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SOUND INSULATION ANALYSIS OF PLATES WITH PIEZOCERAMIC ELEMENTS

SUMMARY

This paper represents general idea research to the possibilities of increasing sound insulation of plates by active control it's vibration through piezoceramic elements placed on the plane. In the preliminary research a rectangular plate 455×560 mm made of steal was analyzed. Sound insulation measurement was executed on a specialized enclosure in reverberation chamber. A PZT piezoceramic was proposed to control vibration of the plate.

Keywords: *vibration, sound insulation, transmision loss, PZT, piezoelectrics, piezoceramics*

ANALIZA WŁASNOŚCI DŹWIĘKOIZOLACYJNYCH PRZEGRÓD Z ELEMENTAMI PIEZOCERAMICZNYMI

Praca przedstawia ogólną koncepcję badań dotyczących analizy możliwości zwiększenia dźwiękoizolacyjności przegród poprzez aktywne sterowanie ich drganiami za pomocą elementów piezoelektrycznych rozmieszczonych na ich powierzchni. We wstępnych badaniach analizowano zachowania przegrody w postaci płyty prostokątnej o wymiarach 455 × 560 mm, wykonanej z blachy stalowej. Pomiary dźwiękoizolacyjności wykonano na specjalizowanym stanowisku w komorze pogłosowej. Do sterowania drganiami przegrody zaproponowano elementy piezoceramiczne PZT-4D.

Słowa kluczowe: *drgania, izolacja dźwiękowa, straty transmisji, PZT, piezoelektryki, piezoceramiki*

1. INTRODUCTION

In the recent times we can see a great increase in the applications of smart materials, or piezoelectric materials, for passive and active structural damping. With the advancement of smart material technology, smaller actuators and sensors have been created, what makes them light and easy to use. This article is the preliminary research for the passive&active controlled smart structure. The intension of the author is to construct a structure based on steal plate with better sound transmission loss (TL). To active reduction of vibration and increase TL the piezoelectric properties of PZT (piezoceramic elements consists of Lead, Zirconium and Titanium) are going to be used and specially vulcanized rubber placed on the plane for the passive damping. The pre-research are the measurements of the fundamental units for the steal plate.

2. THE EXPERIMENTAL SETUP

The experimental setup consists of two chambers, sending chamber and receiving chamber. The sending chamber is a semi – echo tetrahedron pyramid enclosure build inside the echo chamber in the most acute corner [2]. Dimensions of the sending chamber were designed to measure sound insulation of small elements and there are 1802 × 1477 × 1355 mm so the volume is 0.47 m^3. As a matter of fact in such small volume is hard to obtain reverberant field conditions. This is some imperfection of the experimental setup. Furthermore transmission loss measurements are rough. The sending chamber enclosure is a sandwich structure made of steal and rubber with a sound insulation of $R_w = 45$ dB measured when the test hole was plugged with the same material as the enclosure. The test hole size is 565 × 460 mm. According to this the receiving chamber is total echo chamber with reverberation time in frequencies of 9.5 s (100 Hz), 11 s (200 Hz), 10 s (500 Hz) and 8 s (1 kHz) and a volume of 185.6 m^3. The test plate under study was installed in the opening between the two chambers as if it was simple-supported, the plate themselves is a rectangular steal plane with size that can fix the hole. Major parameters are compiled in Table 1.

Table 1
Physical parameters of the test plate

Physical parameters	Density, kg/m^3	Young's modulus, N/m^2	Poisson's ratio	Dimensions, mm
Test plate	7850	2,1E11	0,3	560 × 453 × 1

The experimental setup is shown in Figure 1.

For the data acquisition and measurements a following equipment was utilize:

- Accelerometer B&K 4344,
- Charge Amplifier B&K 2635,
- Microphone G.R.A.S. 40AN (×2),
- Microphone preamplifier SV01 (×2),
- Sound and Vibration Analyzer SVAN 912AE,
- Four Channels Sound & Vibration Analyzer SV 08A,
- Noise Generator B&K 1405,
- Power Amplifier B&K 2706.

