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Evaluation of Vibrating Sound Transducers with Glass Membrane Based on Measurements and Numerical Simulations

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ABSTRACT

In recent years manufacturers introduced so-called "invisible sound" solutions. In-wall, surface mount or glass mount versions of different vibrating transducers are commercially available. The entire surface becomes a speaker delivering sound and the frequency response is said to be equivalent to conventional diaphragm speakers. Furthermore, the sound is omni directional at nearly all frequencies (60 Hz - 15 kHz) while channel separation is maintained. This paper presents measurement results of the SolidDrive SD1g transducer mounted on different glass surfaces, including vibration measurements and acoustic parameters. Furthermore, based on a numerical FEM-model using COMSOL, comparison between measured and simulated results and estimation of transfer function and directional characteristics are presented.

1. INTRODUCTION

Measurement techniques and vibration analysis of conventional loudspeakers, transducers and vibrating membranes have a long history and literature. Furthermore, the use of modern numerical techniques, software solutions for finite or boundary element methods (FEM, BEM) allowed analysis and evaluation based on simulations [1-4].

Some manufacturers offer “hidden sound” solutions instead of classical loudspeaker setups. They are said to be powerful hidden sound transducers that transmits acoustical energy through almost any solid surface. The entire surface becomes a speaker delivering sound and the frequency response is similar to conventional diaphragm speakers. It works with rigid surfaces that include glass, drywall, granite, metal, wood, ceramics, laminates and composites. It could be ideal anywhere an invisible sound source is needed. The technology utilizes very high-powered neodymium magnets and dual symmetrically opposed motors to convert audio signals into powerful vibrations. Sound is generated from these large acoustic-radiating surfaces, and the listener becomes immersed in sound. The sound is omni directional at nearly all frequencies while channel separation is maintained.

All these statements are available in the manufacturers' commercials and homepage, but there are no proof or control measurements. Furthermore, there is no data about actual installations and parameters if the transducer is mounted on a surface. It is clear, that acoustic parameters of the stand-alone transducer differ from parameters obtained e.g. with a glass membrane of 50x50 cm.

2. METHOD OF ANALYSIS

The methods for analysis of transducers and loudspeakers include measurements and simulations using numerical models. Measurements of acoustical (transfer function, sensitivity, directional properties) and mechanical parameters (vibrations, modes) are the most important during design.

Accurate measurement of the effective radiation area of loudspeakers is important because this parameter determines the acoustical power and the efficiency. The conventional methods can fail when the surround geometry is complex and the excursions do not vary linearly [5]. Accurate measurements of the acceleration, velocity, and displacement of a loudspeaker cone can be carried out with the use of a light accelerometer. From these measurements the low-frequency acoustical steady-state performance can be derived [6]. The method is useful in that it dispenses with the need of an anechoic chamber. The accuracy of the measurements permits an easy evaluation of the low-frequency loudspeaker parameters. Laser can be also used to measure vibration and geometry of the radiator [2, 5]. Good knowledge of the velocity distribution on a vibrating surface permits computing the near field from this surface correctly. The amplitudes and phases of the displacement at each point on a source (e.g. a loudspeaker diaphragm) can be determined with harmonic excitation [7]. In a different study, vibroacoustic behavior of a set of loudspeakers below 1 kHz was studied by comparing measurements and element model simulations using analytical, finite- and boundary-element methods, and finite-difference methods [2]. A FEMLAB model of a panel with attached masses was developed and the modes of a loudspeaker were analyzed in [3]. The aim was to make minor modifications to the panel with properly attached masses which will be sufficient to improve its sound pressure response in a given frequency band. Based on the established model, a series of optimized positions of various attached masses was presented using genetic algorithm. The corresponding sound pressure responses were also calculated using the FEMLAB. The attached-masses method (AMM) was verified by experimental investigations.

The goal of our investigation was to test the manufacturer's statements about the transducer, to test different glass surfaces in real-life applications and compare measurement results with numerical simulations. In case of reliable simulations, extensive measurement procedures can be avoided during design and setup of installations. A good FEM model can predict acoustic behavior of the system.

The measurements used the SolidDrive SD1g transducer mounted on glass surfaces with different geometrical parameters, size, form and weight. Measurements included 30-channel vibration measurements and simulations using a Finite-Element-Method (FEM) model. The COMSOL Multiphysics simulation software environment facilitates all steps in the modeling process − defining geometry, meshing, specifying physics, solving, and then visualizing results. Measurements results were compared with simulations. A good agreement allows us to test other geometries and surfaces based on the FEM model and gives opportunity for design, manufacture and maintenance of several applications.

Based on the operation manual of the transducer, acoustic parameters are listed as follows [8]:

- broadband, 70 – 15000 Hz (depending on the vibrating surface),
- impedance 8 Ohm,
- mass 0,5 kg,
- recommended amplifier power 10-100 W,
- sensitivity: N.A.,
- vibrating membrane: glass, wood,
- high-power neodymium magnet, two symmetrical motors,
- achieved STI (Speech Transmission Index) is "excellent": 0,75 points.

Other manufacturers such as PowerView, Feonic [9, 10] offer very similar transducers. There are neither recommendations nor measurement data for size, material, geometry of the applied glass membrane, for placement of the transducer or for mounting of the entire system.

3. VIBRATION MEASUREMENTS

The goal was to measure the vibration modes of the plates in order to compare these with the applied FEM model. For the measurements MLS [12] and white noise excitation, calibrated accelerometers, NI Compact RIO-9014 device and MATLAB were used. For a 30-channel measurement the accelerometers were distributed uniformly over the membrane (Fig.1.). The transducer was mounted on the glass plate by 3M scotch tape without coincidence with any symmetry axis or vibrating node.

