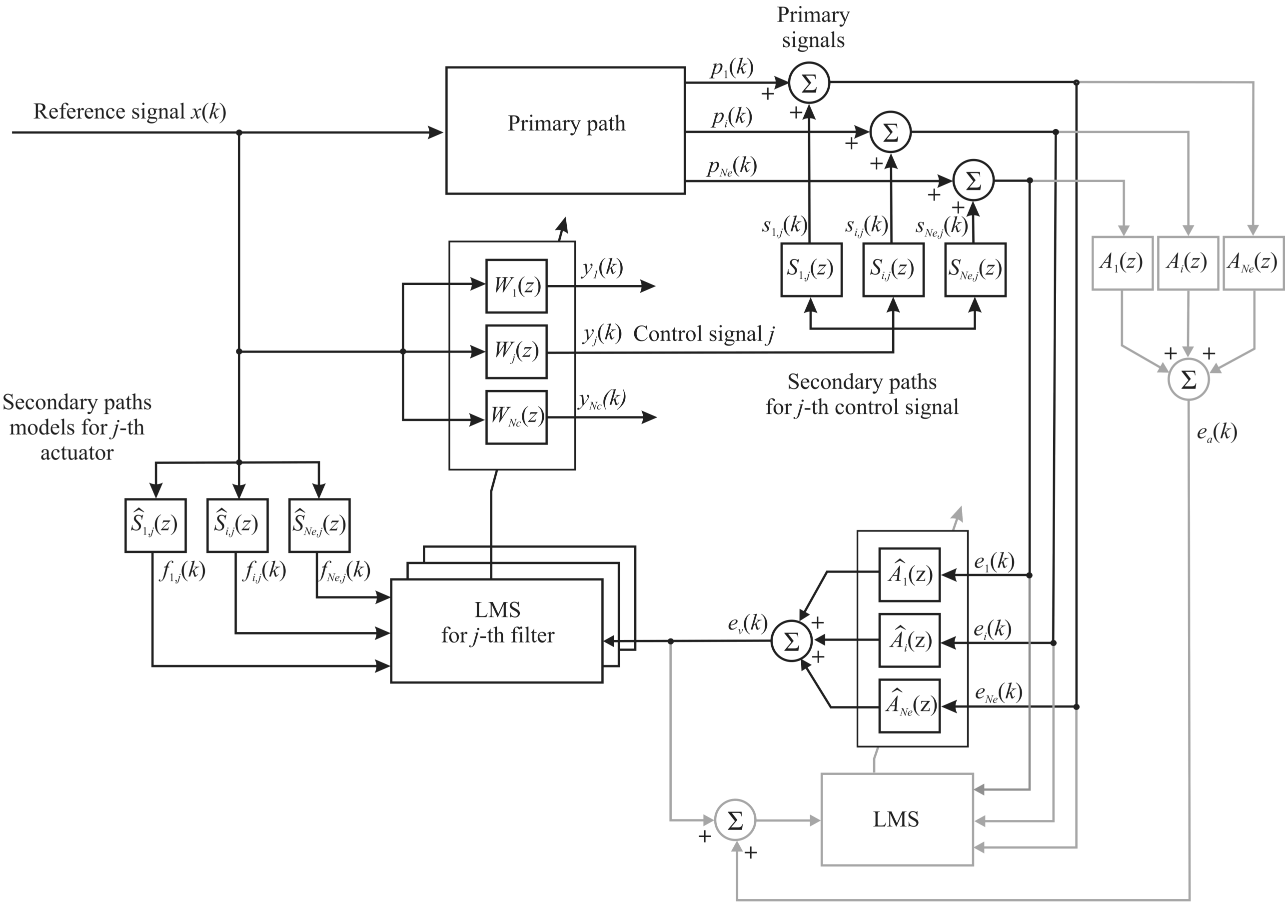

Fig. 3. Active noise reduction algorithm: grey – extrapolation filters identification stage, black – active control stage.

this purpose a real microphone (Røde NT55) placed in the observation point located at a distance of 30 cm from the panel was used.