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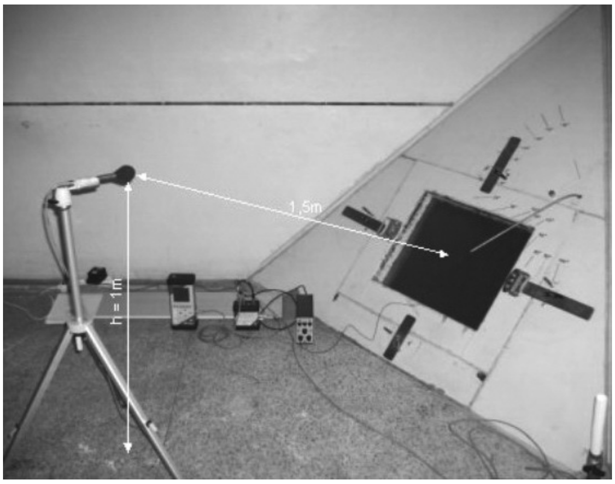

Fig. 1. View of the experimental setup in echo chamber at AGH

3. MEASUREMENTS

The measurements were divided on two basic units, vibration and sound pressure. The acceleration sensor was mounted on thin layer of wax in four different places shown in the Figure 2.

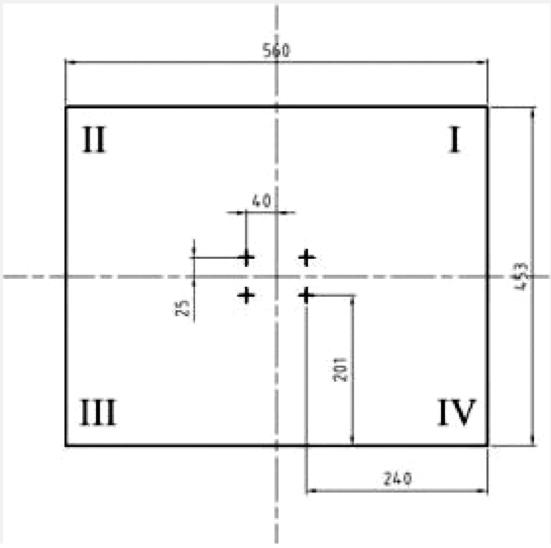

Fig. 2. Plate dimensions and points to install sensor in four quarters

There were two microphones, one installed inside sending chamber, where the speaker was placed, which measured pressure to affect and excite the test plate and second placed in echo chamber measured sound insulation. It made three channel measurement circuit:

Ch1 – sound pressure signal inside sending chamber,
Ch2 – sound pressure signal in the receiving chamber,
Ch3 – vibration signal of the test plate.

As a result of sound pressure and plate vibration measurements the levels are:

Ch1 = 105.7 dB,
Ch2 = 78.8 dB,
Ch3 = 0.891 m/s^2.

On the basis of this measurement a sound transmission loss can be calculated from the equation

$$R = L_1 - L_2 + 10\lg(S/A) \quad (1)$$

where:

- L_1 – sound pressure level in sending chamber,
- L_2 – sound pressure level in receiving chamber,
- S – sample area,
- A – equivalent absorption area in receiving chamber.

Transmission loss (TL) for this plate is 15 dB. It will be useful then to compare the sound insulation with and without active control of vibration. There was also made a measure without the steal plate in the test hole, and the results are Ch1 = 104 dB, Ch2 = 92 dB. It can be seen the connection between this measure and result of equation (1). In the Figure 3 we can see that the noise spectrum inside enclosure does not have a proper linearity. In the future a better speaker and equalizer will be used to smooth away the spectrum.

The Figure 3 shows the resonant peaks of the test plate, with the highest levels occurring at 41 Hz, 79 Hz, 111 Hz, and 131 Hz.

In the Table 2 there is made a comparison of measured modes and theoretical result.

Table 2
Theoretical and measured mode of test plate

Mode		(1.1)	(1.2)	(2.1)	(1.3)	(3.1)	(2.3)	(3.2)	(3.3)
Frequency	Theoretical Result	20	43	56	83	116	119	139	178
	Measured	–	41	–	79	111	–	131	–

We can se that the most excited modes are when the high magnitude occurs where the sensor is placed.

