

Technical Note

Variable Sound Insulation Structure with MFC Elements

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Additional sound sources are used as actuators in the vast majority of active noise reduction systems. One of the possible opportunities to extend the field of applications of active noise reduction systems is using active structures of variable sound insulation. The paper presents an analysis of ways of reducing noise with a structure of variable sound insulation consisting of a metal plate, active elements (Macro Fiber Composite), and a control system. The paper presents results of acoustic radiation simulations and measurements of sound intensity generated by the structure under the influence of stimulation by an acoustic wave. Simulations of mechanical vibrations and acoustic radiation for the plate were performed with the finite element method and ANSYS software. Simulation results made it possible to select locations for gluing the active elements and sensors. Analyses of the sound pressure level in the space to which the plate is radiating made it possible to determine dominant frequencies in the characteristics and, as a result, indicate vibration modes that can be reduced. Sound intensity measurements were performed with a three-way probe of USP mini Microflown. Results of simulations and measurements show that it is possible to achieve an improvement of the insulating power of a metal plate by approx. 10 dB.

Keywords: sound insulation, active noise reduction, MFC.

1. Introduction

Active methods of noise reduction are a dynamically developing area of science in which additional, appropriately controlled sources of vibroacoustic energy (ENGEL *et al.*, 2010) are used to reduce unwanted low frequency noise. Correct selection of executive elements acting as the aforementioned additional sources of energy to a great extent decides on the usefulness of those methods and their practical applicability (DE FONSECA *et al.*, 1999; FRADEN, 2004; KOZIEŃ, WICIAK, 2003). A definite majority of active noise control (ANC) systems use additional sources of noise in the form of loudspeakers as executive elements. A possible way of extending the applicability of ANC systems is the use of active structures of variable sound insulation as executive elements (KOZUPA, BATKO, 2008; STANIEK, PAWEŁCZYK, 2008; MAZUR, PAWEŁCZYK, 2011). Active structures of variable sound insulation

signify systems of materials that change their noise reduction capabilities under the influence of the energy conducted to them. They usually comprise one or more layers of traditional passive materials of specific damping and sound insulation characteristics, and of intelligent materials (piezoceramic active elements) (KOZUPA, BATKO, 2008; MAKAREWICZ, 2005; PIETRZAKOWSKI, 2006). Such a structure features specific noise damping and sound insulation; nevertheless, after conducting energy to intelligent materials and executing appropriate control of them, they may affect passive materials (e.g. by specific vibrations, change of geometry or change of the elasticity module) and thus change the acoustic properties of the entire structure in a desired manner. The article presents an analysis of noise reduction capabilities with the application of a structure of variable sound insulation, a so-called active structure. In the case described, results of an active structure sound insulation improvement for a tonal sig-

nal of known frequency of 150 Hz are presented. It was assumed that an active structure comprised a brass plate of the dimensions of 240 mm × 300 mm and thickness of 0.5 mm, an MFC converter (Macro Fiber Composite) M-8528-P2 by Smart Material of the dimensions of 106 mm × 34 mm, and a control system (Fig. 1).

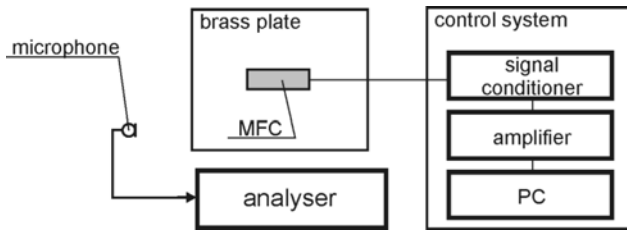


Fig. 1. Model of the active structure of variable sound insulation.