After determining the transfer functions of extrapolation filters a process of identifying the secondary signal paths $S_{i,j}(z)$ and determination of their estimates $\widehat{S}_{i,j}(z)$ necessary for the proper operation of the algorithm FXLMS is initiated (Hansen *et al.*, 2012; Kuo, Morgan, 1995). After completing these steps, the actual process of active structure control, in which the error signal is extrapolated from the virtual microphone error signal, begins. The controller on which the control algorithm was implemented is based on an OMAP L-128 evaluation board completed with A/C and C/A converters board.

An important issue in the ASAC of panel structures is optimal placement of actuators and error transducers (Wrona, Pawełczyk, 2013; Clark, Fuller, 1992). In this study, actuators and error transducers have been placed in regions with highest displacement amplitudes of the vibrating panel. The regions of highest displacement amplitudes corresponding with regions of the highest sound intensities were determined with the use of near field acoustic holography (acoustic camera). The results of preliminary tests of the structure were described in conference proceedings (Morzyński, Krukowicz, 2016).

3. Experimental results

The performance of a double-panel structure with ASAC was investigated during laboratory experiments. In Fig. 4 the block diagram of the experimental setup is presented. The sound insulating enclosure with a double panel structure under tests were placed in the acoustic chamber that is a semi anechoic chamber with high isolation from environmental noise and short (below 0.2 s) reverberation time (time to decay by 60 dB) for frequencies over 60 Hz. In the block diagram the elements of the double panel structure with ASAC are shown in grey. During the experiments the structure was excited using the acoustic signal from a loudspeaker placed inside the enclosure. The sound pressure level of the signal in the observation point was determined using a 1st class integrating sound level meter. Distribution of the sound intensity of sound signal radiated by the structure was investigated with the use of an acoustic camera with the Paddle 2×24 AC Pro microphone matrix.

