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Piezoelements with step changes in material properties in sound and vibration reduction

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ABSTRACT

This paper deals with numerical analyses of the effect of the size of the inner part of a 2-part piezo actuator on the reduction of plate's vibration and the sound pressure generated by said plate. For that purpose numerical models of a square steel plate were created. The plate is 400 mm x 400 mm x 2 mm and is clamped on all sides. 2 piezo actuators are attached to it. One is placed near the centre has homogeneous build (material properties of PZ28) and is used to excite the plate. The other one is placed on one of the diagonals near 1/4 of its length. This element is a 2-part element (material properties is a combination of PZ28 and PZ92) with 3 possible base shapes (square, triangle and circle) and 3 possible sizes of the inner part of the actuator and is used to reduce the vibration of the plate (as well as sound pressure radiated by it). On one side the plate connected to a half sphere of air acting as a sound surroundings. Results are presented for the 4 mode shapes (1st, 2nd, 4th and 5th to be exact).

Keywords: ANC, AVC, FEM, Graded materials
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1. INTRODUCTION

When dealing with mechanical systems excessive vibrations are usually an unwanted phenomenon. Not only can they lead to faster wear of even damage the machine, frequently they are also the source of structure borne sound [1].

Typically there are 2 main types of approach to this problem - passive and active methods of vibration reduction (or control). The main difference for both methods is that in one we usually want do disperse excessive vibration energy, while in active methods vibrations are reduced by introducing an outside source of vibration energy acting to achieve a destructive interference with the vibrations of the machine. To do this some kind of actuator is needed. The placement of that actuator is of course very important, and finding the optimal placement is not an easy task [2].

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One type of actuators used in active methods are so called piezo actuators. These elements are in use for more than 20 years, being first introduced in the works of Fuller, Dimitriadis [3]. Over time of course different materials and compositions were used. So piezo elements used today are more efficient than those used 20 years ago. They are often used in research as they are fairly easy to use, come in many shapes and sizes. There are also accurate numerical models of their behaviour, so they can be used in numerical simulations [4].

In previous publications the authors first introduced a preliminary concept of a 2-part piezo actuator [5]. Then after refining the models some changes in the shapes of actuators along with analytical models were introduced [6]. In later work [7] acoustic surroundings of analyzed plate was added.

This work continues with the analyses of piezo actuators with a step change of material properties. One of the issues that wasn't explored previously was effect of the size of the inner size of said actuator on its effectiveness. Results presented in this work show how the change in the size of inner size of the actuator influences the vibration generated in the plate and the acoustic pressure emitted by said plate.

2. NUMERICAL MODELS

For the purpose of testing the impact of the size of the inner part of 2-part piezo elements numerical models using ANSYS software were created. Each model consisted of a steel plate (400 x 400 x 2 mm) which was clamped on all sides. To each plate 2 piezo elements were attached on one side of the plate (fig. 1 a) and additionally a half-sphere of air was also attached to the plate (fig. 1 b).

a) b)

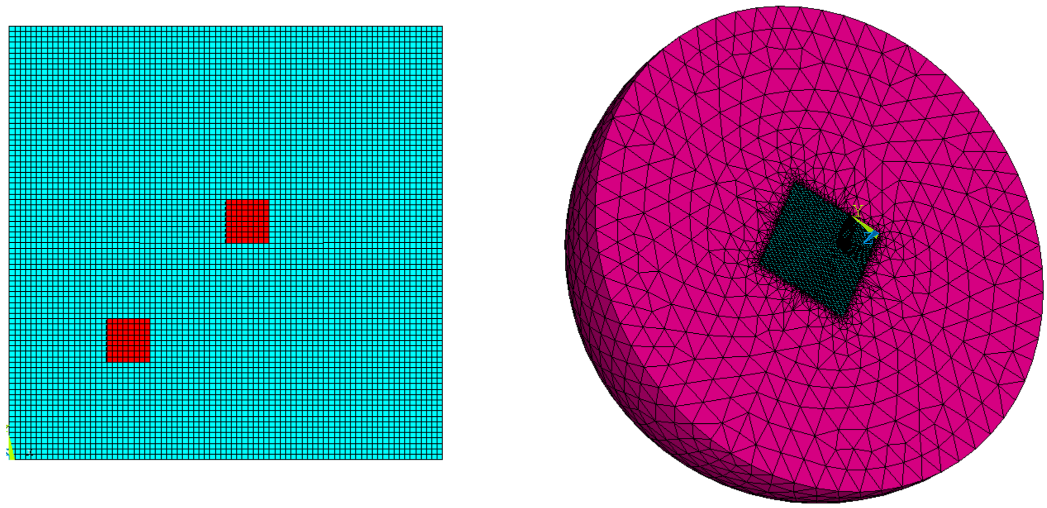

Fig. 1. a) plate with piezo elements; b) plate with a half sphere of "air" attached to it

