Proceedings of Meetings on Acoustics

Volume 19, 2013 http://acousticalsociety.org/

ICA 2013 Montreal
Montreal, Canada
2 - 7 June 2013

Structural Acoustics and Vibration
Session 5aSA: Applications in Structural Acoustics and Vibration IV

5aSA8. A low density, high stiffness flat loudspeaker with improved sound frequency response

Jen-Hsuan Ho* and Arthur Berkhoff

***Corresponding author's address: Department of Electrical Engineering, University of Twente, P.O. Box 217, Enschede, 7500 AE, Overijssel, Netherlands, j.ho@ewi.utwente.nl**

This paper presents a novel flat loudspeaker with improved sound frequency response. Flat loudspeakers provide advantages of compact dimensions and high durability. Known flat loudspeaker technology is based on high modal density. However, the resonances in the panel are complex and difficult to control, which often leads to complicated computations and insufficient low frequency response. The flat loudspeaker in this paper comprises a novel panel structure, which offers low density, high stiffness, and efficient space utilization. Furthermore we have developed a simple and stable control mechanism to obtain flat sound frequency response. Experimental results show that our method effectively improves the performance of the flat loudspeaker with extended low-frequency response.

Published by the Acoustical Society of America through the American Institute of Physics

 [DOI: 10.1121/1.4799712]
Received 22 Jan 2013; published 2 Jun 2013

1. INTRODUCTION

The increasing need for compact dimensions in multimedia and home theatre leads to new challenges to the conventional loudspeaker design. Compact loudspeakers often limit the dimensions of the cabinets. Small cabinets have insufficiently room to produce enough sound pressure level at low frequencies. Therefore, sufficient response at low frequencies is often the goal of the compact loudspeaker design. To increase radiating sound power of loudspeakers, particularly at low frequencies, the cabinet plays an important role. The air volume inside the cabinet acts like a mechanical spring because the air has finite compressibility. The smaller the cabinet is the higher is the stiffness, which leads to lower efficiency of producing sound power. Furthermore, conventional techniques attempt to move the membrane or the panel as a single, rigid body and doing the pistonic movement. However, in reality, there is not only the resonance of pistonic vibration but also the resonances of bending waves. These unwanted resonances of the membrane bring a coloured, uneven frequency response of the loudspeaker. In order to have an even frequency response, many researches were trying to eliminate these unwanted resonances by designing the materials, the structure, and the suspension of the membrane. Distributed Mode Loudspeaker (DML) appeared in 90's. Instead of trying to eliminate these unwanted resonant modes, DML uses every resonant modes of the panel [1-3]. DML applies filters to compensate and to equalise the uneven frequency response. This technique offers the advantage of compact dimensions. However, the resonances in the panel are complex and difficult to control, which often leads to complicated computations and insufficient low frequency response. Extended development of DML was to excite the DML panel by several exciters, which is known as Multiactuator Panels (MAPs) [4, 5]. Moreover, an array of loudspeakers is also used to improve the low frequency response [6]. At low frequencies, these small loudspeakers are driven all together, moving like a large loudspeaker. This technique extends the low frequency response by utilising multiple small loudspeakers. However, to obtain a very low frequency response, this technique needs more loudspeakers, since the radiating sound power efficiency of a small loudspeaker is too low at very low frequencies.

In this paper, a novel panel structure, which has low density, high stiffness and offers the advantages of efficient space utilization and lower modal density, is used as the sound radiating panel. Low modal density reduces the complexity of the panel vibration. We have developed a simple and stable control method to improve the sound response of the flat loudspeaker. Our control method comprises of two parts, the first part is to flatten the frequency response and the second part is to increase the response at low frequencies. Moreover, inappropriate control positions can easily lead to an unstable control system. In order to have a stable control system and economic utilisation of sensors, designed positions of sensor and actuator are necessary and have been done in our work.

2. EXPERIMENT SET-UP AND NUMERICAL MODEL

2.1. Experiment set-up

A novel panel structure with low density and high stiffness was used as the sound radiating panel. The panel was attached to the cabinet with rubber suspension on the edges of the panel. Voice coil actuators were attached to the panel to excite the panel. The dimensions of the panel were 605*415*22 mm^3. The mode shapes and the resonant frequencies of the panel were measured while a shaker applied force on various positions of the panel (Figure 1). The microphone was put 5 cm above the panel to measure the near-field radiating sound pressure from the panel.