The primary element of the control system was a PC provided with an A/D and D/A LC-1-015-1622 converter card by Egmont Instruments, a pre-amplifier, and an analogue system UPS. Signal from the PC was amplified by an STA 1508 end amplifier by Stage Line and sent to the signal conditioner. The signal conditioner was a design made especially to control active elements in the form of MFC converters. This type of device was used because a complete setting of MFC converters required high voltage signals from -60 to $+360$ V. Moreover, correct operation of these elements required initial polarisation with positive voltage within the range from 0 to 210 V; otherwise, distortion of the secondary signal was possible. Structure elements also included a measurement microphone and an analyser, as the frequency, amplitude and phase offset of the compensation signal (sent to the MFC converter) were adjusted on the basis of their readings. The measurement microphone was placed in the axis perpendicular to the structure, passing through its geometric centre and placed 0.5 m away from its surface. Controlling an MFC converter and, consequently, a change of sound insulation of the active structure involved manual selection of the values of frequency, amplitude and compensation signal phase in a manner assuring that the sound pressure level recorded by the measurement microphone was as low as possible.

The article presents the results of acoustic radiation simulations and measurements of the intensity of the noise generated by the structure when excited with an acoustic wave. Simulation of the plate vibrations and acoustic radiation was conducted by means of the method of finite elements and the ANSYS program. Results of a harmonic analysis of the plate vibrations made it possible to define placements of active elements and identify reducible vibration modes. The analysis of the plate acoustic radiation enabled determining the dominant radiation frequencies and

identifying corresponding plate vibration modes reducible with active methods. Measurements of noise intensity were conducted with a USP mini Microflown tri-directional probe.

2. Simulation tests

Due to a complicated design and a high cost of structures of variable sound insulation, an exhaustive knowledge is required at the stage of designing active noise reduction systems to enable estimation of the operating effectiveness of the systems in actual conditions. Computer modelling and simulation tests are a way of solving this problem. In this study, a structure of variable sound insulation was modelled in the ANSYS Multiphysics calculation environment. The software enables integrating the structure design model with the surrounding acoustic volume (ambient air) and allows observing the interaction between the structure and the ambient air.

The structure comprised a brass plate of the dimensions of 300 mm × 240 mm and an MFC converter acting as a source of a compensation signal. The structure, rigidly fixed at the edges, was excited with a flat acoustic wave of the pressure of 2 Pa. By selecting the voltage level and the phase angle of the signal controlling active elements, the radiated acoustic energy of the plate was analysed. Minimisation of the acoustic radiation was the criterion used in selecting the signal controlling the MFC elements. After a correct level and phase angle of the voltage fed to the active element had been selected, the plate vibrations and the emitted acoustic energy with the active elements feeding on and off were analysed.

The ANSYS calculation environment makes the following assumptions regarding the acoustic part of the model:

- The medium is compressible; if pressure changes, so does density.
- The medium is not inviscid; there is no viscotic damping.
- Air mean density and pressure are fixed for the entire liquid.
- Continuity and homogeneity of the medium are assumed.
- Excellent liquidity and elasticity are assumed; the medium cannot feature stresses tangential to the shift direction and, after taking away external forces, the medium returns to its original condition.
- There is no internal thermal inertia and thermal conductivity.

Harmonic analysis also solves the equation of motion depending on the time of linear structures subject to steady vibrations.

Assumptions and limitations:

- Weight, rigidity, and damping of the structure are fixed.
- Exciting force and shift change sinusoidally, both with the same known frequency.
- Exciting force has the real part only, except for the current.

The examined structure brass plate was digitized with $8 \times$ SOLID45 node elements with three levels of freedom: UX, UY and UZ. The digitization grid put on the plate divided it into 14,400 finite elements of the dimensions of $5 \times 5 \times 0.1$ [mm]. The MFC converter was digitized with $8 \times$ SOLID5 node elements with four levels of freedom: UX, UY, UZ and VOLT. The digitization grid put on the converters divided it into 432 finite elements of the dimensions of $5 \times 5 \times 0.1$ [mm].

The acoustic space into which the vibrating plate radiates was digitized with $8 \times$ FLUID30 node elements with four levels of freedom: UX, UY, UZ and PRESS. The digitization grid applied divided the space into 43,200 finite elements of the dimensions of $5 \times 5 \times (8-82)$ [mm].