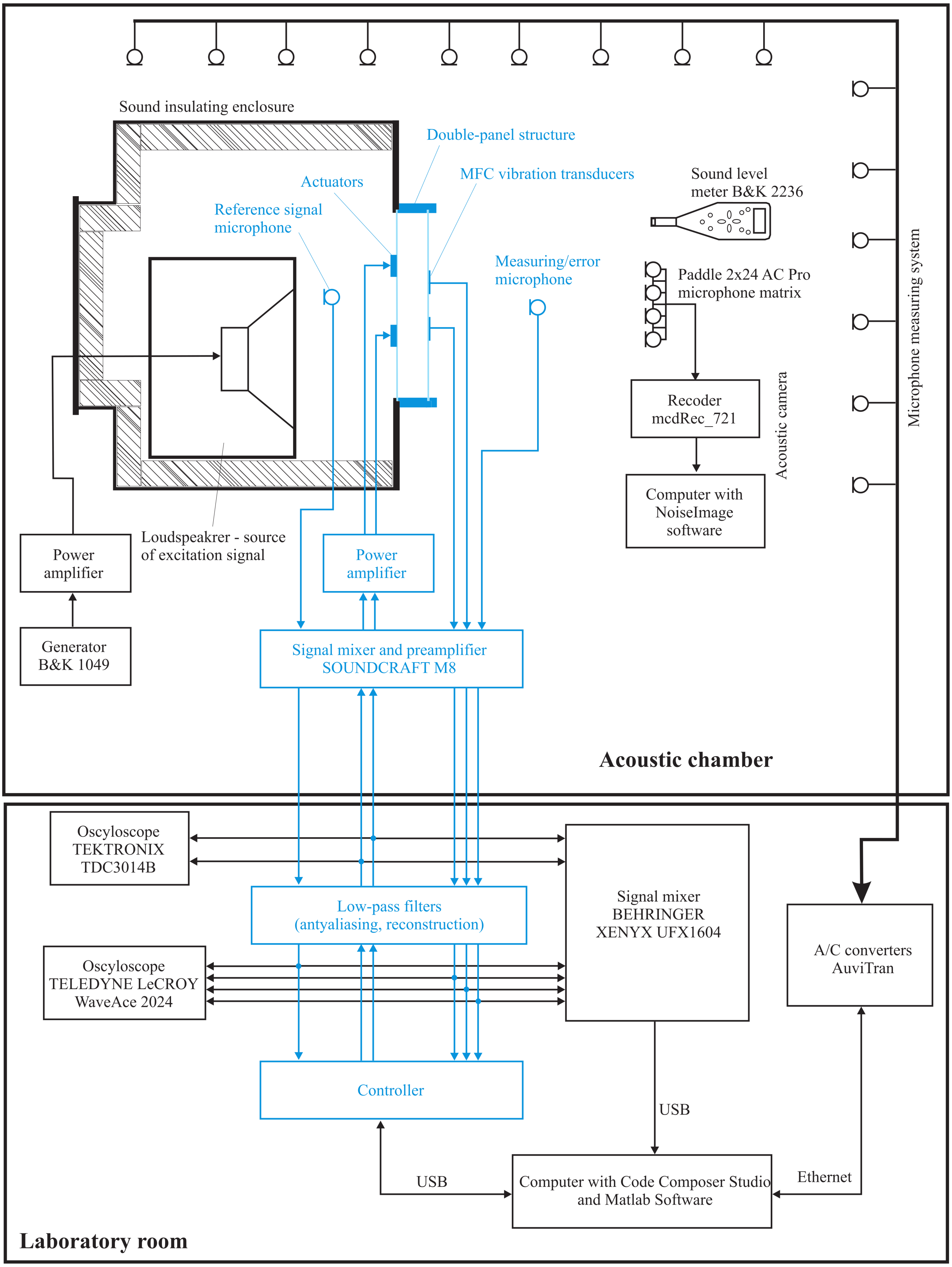

Fig. 4. Block diagram of the experimental setup.

The sound pressure levels of the transmitted through the structure and enclosure signal in an acoustic chamber were measured using a microphone measuring system of the chamber. It consists of 80 microphones placed on chamber walls, ceiling, and in a circle around sound insulating enclosure. Oscilloscopes and Behringer signal mixer with a sound card were used for observation and recording of signals in ASAC system. The recorded signals were processed in Matlab software.

Studies of the structure with ASAC were carried out for tonal excitations with frequencies selected from the range of 20 Hz to 500 Hz. Selected signal frequencies were resonant frequencies of the structure (for which sound radiation through the structure is greater) and, in addition, arbitrarily chosen other frequencies. First, to determine resonant frequencies of the structure, a structure without actuators and transducers was excited by a frequency modulated (chirp) acoustic signal of frequencies from 20 Hz to 500 Hz. Using FFT analysis and acoustic camera resonant frequencies and vibration modes were determined as well as the sound intensity distribution over the panel surface (which corresponds to the plate vibration displacement distribution). Then actuators and vibration transducers were placed in two plates area with the highest displacement, as their frequencies radiated by the plate sound have the highest SPL. For the frequencies about 200 Hz, halves of the plate vibrate in the opposite phase and regions of the highest plate vibration displacements were located in the middle of the plate's halves. After the actuator and transducer's placement, the structure response to chirp excitation was analysed again. The spectrum of this response is presented in Fig. 5.

Basing on the structure frequency response basic excitation frequencies of 70, 125, 150, 165, 200, and 310 Hz were selected. 100, 250, 350, 400, and 450 Hz were selected as additional frequencies. The excitation signals' amplitudes were chosen so that SPL of the excitation signal in the plane of an open enclosure frame (without double panel structure) was 105 dB. During the conducted research the step size of the adaptation algorithm was selected experimentally.

At first, the effectiveness of the active control, defined as SPL differences of acoustic signals measured at the observation point before and after ASAC system was turned on, was investigated for the excitation signal with frequency of 200 Hz. For this frequency regions of the highest vibrations displacements correspond to actuators/transducers' mounting places (Fig. 6). The active control achieved the effectiveness of 27 dB. Figure 7 presents the distribution of the effectiveness of the active control over the acoustic chamber (the number of measuring microphones is given in grey and the corresponding values of effectiveness are given in black, in frames). This shows that the reduction of acoustic signal was global and in most regions of the chamber is between 10 and 20 decibels.

For the structure with two actuators, stable operation of ASAC system of the acoustic signal was achieved also for excitation frequencies of 250 Hz, 310 Hz, and 390 Hz. The effectiveness of active reduction measured in the observation point was 3.4 dB for 250 Hz, 1.5 dB for 310 Hz, and 11 dB for 390 Hz. For other signal frequencies ASAC system was unstable or effectiveness of active reduction was negligible. For the abovementioned frequencies active reduction mostly has a local character and distribution of the effectiveness of the active reduction inside the acoustic chamber is uneven. In Fig. 8 distribution of effectiveness of the active reduction in a circle around enclosure for frequency 390 Hz is presented. For this frequency, the effectiveness at most measuring points was negative, which means that the active control increased the sound pressure level around the enclosure although it was reduced in the observation point by 11 dB.