One of piezo elements (a homogeneous with a square shaped base) was used to excite the plate and had the same dimension, placement and material properties for each model. The other one was used for the purpose of vibration (and structural sound) reduction. This actuator could have a different shape and build depending on the model. However the height and surface area are always the same (1600 mm^2 and 1 mm respectively). Possible shapes of the base of the actuators were: square, disc, and a right angled triangle. As for the build they could be either a homogeneous or a 2-part element with a step change in material properties. 2-part elements consisted of an outer and inner part with different material properties and with an inner part having 3 possible sizes (fig. 2). The areas of the inner size of 2-part piezo actuators were about 9/16, 1/4 and 1/16 the size of the areas of the whole elements. Or in terms of side lengths (or radius) - the length of the side of the base of the inner areas were 3/4, 1/2 and 1/4 of length of the sides of full actuator.

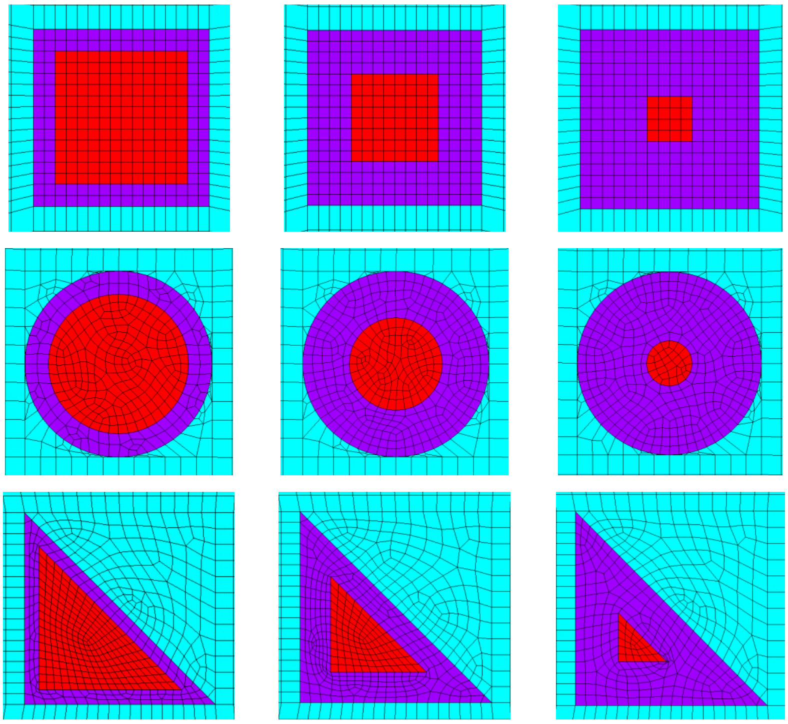

Fig. 2. Close-up on the modelled actuators

Finally the half sphere attached to the plate was modelled as a fluid with material properties of air with its boundaries behaving like an open space (no reflection). This was done for the purpose of simulating structural sound generated by the plate before and after vibration reduction.

Elements as well as properties used in the models can be found in table 1.

Table 1. Models parameters

Structural element	**Element used for modeling**	**Properties**
Plate	SOLSH190	$E = 1.93*10^{11}$ Pa, $\nu = 0.29$, $\rho = 7800\ kg/m^3$
Piezo element used to excite the plate	SOLID226	Properties of PZ 28
Actuator	SOLID226	Combination of properties of PZ 28 and PZ 29
Air	FLUID30	$P = 1.2\ kg/m^3$ c = 343 m/s

4 modes were selected for analyses - 1st, 2nd, 4th and 5th. Figure 3 shows the displacement vector sums for the modes before reduction. Figure 4 shows the corresponding acoustic pressure levels emitted by plate for these modes.