3.1. Acoustic field diffusivity

It was examined the diffusivity of acoustic field inside the volume, to find out whether acoustic pressure affecting and exciting the test plate is spread evenly. The microphone has been moved by radius in distance of 10 cm from the plate mounted in the hole shown in Figure 4.

The obtained results of equivalent continuous sound pressure level (L_{eq}) and spectrum are shown in Table 3 and Figure 5.

Table 3
Measures Leq in different angles

Angle	30°	40°	50°	60°	70°
L_{eq}, dB	104.3	104.7	105.3	105.8	105.6

Maximum difference between levels is 1.5 dB. Additionally taking into consideration spectrum change in different angles, the diffusivity of acoustic field inside sending chamber was positively revived.

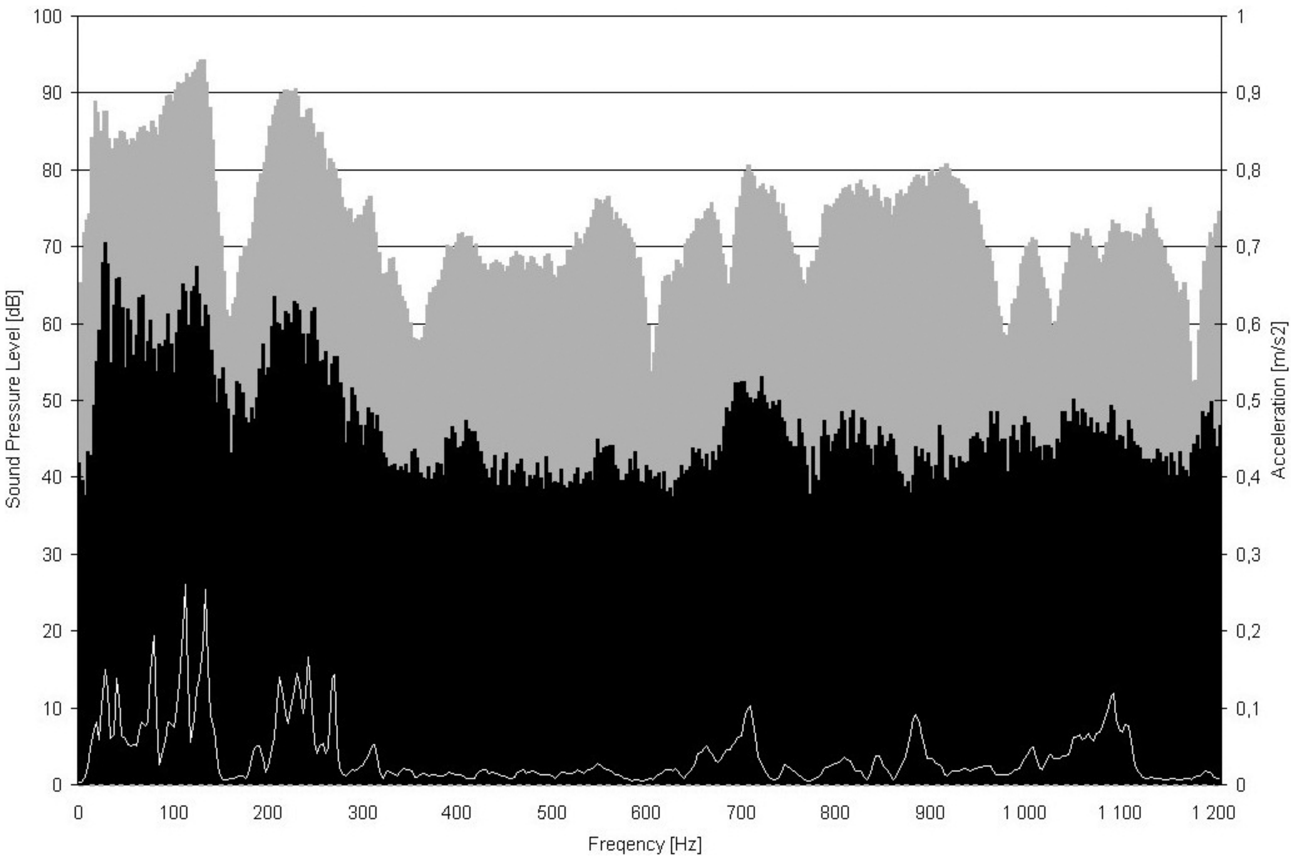

Fig. 3. Measured white noise spectrum on both sides of the test plate inside echo chamber and vibration magnitude of the plate. Gray color is Ch1 spectrum, black color is Ch2 spectrum and the white line is Ch3 vibration spectrum