In the next stage of the experiment an additional actuator was added in the center of the incident plate. This was because in some modes of vibration of plates

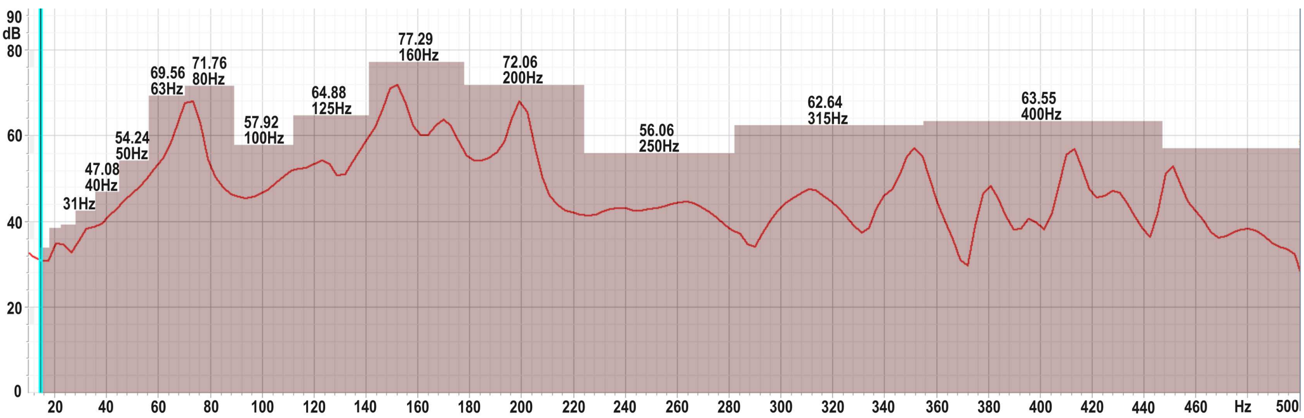

Fig. 5. Spectrum of the double panel structure response to chirp signal excitation.

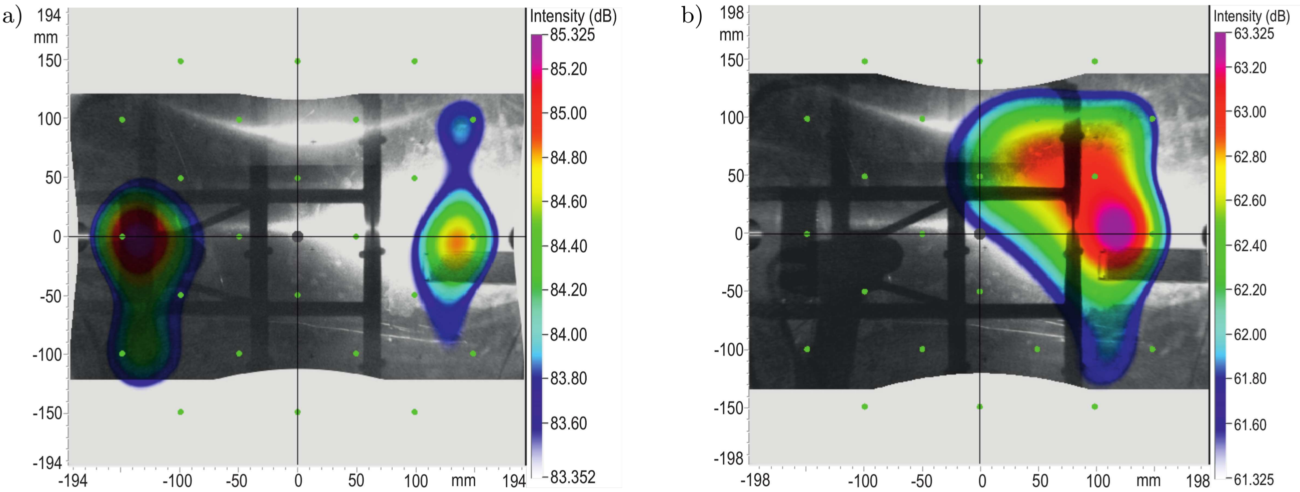

Fig. 6. Sound intensity levels and its distribution over the structure plate surface before (a) and after (b) ASAC system turned on.