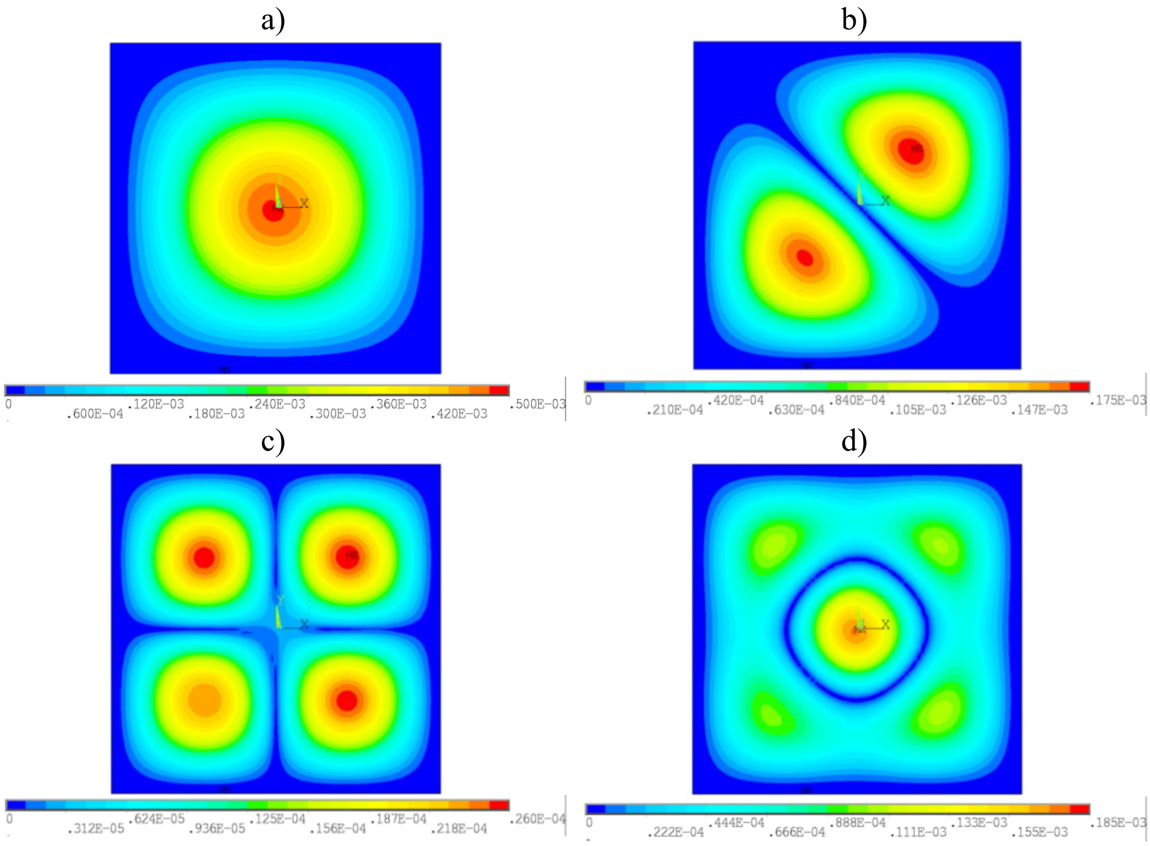

Fig. 3. Mode shapes used in simulations

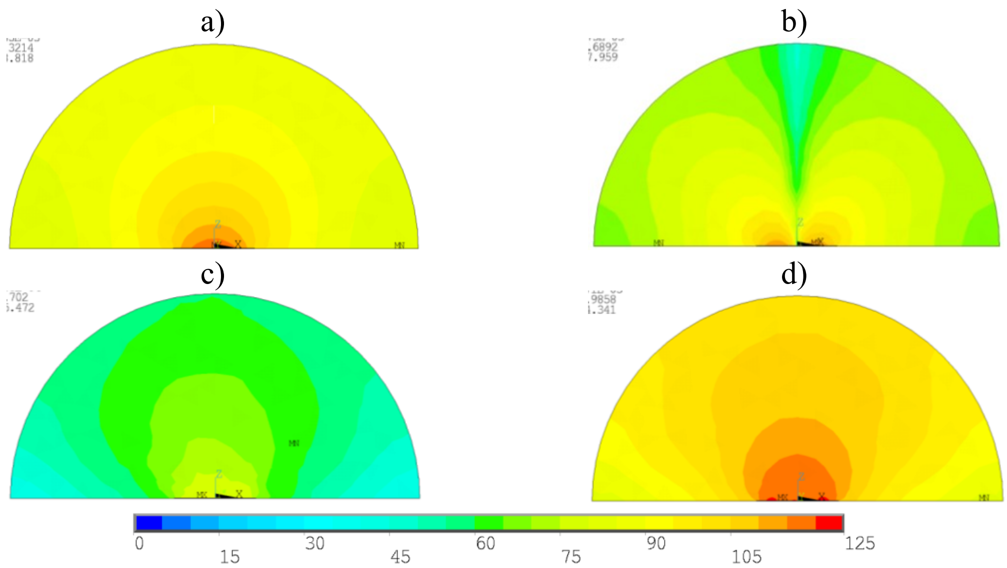

Fig. 4. Sound generated by the plate

For harmonic analyses a voltage with an amplitude of 100 V was applied to the first piezo element to excite the plate. Next using internal ANSYS optimisation procedures we searched for optimal amplitude of voltage for the second element. The goal function was given in the form:

$$J_1 = \min \sum_{i=1}^{n} \left| \mathbf{X}_{sum}(i) \right| \quad \textbf{(1)}$$

where: min is the smallest value of sum; $\mathbf{x}_{sum}(i)$ is the displacement vector of the i-th node, n is the number of nodes on the back area of the plate (the one opposite of piezo actuators).

