MECHANICS AND CONTROL
Vol. 29 No. 3 2010

Michał KOZUPA*, Jerzy WICIAK*

COMPARISON OF PASSIVE AND ACTIVE METHODS FOR SOUND RADIATION REDUCTION FROM THE CLAMPED PLATE

SUMMARY

The paper is an analytical and experimental study of smart structure, which consist of steel plate with bonded PZTs and porous elastomer layer. Active control of sound radiation from a clamped at the edge square plate is examined. Simulations and numerical computation of the experiment are performed in ANSYS environment. Calculations of plate vibration and sound radiation under stepped harmonic force are performed. The experimental set-up is placed in coupled reverberation chambers and the test plate is placed in the hole. A variety o test cases were studied for three different plates: steel plate + PZT, steel plate + elastomer layer, steel plate + PZT + elastomer layer. The aim of the paper is to illustrate the possibilities of using piezoelectric materials as an active control and elastomer layers as passive methods in one structure to improve the transmission loss.

Keywords: *smart materials, active control, vibrations, PZT, FEM*

PORÓWNANIE AKTYWNYCH I BIERNYCH METOD
W REDUKCJI PROMIENIOWANIA AKUSTYCZNEGO UTWIERDZONEJ PŁYTY

Artykuł przedstawia badania analityczne i symulacje oraz pomiary eksperymentalne inteligentnej struktury składającej się z płyty stalowej z przyklejonymi elementami aktywnymi PZT i naniesioną na powierzchnię warstwą elastomerową. Zbadano aktywne sterowanie promieniowaniem akustycznym płyty utwierdzonej na brzegach. Obliczenia numeryczne symulacji wykonano w środowisku obliczeniowym ANSYS. Obliczone zostały drgania i promieniowanie akustyczne płyty pod wpływem wymuszenia harmonicznego przez jeden z elementów PZT. Stanowisko pomiarowe usytuowano w zespole komór sprzężonych. Na stanowisku przetestowano kilka rodzajów obiektów badań: płyta stalowa z elementami PZT, płyta stalowa z warstwą elastomerową, płyta stalowa z elementami PZT i warstwą elastomerową. Celem artykułu jest pokazanie możliwości wykorzystania w jednej strukturze materiałów piezoelektrycznych, jako metody aktywnej i warstwy elastomerowej, jako metody pasywnej do zwiększenia dźwiękoizolacyjności struktury.

Słowa kluczowe: *materiały inteligentne, metody aktywne, drgania, PZT, MES*

1. INTRODUCTION

The paper shows operation of passive and active methods for improving transmission loss in one structure. In the field of active methods piezoceramic elements are used. Changing vibration shapes and mechanical impedantion by PZTs, the sound radiation can be reduced (Fuller *et al*. 1996) (Wallace 1993). Earlier experiments examined rectangular plate with five PZT (Kozupa 2009). The following article is an evaluation of previous experiment. The authors used bigger (0.5 m^2) quadratic plate with twice the number of PZTs.

In the preliminary research, mechanical force input is used to excite the test plate to vibrate. The mechanical force is harmonic voltage signal applied on 9th PZT (Fig. 1) element located near the centre of the test plate. Eight others PZT patches are divided on two sets, in which three elements are used as damping actuators and one as a sensor. One of two patches configuration is used in experiment, set I is near the edges (PZT no. 1, 2, 3, 4) and set II is near the centre of the test plate (PZT no. 5, 6, 7, 8) as illustrated in Figure 1. The quasi-optimal idea that PZTs should be attached at points in which the curvatures of the surface locally take their maximum is applied (Brański *et al*. 2007). Clamped boundary conditions of the test plate are used, rigidly around the edges.