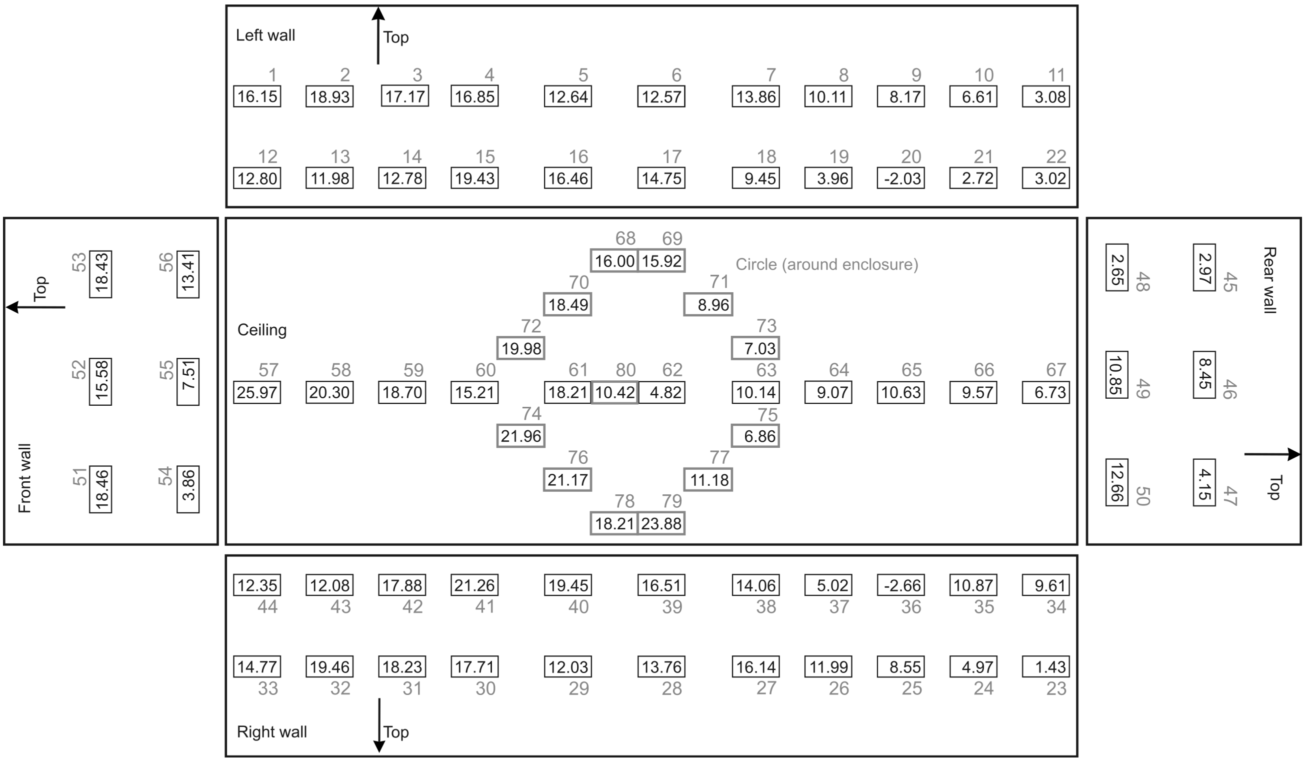

Fig. 7. Distribution of the effectiveness of active control for excitation signal of frequency 200 Hz in the acoustic chamber (in dB).

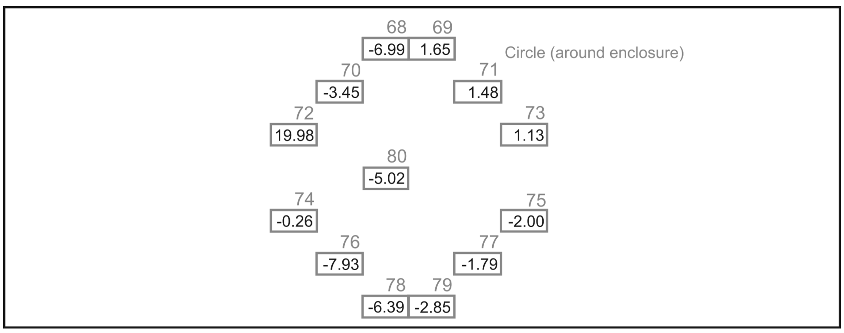

Fig. 8. Distribution of the effectiveness of active control for excitation signal of frequency 390 Hz in the circle around the sound insulating enclosure (in dB).