During the simulation cases of different location of the active element and different types of the exciting signal were analysed. The results of a harmonic analysis made it possible to define placements of active elements and sensors and identify reducible vibration modes. Figure 2 shows an example of the dis-

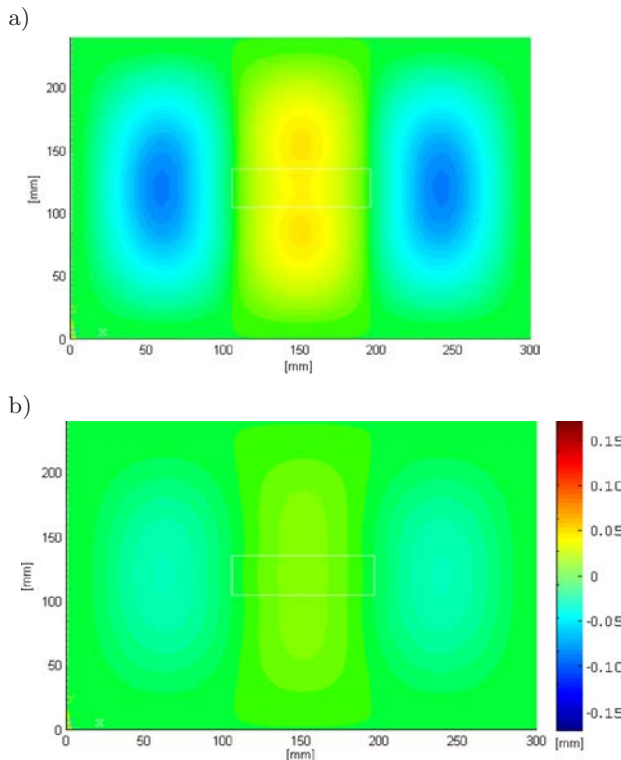


Fig. 2. Vibration modes of the active structure for 150 Hz; a) ANC system disabled, b) ANC system activated; [mm].

tribution of vibration amplitudes on the surface of the structure before and after the activation of the ANC system. Both cases clearly show vibration modes and their significant reduction after the activation of the ANC system. An analysis of the sound pressure level in the space to which the plate emitted made it possible to identify dominating noise frequencies reducible with active methods (Fig. 3). By analysing the distribution of acoustic pressure around the emitting structure, it is possible to define the areas of the plate whose reduction will provide greatest results.

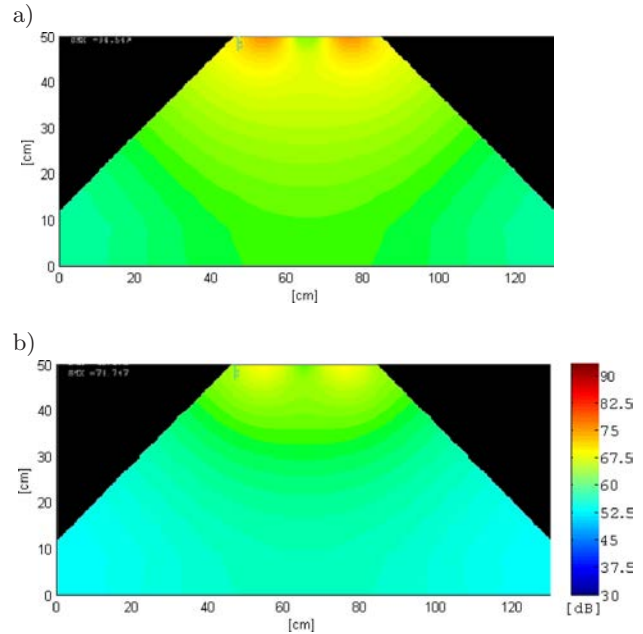


Fig. 3. Acoustic radiation of the active structure for frequency 150 Hz; a) ANC system disabled, b) ANC system activated; [dB].