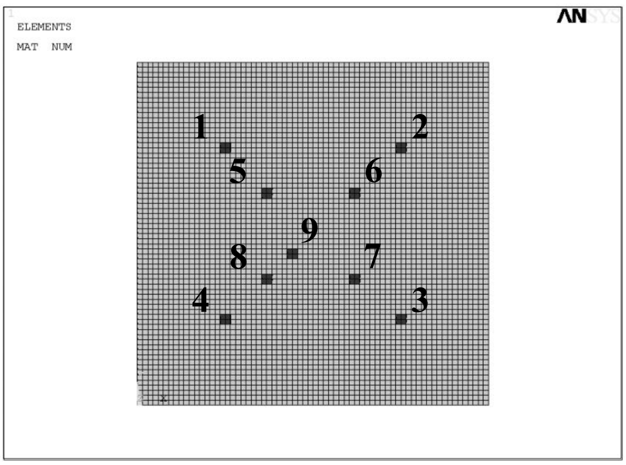


Fig. 1. PZT location on the structure, FE-model

The test structure is placed between set of reverberant chambers for sound insulation measurements. Receiving chamber is modified and a sound-absorbing enclosure is build to obtain semi-anechoic conditions.

* Department of Mechanics and Vibroacoustics, AGH University of Science and Technology, Krakow, Poland; Michal.Kozupa@agh.edu.pl

To identify radiation modes and vibration causing structure borne sound (Elliott *et al*. 1993), finite element model is build in ANSYS software. Entering in FE-model the exact parameters of piezoceramics including permittivity, elastic compliance and piezoelectric charge constant voltage is used as an input parameter (Kozień *et al*. 2008). Additionally acoustic volume is modelled on both sides of the test structure. In this case pressure is the input parameter to simulate incident wave from sending chamber.

2. TRANSMISSION LOSS IMPROVEMENT

2.1. Passive method

For increasing sound insulation with passive technique, the elastomer layer is placed on the plane (Rao 2003). Flexible porous rubber with open cells is generally considered to be good sound absorber and vibration isolator, and is often used to reduce noise and vibration. Steal plate is covered with a layer of 2.5 mm porous open cell rubber which brings additional 0.6 kg/m^2 approximately.

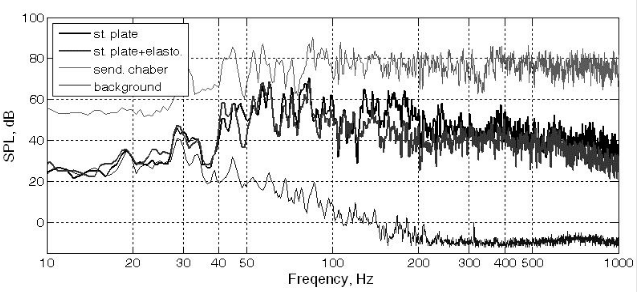


Fig. 2. Elastomer layer impact on plate radiation

Figure 2 shows frequency response function on white noise sound wave measured in receiving chamber. Red graph shows sound pressure level when steal plate with elastomer layer is mounted in the test opening, black graph is for steal plate without layer, green and blue graph represent respectively sound pressure level (SPL) in sending chamber and background in receiving chamber. Sound reduction increases about 1 dB(A) in the whole frequency range.

2.2. Active method

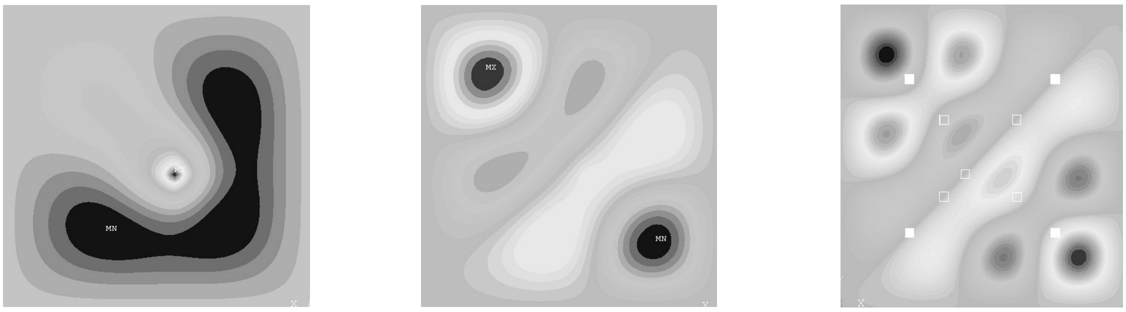
The use of PZT elements was preceded with simulations in Ansys environment. Modelling the impact of mechanical force from PZT vibration modes of the test plate are obtained and in consequence sound radiation to acoustic volume. Figure 3 shows mode shapes corresponding to resonant frequencies at specific situations.

