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EXPERIMENTAL INVESTIGATION ON INERTIAL ACTUATORS ARRANGEMENT OPTIMIZATION FOR ACTIVE CONTROL APPLICATIONS

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ABSTRACT

Active control of noise transmitted through structures has been gaining a significant interest. The authors have developed an idea of active casings reducing noise generated by devices. For such noise barriers which vibrations are actively controlled, locations where inertial actuators are attached are crucial. It determines the barrier performance to a great extent. However, its not obvious what is exactly the advantage of a precise modeling and optimization over a random or quasi-random arrangement. Depending on the barrier complexity, the modeling and optimization process may be difficult and time consuming. This paper presents a study investigating this aspect with experimental results, attempting to answer whether the effort are worth the obtained results.

Keywords: *Active structural acoustic control, active noise control, electromagnetic actuators.*

1. INTRODUCTION

Numerous applications employ thin panels and shells to act as noise barriers, which helps to reduce the propagation of sound waves [1–6]. To improve the efficiency of such barriers, active control systems using inertial actuators can be used. Active structural acoustic control (ASAC) systems exhibit excellent performance when applied to individual panels or device casings [7–11]. However, correct positioning of the actuators is crucial for the system to operate effectively, as the proximity of actuators to nodal lines can make controlling cartain modes impossible [12]. Using numerous actuators is necessary to achieve a balanced arrangement, allowing to control multiple modes across a wider frequency range. Nevertheless, it is uncertain whether precise modeling and optimization offer a significant advantages over a random or quasi-random arrangement. The paper's research aims to answer whether the benefits of precise modeling and optimization are worth the effort in terms of system controllability.

2. LABORATORY SETUP

This section describes the experimental setup used in the presented research. The system comprises of a rectangular steel plate that is mounted onto a heavy concrete box and excited with a loudspeaker placed within the box. The loudspeaker is driven to generate a random, broadband noise (band-limited white noise). The concrete walls of the box provide a high degree of noise attenuation, ensuring that the majority of the acoustic energy that exits the box is transmitted through the steel plate. The acoustic excitation distribution across the plate is influenced to some extent by the acoustic modes of the box interior, but laboratory equipment detected all the vibration modes of the panel that can be expected in the considered frequency range. The experimental setup photograph is shown in Figs. 1-2.

For the study, commercially available Dayton Audio DAEX32EP-4 are used as actuators. These are

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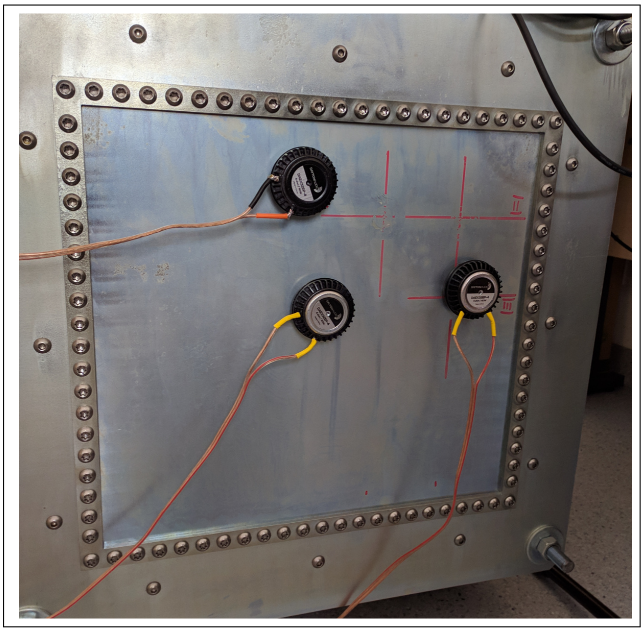

Figure 1. A rectangular plate with attached actuators.

Figure 2. A photograph of the inertial actuator Dayton Audio DAEX32EP-4.

lightweight actuators (123g) of small size (60mm) relative to the plate. Each actuator is magnetically mounted onto the plate using neodymium magnets. The actuator mass is accounted for in the mathematical model, but due to their small height, the actuator moment of inertia is ignored. For efficient mode control, the inertial actuators must be positioned at the anti-nodes of the plate's modes (generating force perpendicular to the panel surface) and kept away from nodal lines as such a mode would be uncontrollable by the particular actuator. Therefore, a mathematical model of the system is required, along with the optimization algorithm, to ensure that at least one actuator for each mode is far from nodal lines and preferably near the anti-nodes [12, 13].

In order to experimentally evaluate the controllability of the system for a particular arrangement of the actuators, a set of paths is identified in form of a mathematical model. The first set represents paths between the noise source (loudspeaker) and the monitoring microphones. The second set represents paths between actuators and the microphones. In both cases the identification is done by exciting the system with a random broadband noise, either by the loudspeaker or the actuators.