3. Laboratory measurements

Simulation results were verified on the basis of laboratory tests (Fig. 4). The tests were conducted with an acoustic waveguide at the beginning of which a sound

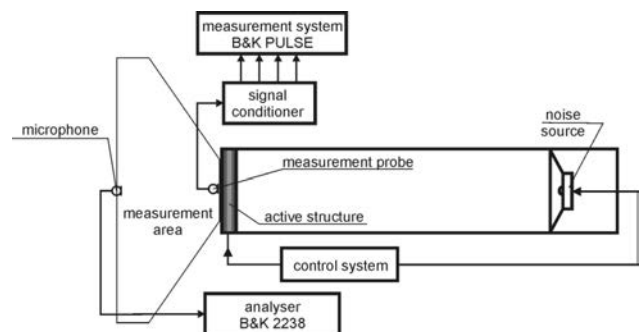


Fig. 4. Diagram of the laboratory stand.

source (loudspeaker) was installed. The length of the acoustic waveguide was 200 cm, and its cross section was a square with 40 cm long sides. The inside of the waveguide was coated with a 5 cm thick layer of foam. At the end of the acoustic waveguide a brass plate with an active element of the structure of variable sound insulation was installed.

The active element, in the form of an MFC piezolaminate, was controlled via a control system called ANC system. At the same time and with the same control system an acoustic signal in the form of a tone of the frequency of 150 Hz was generated. Amplification of the signal was selected in a manner ensuring that at the measurement point located on a straight line perpendicular to the plate, passing through its geometric centre and placed 0.5 m away, the measured sound pressure level was equal to the level from the simulation. The measurements were taken at a distance of 4 mm from the surface of the active structure, recording the distribution of the acoustic velocity and acoustic pressure, and within the measurement area (see Fig. 4) recording the sound pressure level. The measurement area corresponded with the area modelled in the simulation tests.

Measurements of the acoustic velocity and acoustic pressure in the vicinity of the plate surface were taken with a USP mini Microflown tri-directional probe (Fig. 5). The probe directly measures the acoustic velocity in three dimensions, as well as acoustic pressure, thus enabling determination of the noise intensity vector (DONADON, 2005; WEYNA, 2005).

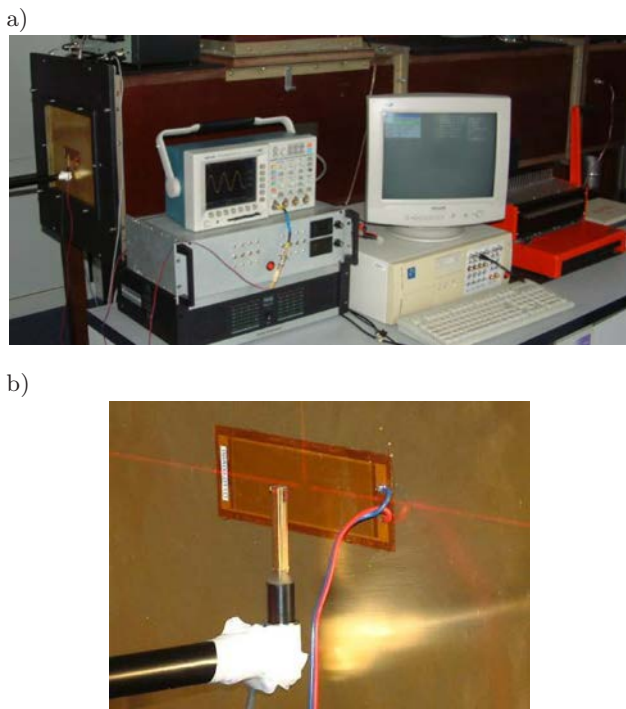


Fig. 5. Laboratory stand; a) general view, b) measurement probe and MFC converter.

Figure 6 shows the distribution of the values of the acoustic velocity on the surface of the examined structure. The values of the acoustic velocity are convergent with the simulatory harmonic analysis presenting the distribution of the structure vibration amplitudes (Fig. 2). It shows areas of a greater acoustic velocity convergent with the distribution of the vibration modes. Activation of the ANC system resulted in an approximately double decrease in the measured velocities.