As for the phase of the voltage applied to the second piezo element - it was given as a fixed value of either 0˚ or 180˚ since earlier test showed that those were optimal values.

One cycle of optimisation procedure was set to 30 steps. After completion of the procedure a new one was started with the possible range of voltage amplitude narrowed. In the final it was about ± 2,5 V from the value of the last run.

3. RESULTS AND ANALYSES

The reduction of vibrations (L_{red}) was calculated as:

$$L_{red} = 20log\frac{\sum_{i=1}^{n}|\boldsymbol{X}_{1sum}(i)|}{\sum_{i=1}^{n}|\boldsymbol{X}_{2sum}(i)|} \quad \textbf{(2)}$$

where $\mathbf{X}_{1sum}(i)$ is the displacement vector in i-th node before reduction and $\mathbf{X}_{2sum}(i)$ is the displacement vector in the i-th node after the reduction.
Whereas for the radiated sound (L_{pred}) is the difference between the max value of SPL before and after the reduction.

Obtained results for the vibration and structure sound reduction are shown in tables 2-4.

Table 2. Results for square shaped actuators; mode - number of mode; inner part - size of the inner part; U_a - amplitude of voltage applied to actuator; φ_a - phase of the votage applied to the actuatorl; L_{red} - vibration reduction; SPL_{red} - acoustical pressure level reduction

mode	inner part	U_a [V]	φ_a [°]	L_{red} [dB]	SPL_{red} [dB]
1	0,25	343,36	180,00	41,3	40,9
1	0,50	294,88	180,00	41,3	41,2
1	0,75	238,29	180,00	41,2	41,1
2	0,25	54,39	360,00	42,7	42,6
2	0,50	46,58	360,00	43,1	42,6
2	0,75	37,61	360,00	42,8	42,3
4	0,25	11,39	180,00	26,0	24,0
4	0,50	9,69	180,00	25,9	23,9
4	0,75	7,82	180,00	25,4	23,2
5	0,25	150,92	360,00	35,2	35,9
5	0,50	129,10	360,00	35,0	35,3
5	0,75	104,19	360,00	34,6	35,2

For square shaped piezo actuators the differences between the reduction of plates vibration were fairly small, the biggest difference was noted for the 5th mode and was about 0,8 dB (table 2). A similar situation can be seen when we look at the structure sound reduction - the biggest difference is also seen for the highest frequency and is 0,7 dB.

Table 3. Results for triangle shaped actuators; mode - number of mode; inner part - size of the inner part; U_a - amplitude of voltage applied to actuator; φ_a - phase of the votage applied to the actuatorl; L_{red} - vibration reduction; SPL_{red} - acoustical pressure level reduction

mode	inner part	U_a [V]	φ_a [°]	L_{red} [dB]	SPL_{red} [dB]
1	0,25	241,81	180,00	43,5	43,7
1	0,50	210,98	180,00	42,4	43,4
1	0,75	173,17	180,00	42,0	43,2
2	0,25	52,29	360,00	43,4	42,4
2	0,50	44,51	360,00	43,5	42,0
2	0,75	35,93	360,00	43,6	41,9
4	0,25	10,92	180,00	25,3	23,4
4	0,50	9,32	180,00	25,8	23,7
4	0,75	7,49	180,00	25,9	23,6
5	0,25	180,55	360,00	34,5	35,6
5	0,50	151,29	360,00	34,6	35,3
5	0,75	121,04	360,00	34,8	35,4

For triangle shaped actuators the biggest difference in obtained vibration reduction can be seen for the 1st mode. The difference is about 1,5 dB. For other modes the differences are less than 0,6 dB (table 3). When looking at the sound pressure levels reduction observed differences are at most 0,5 dB.