For the first mode shape one can observe two different reactions on vibration damping with outer PZTs (set I) and inner PZTs (set II). At the second case vibration reduction of 16 dB gives only 10 dB of sound radiation reduction. In contrary to this set I gives totally reverse results. Mode shape at 90 Hz can be only controlled with outer PZTs due to localization. Set II is located in nodes where amplitude for vibration is very small. However, is that small change of vibrations at 165 Hz frequency under the same condition of localization gives 17 dB reduction in sound radiation.

Summary for all resonant frequencies in which reduction of sound radiation was achieved are shown in Figure 4. In most cases vibration reduction results give almost double reduction in sound radiation. Figure 5 compares vibration and sound radiation reduction for the same resonant mode in frequency domain. Red graph show frequency response function on harmonic force when the active control is turned off, black graph show effect of the active controlled PZTs.

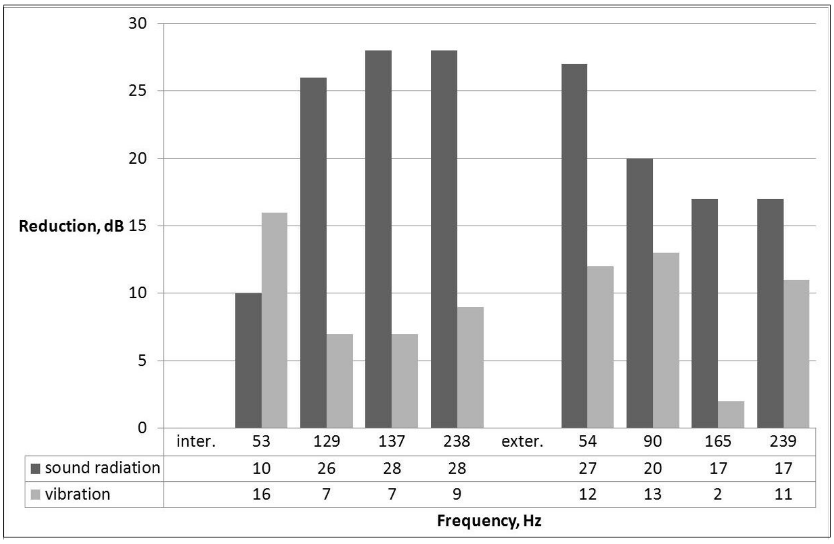
2.3. Passive and active method

Structure with porous layer and PZT patches combines passive and active methods in one. Application of elastomer layer is a protection coating for PZTs and wiring of PZT patches which are easy to damage. The temperature of vulcanization for elastomer is small enough (less than half of Curie temperature) to keep the piezoelectric effect in PZT patches.