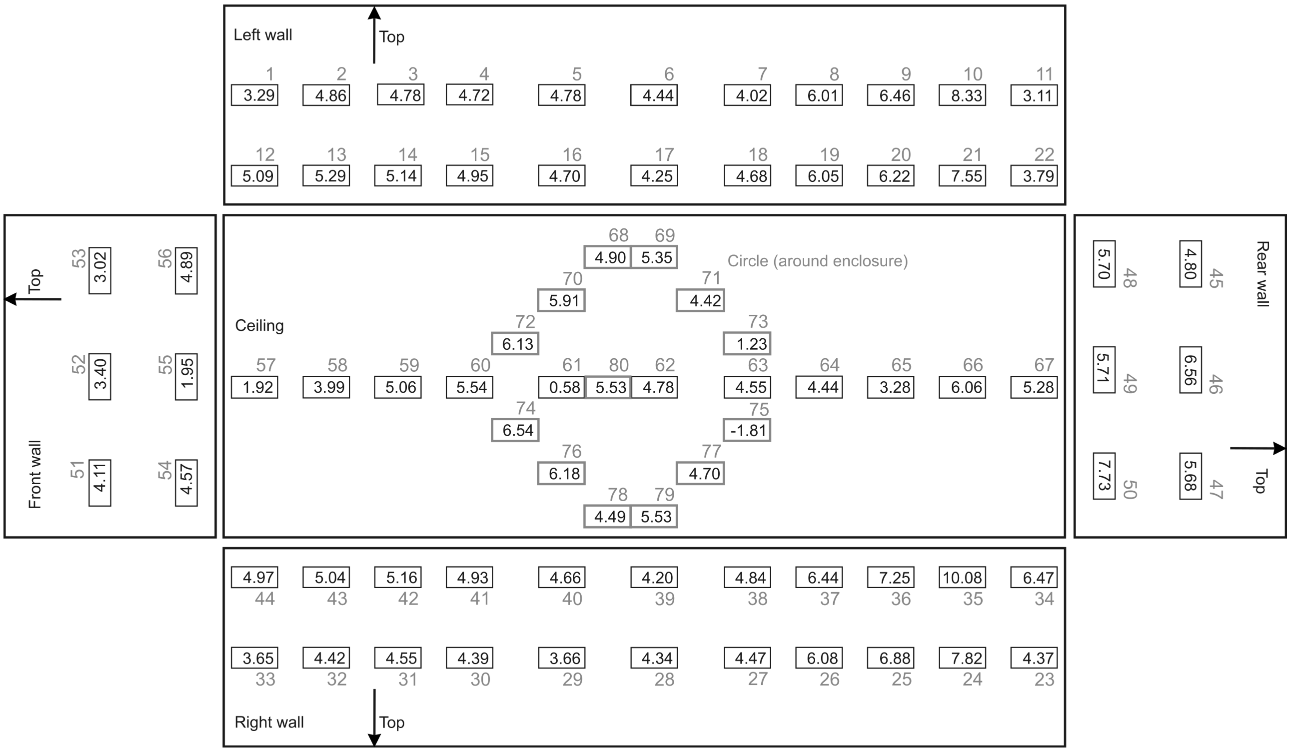

Fig. 9. Distribution of the effectiveness of active control for excitation signal of frequency 70 Hz in the acoustic chamber (in dB).