Table 4. Results for disc shaped actuators; mode - number of mode; inner part - size of the inner part; U_a - amplitude of voltage applied to actuator; φ_a - phase of the votage applied to the actuatorl; L_{red} - vibration reduction; SPL_{red} - acoustical pressure level reduction

mode	inner part	U_a [V]	φ_a [°]	L_{red} [dB]	SPL_{red} [dB]
1	0,25	351,05	180,00	40,1	41,2
1	0,50	300,24	180,00	39,8	41,1
1	0,75	241,37	180,00	40,3	41,0
2	0,25	55,29	360,00	43,1	42,5
2	0,50	47,27	360,00	43,1	42,6
2	0,75	38,08	360,00	43,0	42,4
4	0,25	11,58	180,00	25,8	24,0
4	0,50	9,88	180,00	25,8	23,9
4	0,75	7,93	180,00	25,3	23,4
5	0,25	152,98	360,00	35,0	35,2
5	0,50	131,24	360,00	34,8	35,3
5	0,75	105,54	360,00	35,4	36,2

For disc shaped piezo actuators again the differences in vibration levels reduction are fairly negligible - no more than 0,6 dB (table 4). As for sound pressure levels reduction we can see the biggest difference yet - about 1 dB for the 5th mode.

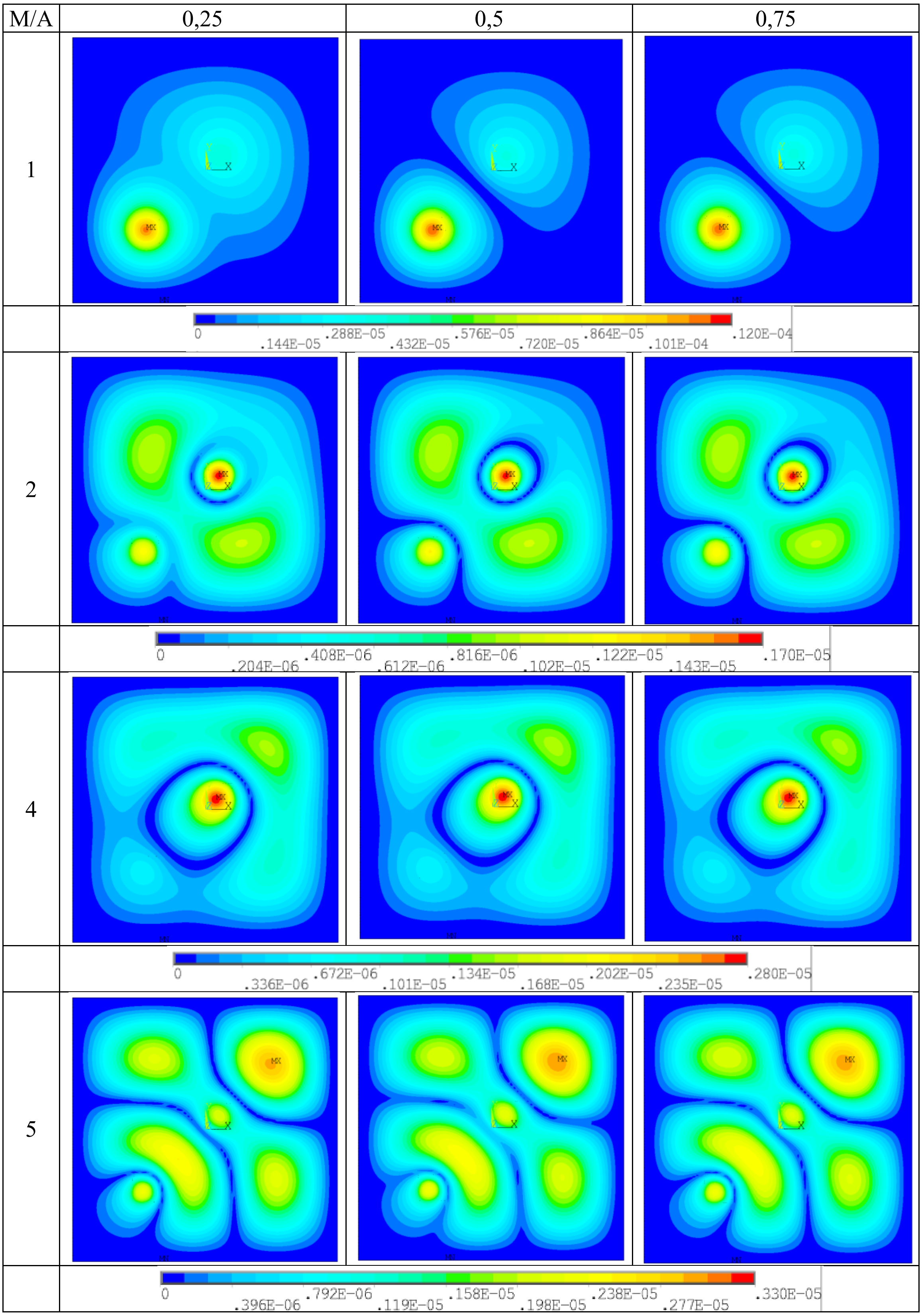

Fig. 5. Numerical results of vibrations on the plate after reduction using square shaped piezo actuators

Figure 5 presents vibrations of the back of the plate after the reduction using square shaped piezo actuators. Each column corresponds to the size of the inner part of the actuator, whereas each row corresponds to a mode of the plate and has a separate legend as the results are shown in meters. Vibration distribution of each mode before reduction can be seen on fig. 3. It can be seen that the biggest differences in the distribution of vibrations can be seen for the first mode. There are also visible changes for the second mode (especially around the placement of the actuator). For the last two modes the changes are almost undistinguishable.