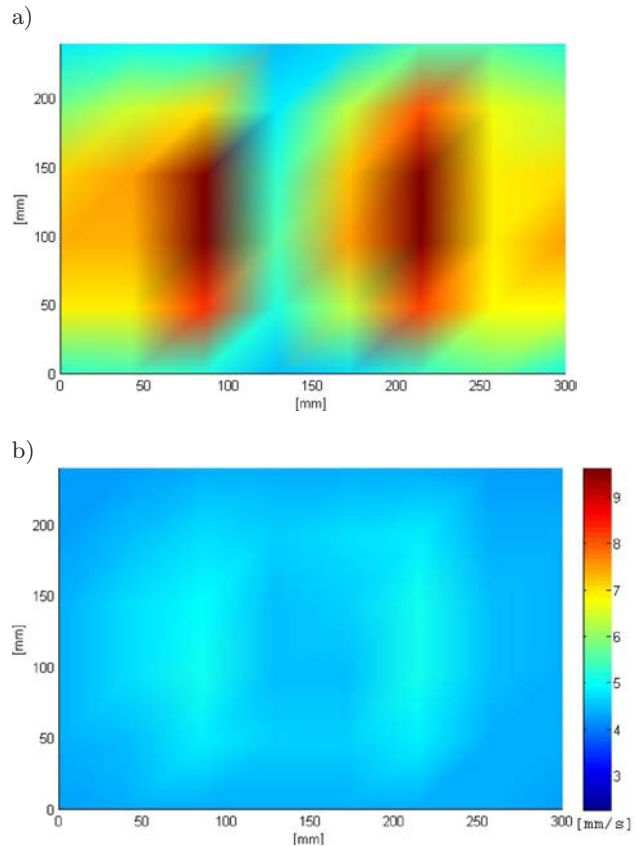


Fig. 6. Distribution of the values of acoustic velocity; a) ANC system disabled, b) ANC system activated; [mm/s].

On the basis of the acoustic velocities and acoustic pressures measured, the distribution of noise intensity was determined for three directions (x, y, z). Figure 7 shows the distribution of the values of noise intensity for the ANC system disabled and activated. Before the ANC system was activated, the values fell within the range between 75 and 90 dB. After the ANC system was activated, the maximum values decreased to 80 dB and slightly increased near the geometric centre of the plate to 85 dB.

As a result of activation of the ANC system, the effectiveness of the active noise control reaching 15 dB (Fig. 8) was obtained. The distribution of the effectiveness of the active noise control on the surface of the plate is non-uniform; in the central part of the struc-

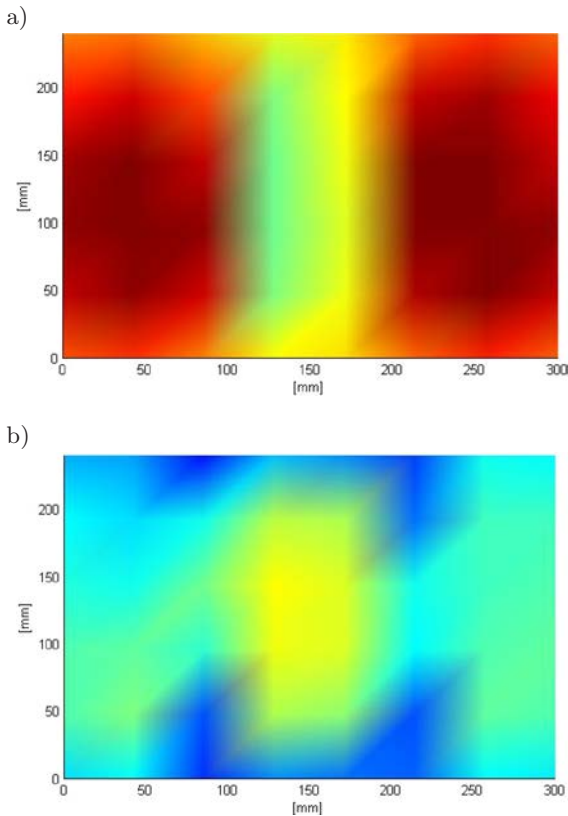


Fig. 7. Distribution of the values of the sound intensity level; a) ANC system disabled, b) ANC system activated; [dB].