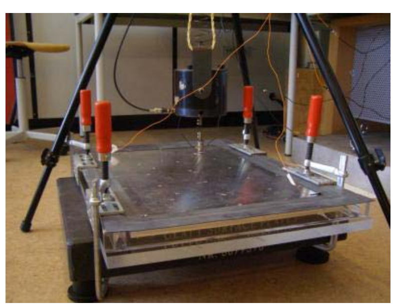

FIGURE 1. Mode shapes and resonant frequencies measurement of the panel attached to the cabinet.

2.2. Numerical Model

We used the finite element method (FEM) with the COMSOL Multiphysics 4.2 (COMSOL, Inc., Burlington, MA 01803, USA) to model our system. To accurately model the characteristics of the system, the acoustic and structural properties must be considered simultaneously. There were two domains in our model: the fluid domain and the solid domain. The physical quantities on the fluid-solid interacting boundaries of these two domains were coupled. On the fluid-solid interacting boundaries: The fluid pressure in the fluid domain produced the normal force to the structure in the solid domain. In the meanwhile, the normal acceleration to the acoustic pressure in the fluid domain can be derived from the acceleration of the structure in the solid domain. To validate our numerical model, we compared the resonant frequencies between the simulation and experiment. Table 1 shows that our numerical model can estimate the resonances of the system with reasonable error.

TABLE 1. Resonant frequencies of the panel.

Mode	Experiment [Hz]	Simulation [Hz]	Error
1	221	218	1.3%
2	256	243	5.0%
3	506	510	7.9%
4	571	541	5.2%
5	611	643	5.2%

3. CONTROL PERFORMANCE

3.1. Control and Excitation Positions

We applied voice coil actuators on the panel to excite and control the panel. However, the position of the actuators affects the vibration response of the flat loudspeaker system. Figure 2 shows the kinetic energy response of the panel varies when the excitation position changes. The energy of the near field sound pressure wave is related to the kinetic energy of the radiating panel at lower modes [7]. Therefore, the kinetic energy of the radiating panel can represent the near field sound.

Moreover, the configuration of the sensors and actuators also affects the control stability and performance. Therefore, we have analysed the response and the mode shapes of the flat loudspeaker to obtain the optimal control configuration. Figure 3 shows the near-filed sound pressure level response of the control results of two sensor-actuator configurations. With control, the first resonant peak was reduced remarkably by both of these two configurations. However, the resonant peak at 420 Hz was hardly reduced by applying sensor-actuator configuration 2. This peak was even increased by applying sensor-actuator configuration 1. In order to control this resonant peak, a further sensor-actuator configuration design is necessary. Therefore, we selected different detection and excitation positions based on the mode shapes analysis.

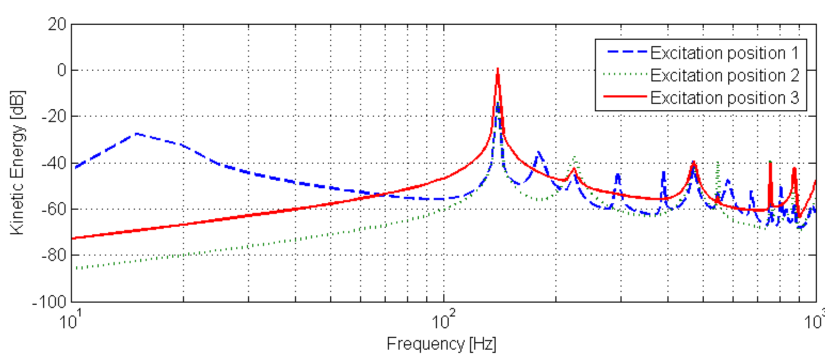

Figure 2. Simulation of the kinetic energy response of the panel with various excitation positions.

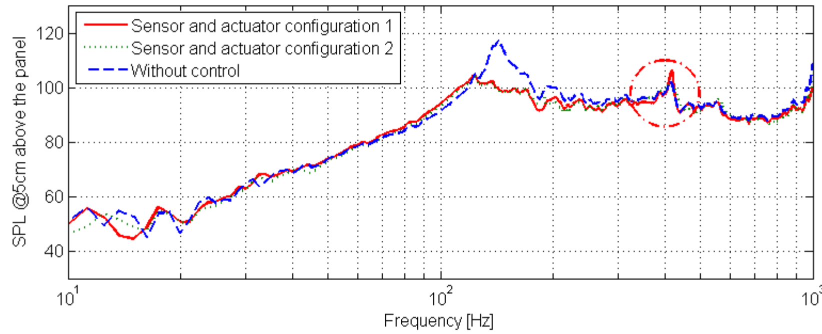

FIGURE 3. Sound pressure level (SPL) response of the flat loudspeaker with various sensor-actuator configurations.