In case of triangle and disc shaped piezo actuators only some of the results will be shown, as there is no need to show them if there are no visible differences.

One can see the results for the 4th mode on figure 6. It can be seen that for each change in size there is a difference in vibration distribution on the back of the plate. With the biggest difference for when the size of the inner part of the actuator is in the middle.

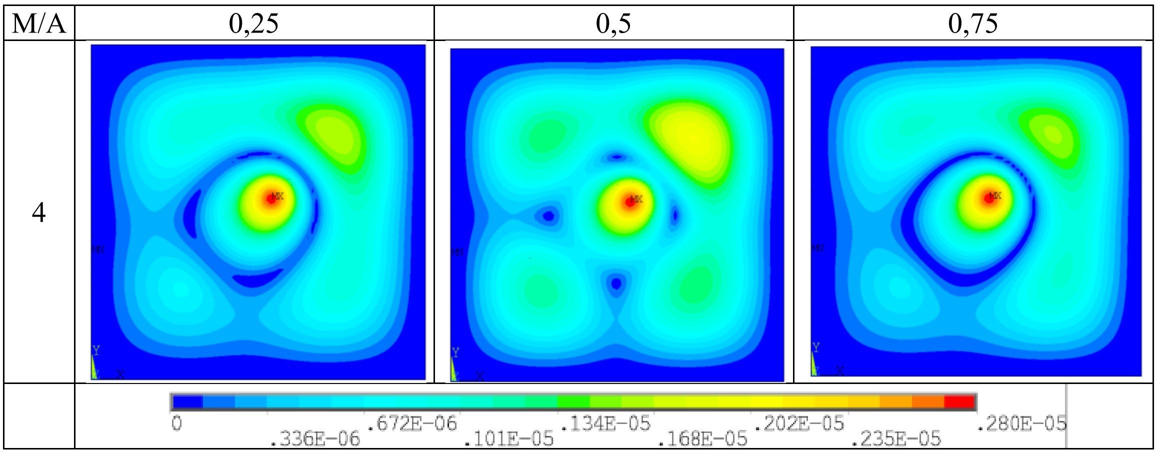

Figure 6. Numerical results of vibrations on the plate after reduction using triangle shaped piezo actuators for the 4th mode

As for the disc shaped actuators, they appear to be most stable/resistant to change in vibration distribution when introducing a 2 part actuator. Fig. 7 shows results for the 1st mode and although the differences can be seen, comparing to other shapes of actuators, they are the smallest.

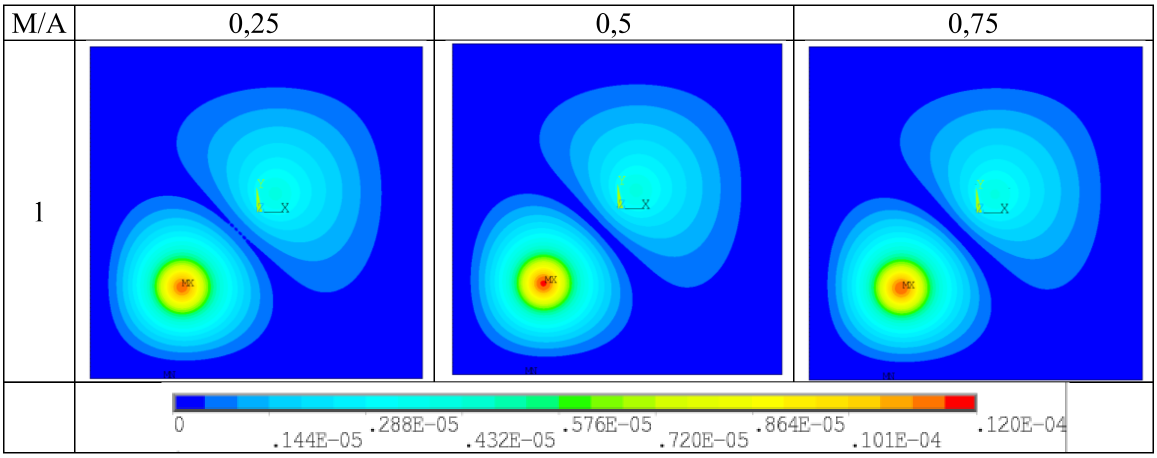

Figure 7. Numerical results of vibrations on the plate after reduction using disc shaped piezo actuators for the 1th mode