3. MEASUREMENTS

An exemplary set of obtained magnitude responses of the identified paths are presented in Fig. 3. The three columns corresponds to three utilized monitoring microphones. The last row presents the noise source's responses, while the middle row shows actuators' responses. Finally, the first row presents a controllability measure, calculated as the actuators' magnitude response divided by the noise source's response. With such a formula, low values of the controllability measure for particular frequencies means that either the actuators' response is weak (the system requires a lot of energy to control) or it means that the noise source's response is strong (the noise is easily transmitted through the barrier in this frequency range and it needs a counteraction from the active control system). Thus, higher values of the controllability measure are beneficial from the control point of view, while dips should be strictly avoided.

As it follows from analysis of Fig. 3, for the considered actuators arrangement it would be difficult to control noise generated around frequencies of 180 Hz and 225 Hz. It would be very energy-consuming or even infeasible. Such dips should be avoided.

In order to optimize the actuators' arrangement, an optimization procedure described in details in [12] is employed. The obtained locations are evaluated experimentally and compared with ten randomly generated arrangement. The controllability measures, averaged over micro-

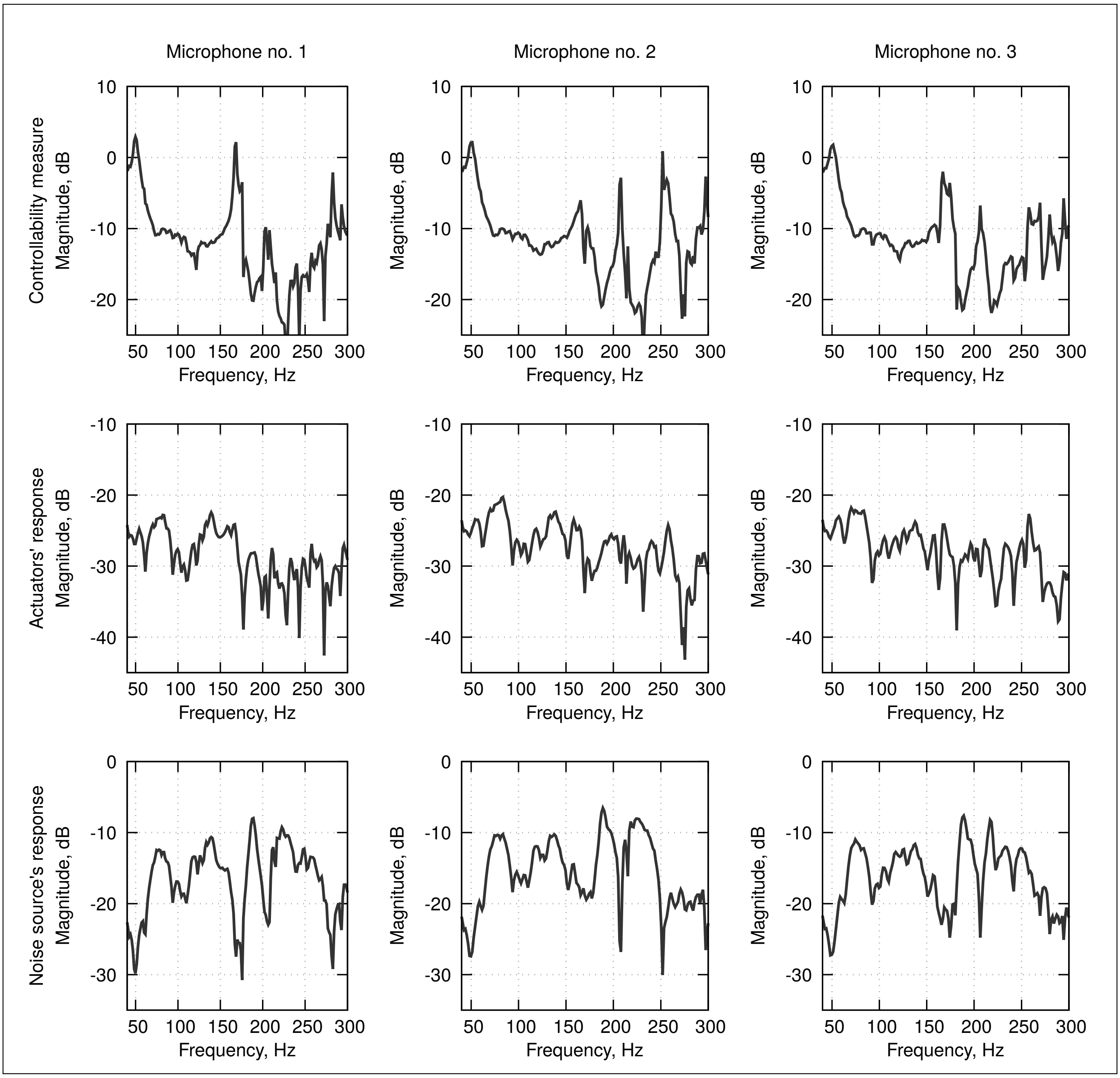

Figure 3. Magnitude responses of paths between actuators attached at positions no. 1, 2 or 3 and microphone no. 1. The figure compares different mountings of the actuator.