3.2. Combined Control Performance

With further mode shapes analysis, the optimised control configuration 3 was obtained. This configuration did not only reduce all the resonant peaks below 1 kHz, it also reduced the amount of sensors. Figure 4 shows that the control method 1 remarkably flattened the sound response of the flat panel. With the combination of method 1 and 2, the insufficient response of the loudspeaker at low frequencies can be increased.

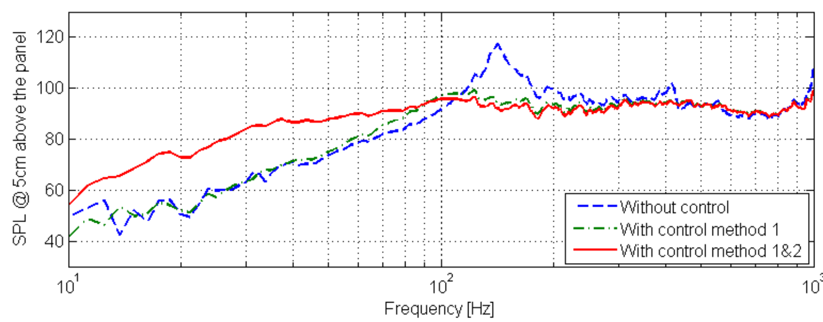

FIGURE 4. SPL response of the flat loudspeaker with control sensor-actuator configuration 3.

4. CONCLUSIONS

A flat loudspeaker comprising a novel panel structure with a stable and simple control method has been studied in this paper. This novel panel structure offers low density, high stiffness, and efficient space utilization. Our work shows the sound frequency response of the flat panel can effectively be flattened. The insufficient response of the flat panel loudspeaker at low frequencies can be increased. Furthermore, appropriately designed positions of sensors and actuators can stabilize the control system and minimize the amount of sensors. The flat loudspeaker in this paper obtains a very even frequency response below 1kHz to 30Hz and offers compact dimensions, a simple algorithm, a stable control, fewer sensors.

ACKNOWLEDGMENTS

This work was supported by STW (De Stichting voor de Technische Wetenschappen, The Foundation for Technical Sciences), project No.10602 IMPEDANCE (Integrated Modules for Power Efficient Distributed Active Noise Cancelling Electronics). The experimental development was supported by Henny Kuipers and Geert Jan Laanstra of the Signals and Systems Group, Faculty of EEMCS, University of Twente.

REFERENCES

1. N. Harris and M.O. Hawksford. "The Distributed-Mode Loudspeaker (DML) as a Broad-Band Acoustic Radiator," in the 103rd Convention of the Audio Engineering Society, September, 1997, New York, USA.
2. J. Panzer and N. Harris, "Distributed-Mode Loudspeaker Radiation Simulation," in the 105th Convention of the Audio Engineering Society, September, 1998, San Francisco, USA.
3. N.J. Harris and M.O.J. Hawksford, "Introduction to distributed mode loudspeakers (DML) with first-order behavioural modeling," Circuits, Devices and Systems, IEE Proceedings, **147**(3), 153-157(2000).
4. D. Beer, S. Mauer, S. Brix, and J. Peissig, "Flat Panel Loudspeaker Consisting of an Array of Miniature Transducers," in the 126th Convention of the Audio Engineering Society, May, 2009, Munich, Germany.
5. M. M. Boone, "Multi-Actuator Panels (MAPs) as Loudspeaker Arrays for Wave Field Synthesis," Journal of the Audio Engineering Society, **52**, 712-723(2004)
6. M. Kuster, D. De Vries, D. Beer, and S. Brix, "Structural and acoustic analysis of multiactuator panels," Journal of the Audio Engineering Society, **54**, 1065-1076(2006).
7. M.E. Johnson and S.J. Elliott, "Active control of sound radiation using volume velocity cancellation," Journal of the Acoustical Society of America, **98**, 2174-2186(1995).