Figure 8 presents the results of sound pressure distribution in created acoustical surrounding after reduction of plates vibration. Again it can be seen that the most noticeable difference in sound pressure levels distribution can be observed for the 1st mode. Where when using the actuator with the smallest inner part the distribution appears to be symmetrical. Then for the middle size of the inner part the sound pressure levels are lower than on the left side. And when using the actuators with the largest inner part sound pressure levels in the right part of the half sphere are again slightly higher. There are no distinguishable differences for the 2nd and 3rd mode, and for the 4th mode there is a slight elevation in the levels in the middle part of the half spehere when using actuators with a medium sized inner part (might be difficult to see with the size of the picture in the article).

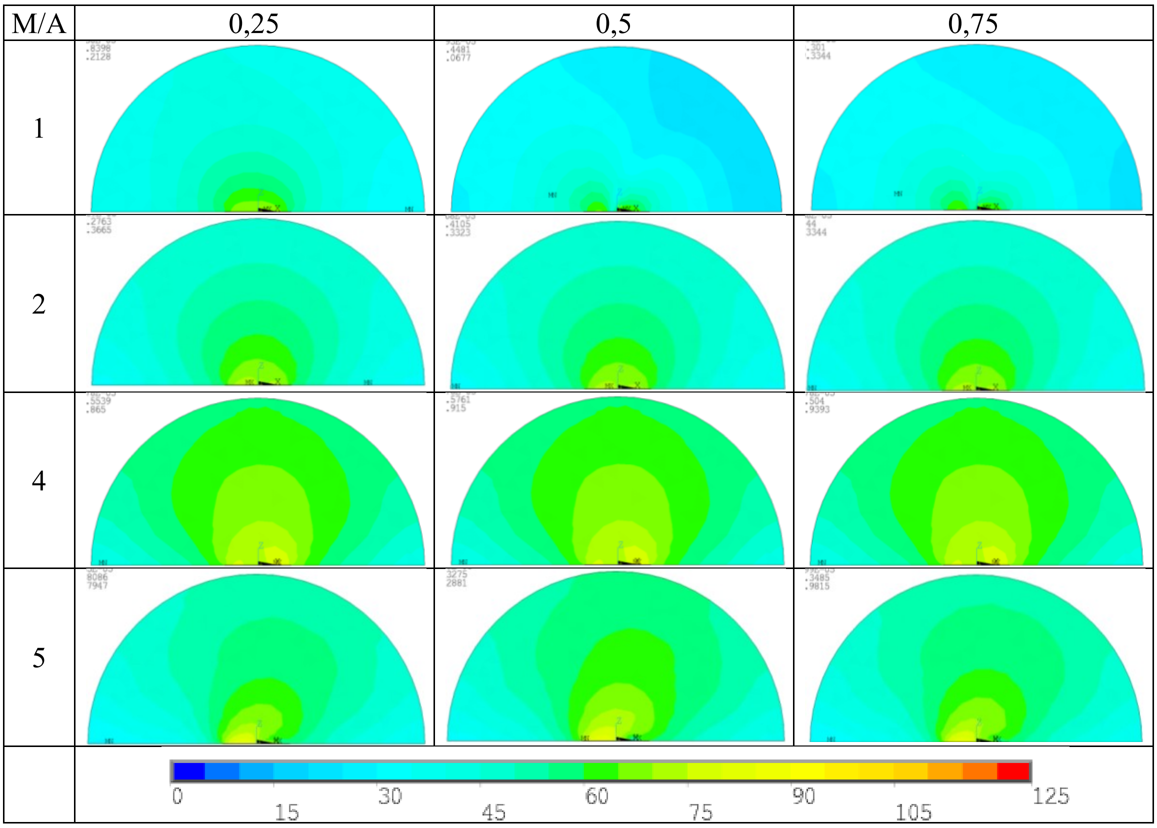

Fig. 8. Numerical results of structure sound pressure levels after reduction using square shaped piezo actuators

Again for the triangle and disc shaped elements only some results will be shown.