54 Hz 90 Hz 165 Hz

Fig. 3. Free vibration modes of the test plate



	inter.	53	129	137	238	exter.	54	90	165	239
■ sound radiation		10	26	28	28		27	20	17	17
■ vibration		16	7	7	9		12	13	2	11

Fig. 4. Steal plate + PZT

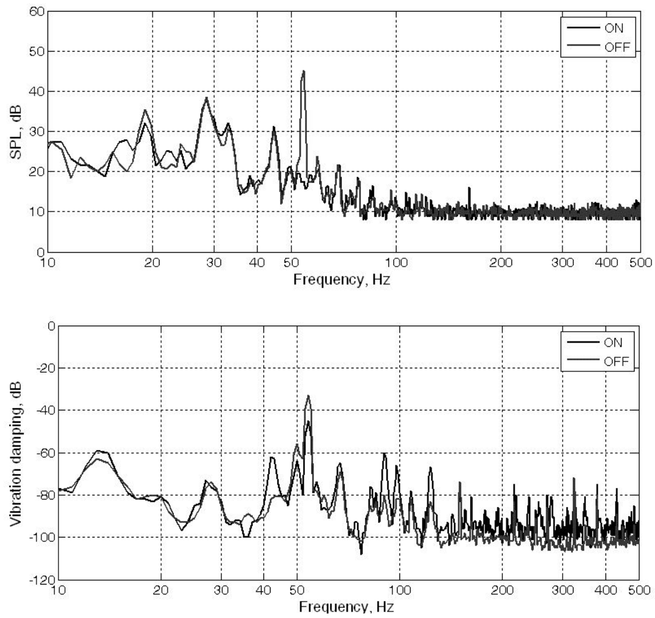
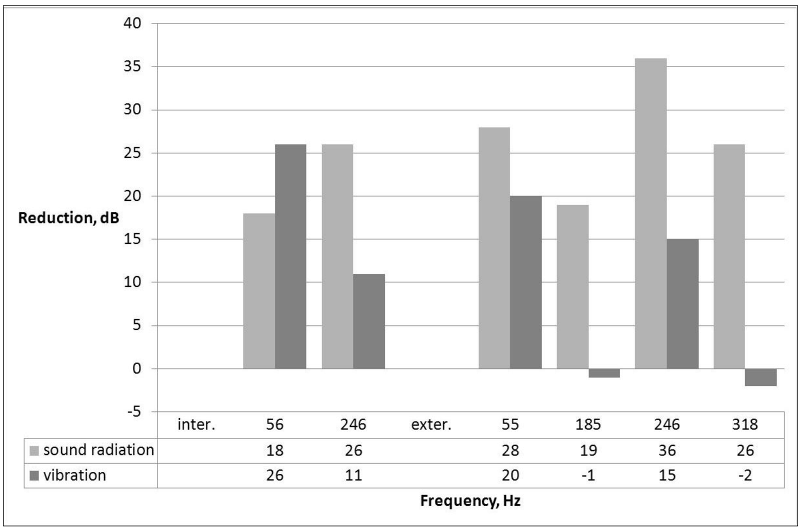


Fig. 5. Sound radiation reduction and vibration damping. Steal plate + PZT



	inter.	56	246	exter.	55	185	246	318
■ sound radiation		18	26		28	19	36	26
■ vibration		26	11		20	-1	15	-2