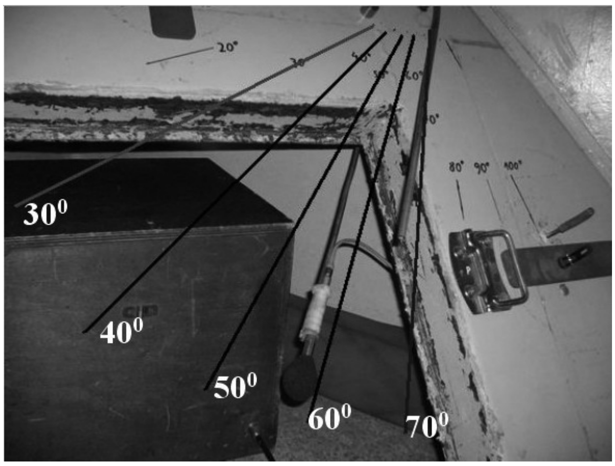

Fig. 4. View of measured points in different angles

4. APPLICATION OF PIEZOCERAMIC ELEMENTS

The piezoelectric effect provides the ability to use this material as both sensor and actuators. The most common material with this effect is piezoceramic consist of Lead, Zirconium and Titanium (PZT).

To use the piezoefect for damping vibration two types of control are used:

1) The passive control which consist almost entirely of various shunt circuit techniques, like: Inductive, Resistive, Capacitive, Switched. All of them were described in one particular study [5]. According to Lesieutre [5], each type of shunt circuit exhibits its own type of behavior: a resistive shunt dissipates energy through joule heating, which provides structural damping; an inductive shunt is analogous to a mechanical vibration absorber (tuned mass damper); and a capacitive shunt changes the effective stiffness of piezoelectric elements; a switched shunt offers the possibilities of controlling the energy transfer to reduce frequency dependent behavior.
2) The active control via two control schemes: feed forward and feedback. Feed forward control is particularly suited to the control of tonal disturbances for which a reference signal is available. Feedback control is advantageous for the control of steady state, random and transient disturbances. Some study point out some of the disadvantages with active control. For example McGrowan [6] points out that there are two important issues that need to be considered in using piezoelectrics as actuators for active control systems: they usually require large amount of power for operation, and the complexity of the hardware involved with active control.