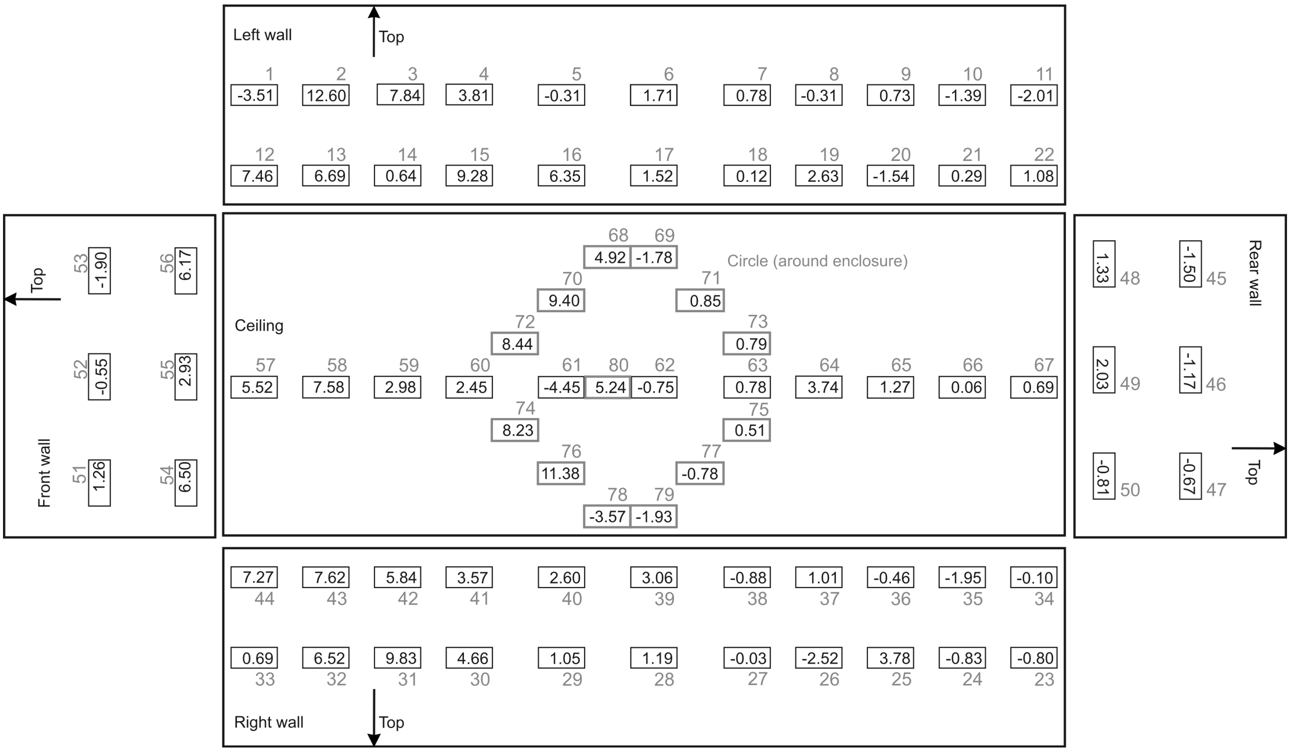

Fig. 10. Distribution of the effectiveness of active control for excitation signal of frequency 450 Hz in the acoustic chamber (in dB).

the region of maximum vibration displacement was in the centre of the plate or close to it. During the experiments only two actuators were used – the central and the left ones.

For these actuators arrangement, active reduction of acoustic signal was achieved for the excitation signal frequencies of 70 Hz, 165 Hz, 350 Hz, and 450 Hz. The effectiveness of active reduction in the observation point was, respectively, 6.3 dB, 5.8 dB, 3.8 dB, and 11.7 dB. The reduction of acoustic signal was global but the distribution of effectiveness over the acoustic chamber was uniform for 70 Hz (Fig. 9) and uneven for other frequencies (Fig. 10). These differences result mostly from the sound radiation pattern of the structure mounted in the enclosure for different frequencies.

4. Conclusions

Low frequency noise reduction is a common problem in working environment. The results of the research presented in this paper show that double panel structure can be an effective solution for this problem in case of noise with strong tonal components. The proposed control strategy with the virtual error microphone signal obtained basing on signals from vibration sensors works well and allows to achieve high low frequency signal reduction, up to 27 dB. A proper arrangement of actuators and vibration sensors on the structure plates taking into account vibration displacement distribution on the structure plates is of great importance for the effectiveness of the ASAC system. Application of the developed double panel structure with ASAC in the sound insulating enclosures or other partitions can be effective means for low frequency noise reduction.

Acknowledgments

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