Fig. 6. Steal plate + PZT +elastomer

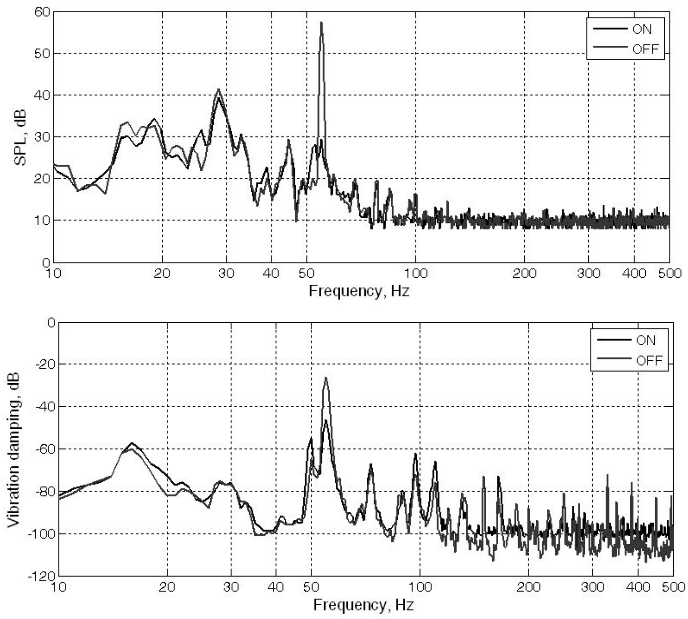


Fig. 7. Sound radiation reduction and vibration damping. Steal plate + PZT + elastomer

On the Figure 6 one can see reduction of vibration and sound radiation for combined structure. Not all resonant frequencies from the steal plate has been examined but comparison for those can be made. Similar situation for the first frequency can be observed, like steal plate, this structure gives better result using external PZTs. There are also two frequencies when sound radiation reduction is achieved even the vibration increases. It is supposed, that additional mechanical impedance from PZT actuators causes reduction in sound radiation simultaneously increasing vibrations at the same point.

Figure 7 compares vibration and sound radiation reduction for the same resonant mode at 55 Hz in frequency domain. Red graph show frequency response function on harmonic force when the active control is turned off, black graph show effect of the active controlled PZTs.

3. CONCLUSIONS

The possibility of improving the transmission loss of a square plate by using PZT patches and elastomer porous layer has been investigated numerically and experimentally. It has been shown that additional elastomer layer placed on the plane is to thin and light to increase sound reduction significantly. Modern technology, however, requires a minimum of additional weight in order to improve the acoustic conditions. With the help of intelligent materials like PZT allow the condition to keep a marginal increase in weight. Combination of both methods can augment some difficulties. However, the reduction of radiated sound achieved for some particular frequencies was much higher. For example radiation mode about 240 Hz was minimized much better for plate with elastomer layer, damping via external actuators gave 20 dB improvement. The next stages of research will be based on acoustic excitation of the test plate and will be more similar to natural conditions.

Acknowledgments

This research work is supported by the Polish Ministry of Science and Higher Education grant No. N N504 282737.

References

Brański A., Szela S. 2007, *On the quasi optimal distribution of PZTs in active reduction of the triangular plate vibration*. Archives of Control Sciences, vol, 17 (4), pp. 427–437.

Elliott S.J., Johnson M.E. 1972, *Radiation Modes and the Active Control of Sound Power*. The Journal of the Acoustical Society of America, vol. 51 (3), pp. 946–952.

Fuller C.R., Elliott S.J., Nelson P.A. 1996, *Active Control of Vibration*. Academic Press, London.

Kozień M., Wiciak J. 2009, *Choosing of optimal voltage amplitude of four pairs square piezoelectric elements for minimization of acoustic radiation of vibrating plate*. Acta Physica Polonica A, vol. 116 (3), pp. 348–350.

Kozień M., Wiciak J. 2008, *Reduction of structural noise inside crane cage by piezoelectric actuators – FEM simulation*. Archives of Acoustics, vol. 33 (4), pp. 643–652.

Kozupa M. 2009, *Acoustic emission reduction of rectangular plate with active elements* [Abstract]. Archives of Acoustics, vol. 34 (3), pp. 376.

Kozupa M., Wiciak J. 2010, *Analiza mes płyty kwadratowej z elementami PZT promieniującej do objętości akustycznej*. XII Sympozjum „Wpływ wibracji na otoczenie", Janowice 27–30 września 2010.

Rao M.D. 2003, *Recent applications of viscoelastic dampingfor noise control in automobiles and commercial airplanes*. Journal of Sound and Vibration, vol. 262, pp. 457–474.

Wallace C.E. 1993, *Radiation Resistance of a Rectangular Panel*. The Journal of the Acoustical Society of America, vol. 94 (4), pp. 2194–2204.