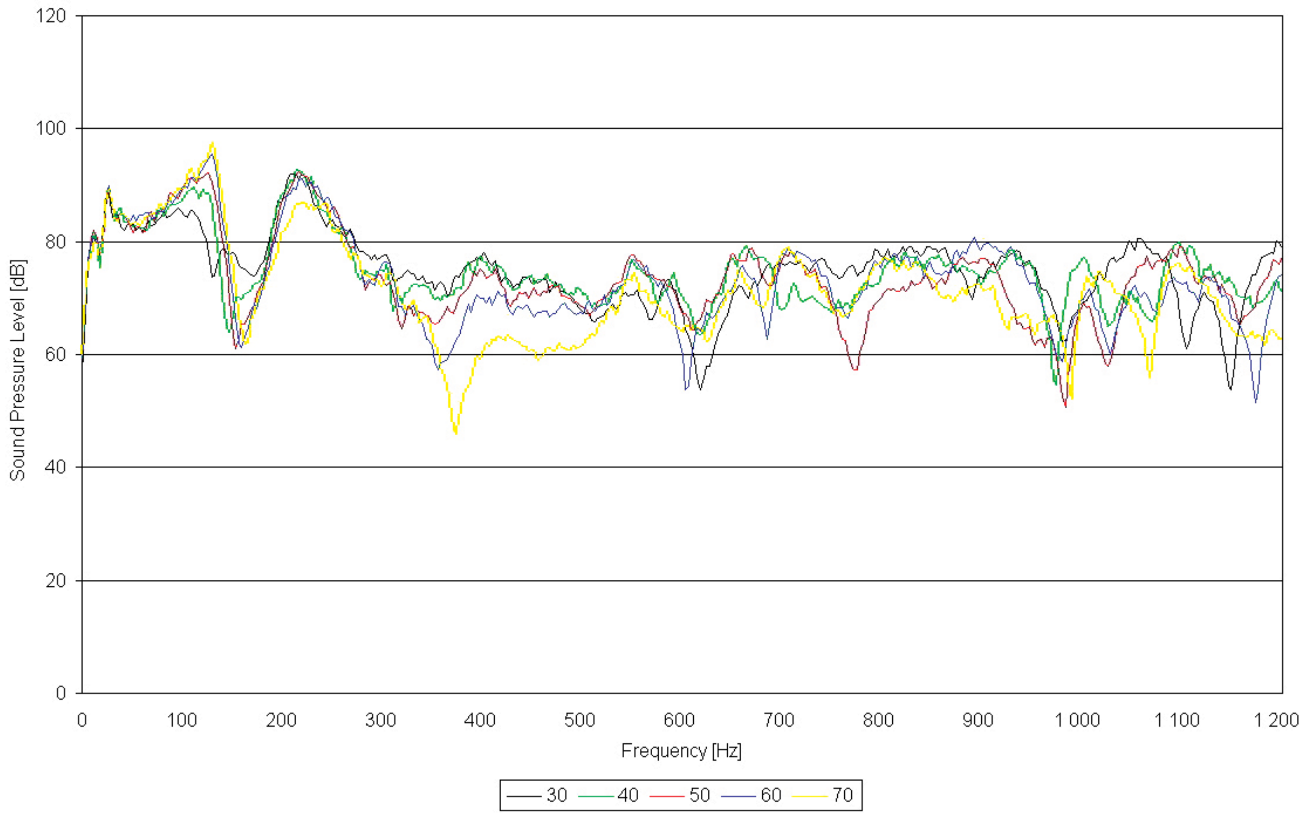

Fig. 5. Spectrum in different angles

For the future application (passive/active) a PZT was chosen. The size of PZT plate is 20 mm × 20 mm × 1 mm, material properties are summarized in Table 4. PKT is the name for piezoceramics in pressing technique.

Table 4
Technical data of the piezoceramic material

Technical Data		PKT P840	
Curie temperature, ϑ_c		325°C	
Density, ρ		7600 kg/m^3	
Stiffness constant	s_{33}^E	14.7	10^{-12}/Pa
	s_{11}^E	12.5	10^{-12}/Pa
Mechanical quality factor, Q_m		500	
Piezoelectric charge constant	d_{33}	290	10^{-12}C/N
	d_{31}	125	10^{-12}C/N
Coupling factor	k_{33}	0.72	–
	k_{31}	0.35	–

Description of technical data placed in Table 4 is listed below.

Curie temperature – value at which phase transition of the crystal structures occurs. As a rule the application temperature range of piezoceramics lies at $0.5\vartheta_c$.

Stiffness constant – ratio of the relative elongation to the mechanical tension.

Mechanical quality factor – the ratio of the elongations of a body, able to vibrate, in resonance and in static operation.

Coupling factor – describes the ability of a material to transform electrical energy into mechanical energy and vice versa. The coupling factor allows a direct comparison of different materials: k_{33} – coupling factor of the length mode; k_{31} – coupling factor of the transverse mode.

Piezoelectric charge constant – describes the ratio from relative elongation and electrical field strength at constant mechanical tension.

5. CONCLUSION AND FUTURE DIRECTIONS OF RESEARCH

This paper has presented basic measurements of transmission loss and vibration functional to begin applying actuators for damping. The next step for this researches is the application of piezoceramics materials (PZTs) to control structural vibrations and noise without adding much weight to the structure, afterwards adding passive damping. The location for putting the PZT plates on the steal plane will be chosen in the criteria of high levels of strain energy for the resonant frequencies. The control of piezoceramic elements is going to be active and in feedback technique. Probably the source of acoustical energy will be changed to better linearity of white noise spectrum.

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