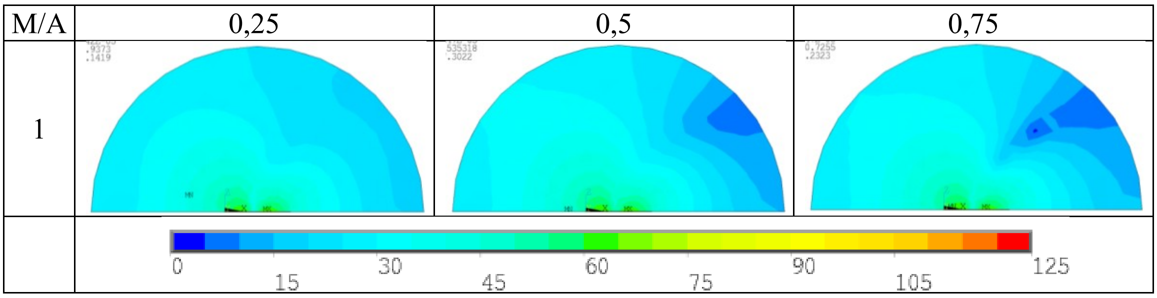

Fig. 9. Numerical results of structure sound pressure levels after reduction using triangle shaped piezo actuators for the 1st mode

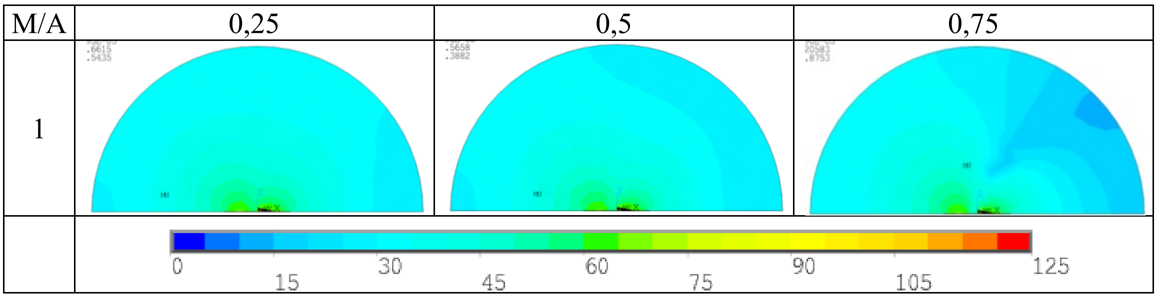

Fig. 10. Numerical results of structure sound pressure levels after reduction using disc shaped piezo actuators for the 1st mode

For both the triangle (fig. 9) and disc shaped (fig. 10) actuators the biggest changes in sound pressure levels distribution after the reduction of plates vibration can be observed for the 1st mode. Unlike for the square based actuators these changes seem to follow a linear trend corresponding to the size of the inner part of the actuator.

4. CONCLUSIONS

When looking at the levels of vibration reduction changing the size of the inner part of a 2-part piezo actuator does not have a great impact on obtained results.

Change in the size and material properties of the inner size of piezo actuator had an effected the distribution of vibration of simulated plate.

Change in the size and material properties of the inner size of piezo actuator had an effect the distribution sound pressure levels emitted from the simulated plate into its acoustical surrounding.

Distinguishable changes to the vibration distribution of the simulated plate doesn't necessarily entail visible changes in structural sound pressure levels distribution in the acoustical surroundings.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

1. W.P. Rdzanek, "*Sound radiation of a vibrating elastically supported circular plate embedded into a flat screen revisited using the Zernike circle polynomials*", Journal of Sound and Vibration, 434, 2018

2. E. Zołopa, A. Brański, "*Comparison of formulas obtained for analytical and LQ idea approaches to determine the optimal actuator location in active multimodal beam vibration reduction*", Archives of Acoustics, 39(4), 2014

3. E.K. Dimitriadis, C.R. Fuller, C.A. Rogers, "*Piezoelectric Actuators for Distributed Vibration Excitation of Thin Plates*", Journal of Vibration and Acoustics, 113(1), 1991

4. M.S. Kozień, Ł. Ścisło, "*Simulation of control algorithm for active reduction of transversal vibrations of beams by piezoelectric elements based on identification of bending moment*", Acta Physica Polonica A, 128(1), 2015

5. R. Trojanowski, J. Wiciak, "*Comparison of Efficiency of Different Shapes of Homogeneous and Two-Part Piezo Elements on Vibration Reduction*", Acta Physica Polonica A, 122(5), 2012

6. M. Wiciak, R. Trojanowski, "*Numerical Analysis of the Effectiveness of Two-part Piezoactuators in Vibration Reduction of Plates*", Acta Physica Polonica A, 125(4A), 2014

7. J. Wiciak, R. Trojanowski, "*Comparison of Vibration and Acoustic Pressure Reduction Using Different Types of Piezo actuators*", Acta Physica Polonica A, 128(1A), 2015