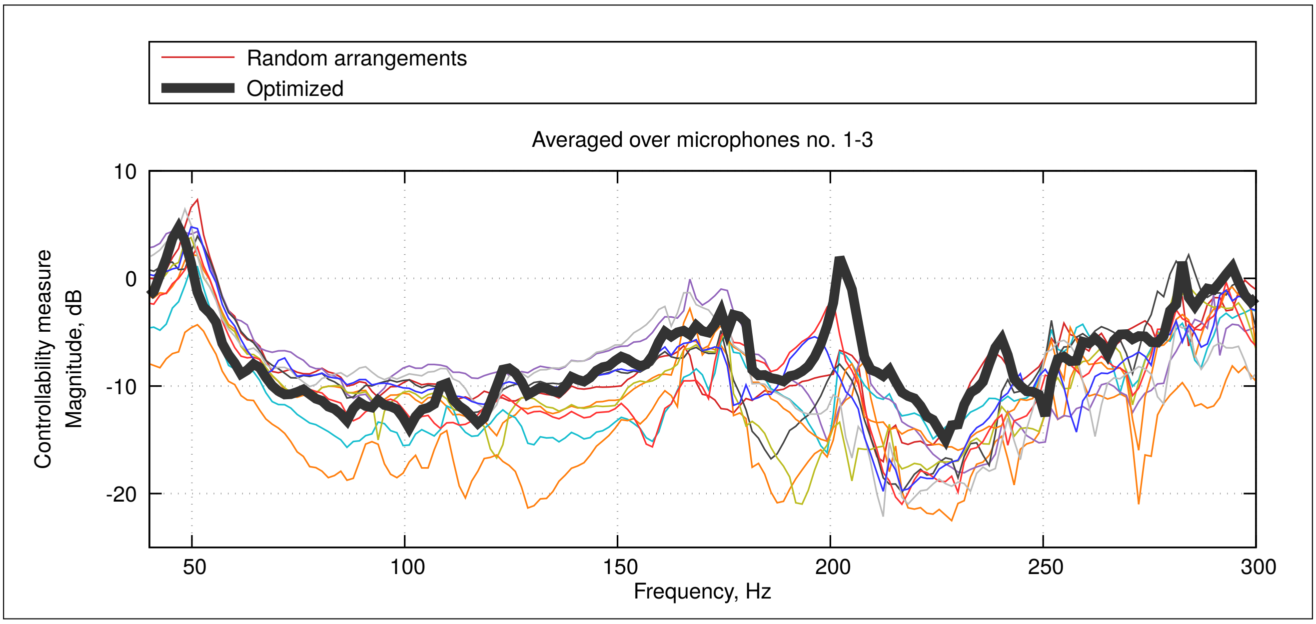

Figure 4. Magnitude responses of paths between actuator attached at position no. 2 and microphone no. 1. The first measurement marked with black colour was followed by another nine, with the actuator detached and attached again at the same position.

phones no. 1-3, are presented in Fig. 4. What follows from analysis of the Figure is that the optimized arrangement resulted in clearly higher values of the controllability measures, compared to random arrangements. The values obtained for optimized arrangement are not always the highest, but the optimization allows to avoid dips. As already mentioned, it is particularly important. To facilitate a comparison, Table 1 shows the minimal value of controllability measures of all evaluated arrangements. The optimized solution allowed to avoid the dips.

4. CONCLUSIONS

This paper experimentally investigated results of optimization process for actuators arrangement. The results were compared with randomly generated arrangement in order to answer a question: is the optimization process worth the efforts?

The analysis of the obtained results clearly shows an advantage of the optimized solution compared to random ones. Although the optimized controllability measures do not dominate over the other randomly obtained solutions, the optimization process allows to avoid the dips in the considered frequency range, which could ruin the active control system efforts.

Table 1. A comparison of minimal values of controllability measures obtained for all evaluated arrangements.

Arrangement no.	min. value of the controllability measure
1	-17.0 dB
2	-22.5 dB
3	-16.1 dB
4	-18.0 dB
5	-19.8 dB
6	-20.9 dB
7	-21.3 dB
8	-20.9 dB
9	-22.1 dB
10	-19.7 dB
Optimized	-15.0 dB

5. ACKNOWLEDGMENTS

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