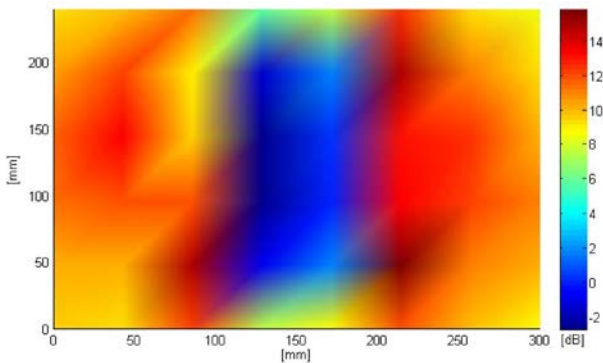


Fig. 8. Distribution of the sound intensity level reduction on the active structure surface; [dB]

ture, the effectiveness has negative values of approx. -2 dB.

The result of the aforementioned active noise control on reducing noise emitted into a room is shown in Fig. 9. In the case shown, the sound pressure level was measured within a measurement area analogical with the area of the simulation tests of the acoustic radiation of the structure (Fig. 3). Within the measurement area, the sound pressure level was measured before and after activating the ANC system and, on this basis, the effectiveness of active control was determined. The effectiveness of active noise control reaches

the values from 16 dB near the structure to 0 dB at the boundaries of the measurement area.

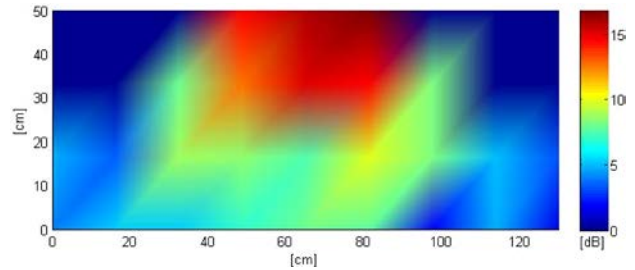


Fig. 9. Distribution of the sound radiation reduction emitted into the room.

The differences between the values of effectiveness are related to the value of the sound pressure levels to be reduced. Due to the presence of the acoustic background, the lower the sound pressure level before reduction, the lower the reduction value. There were no negative values of effectiveness of active noise control.

4. Conclusions

The comparison of the results of simulation tests and laboratory measurements which aimed at improving sound insulation with an active noise control system showed a significant convergence of results. The table below contains the values of the sound pressure level at a distance of 0.5 m away from the structure obtained in the course of simulation tests and measurements.

In the simulation, before the ANC system was activated, the sound pressure level was approximately 60 dB. After the ANC system was activated, the sound pressure level decreased to 51 dB. In the laboratory measurements, before the ANC system was activated, the sound pressure level was approximately 61 dB. After the ANC system was activated, the sound pressure level decreased to 53 dB. The differences between the values oscillate around 1 dB, which is satisfactory. Therefore, it may be assumed that simulation tests with the application of the ANSYS package are a useful tool for estimating the effectiveness of active sound-absorbing and insulating structures and for determining the location of active elements in the structures.

As a result of the ANC system activation there was a decrease in the level of noise intensity on the surface of the structure reaching 15 dB. The distribution of the active noise control efficiency on the plate surface is non-uniform; in the central part of the structure, efficiency has negative values of approx. -2 dB. In the case of noise emitted into a room, differences in the sound pressure level within the measurement area before and after activation of the ANC system oscillate between around 0 dB at the boundaries of the measurement area to 16 dB near the structure.

Test results showed that it was possible to improve sound insulation of a structure with a brass plate by approx. 16 dB by using active elements in the form of the MFC piezolaminate. Therefore, it may be assumed that using MFC materials as secondary sources in ANC systems is plausible and provides desired results. Acoustic barriers comprising sheet metal and MFC converters may be a sufficient element of noise insulation where it is necessary to apply elements of significant thermal conductivity (e.g. in transformer enclosures) or in applications that exclude the use of thicker and heavier barriers.

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