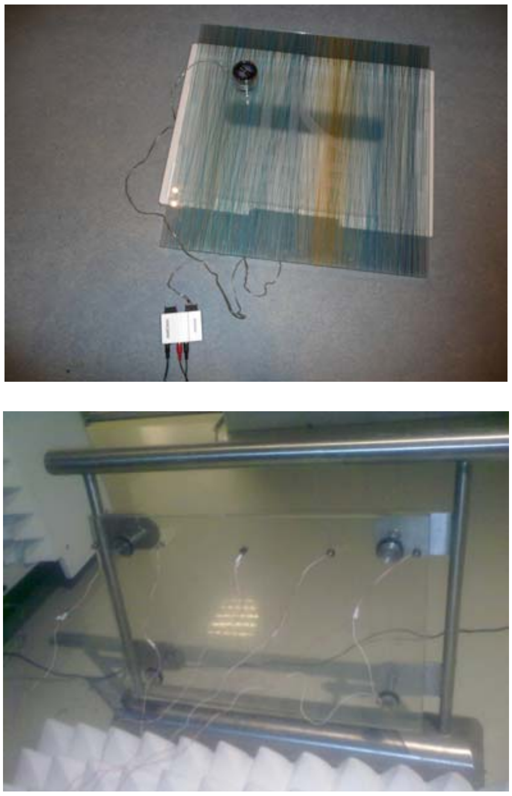

Fig.1. The transducer mounted on the one-layer glass with a digital amplifier (top) and fixing of the glass for the vibration measurements (bottom).

Size of the measured devices were: 50x50x0,6 cm one-layer glass (5x5 cm sectors) and 96x,31x0,8 cm two-layer glass (6,2x4,8 cm sectors). Figures 2 and 3 show the resonances for both types.

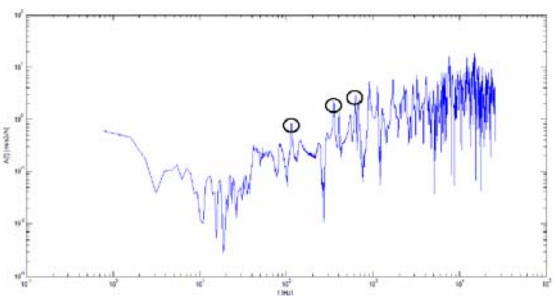

Fig.2. Resonances of the one-layer glass membrane (113, 354, 629 Hz).

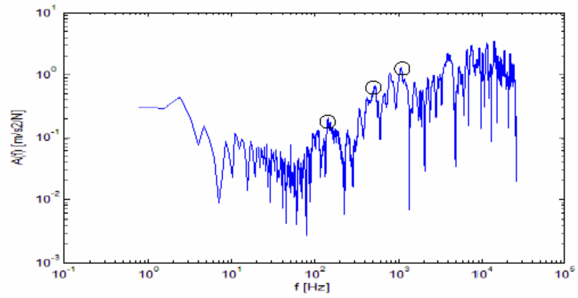

Fig.3. Resonances of the two-layer glass membrane (142, 540, 1077 Hz).

Measruement of the impeadance of the transducer and its wiring without membrane attached showed 6,8 Ohm for /Z/ and 6,55° for phase at 1 kHz (accuracy 1%).

4. SIMULATION

For the numerical analysis COMSOL Multiphysics 3.5 (former FEMLAB) was used on a Sun Fire X2250 computer system with 2xDual Core Xeon 5160 processors and 32GB DDRII ECC RAM modules [12]. Figures 4-6 show the vibrating plate from measurements (left) and simulation (right) at the resonance frequencies.

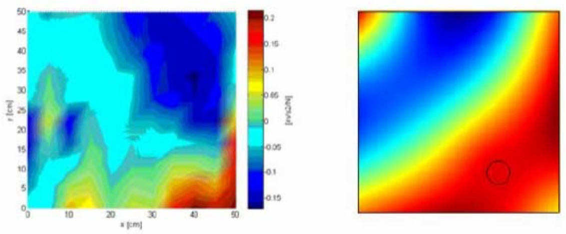

Fig.4. Vibration plots of the membrane at 113 Hz from a 30-channel measurement (left) and COMSOL simulation (right).

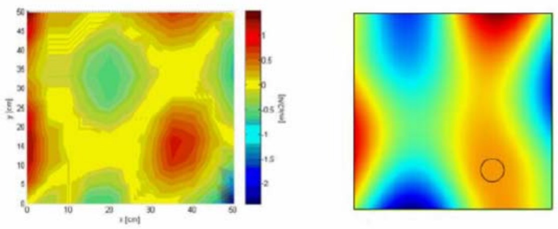

Fig.5. Vibration plots of the membrane at 354 Hz from a 30-channel measurement (left) and COMSOL simulation (right).

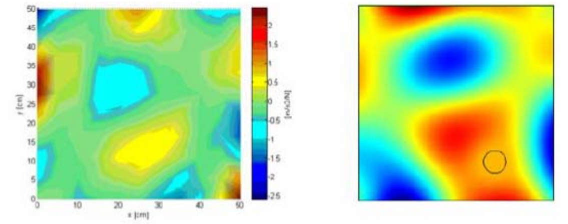

Fig.6. Vibration plots of the membrane at 629 Hz from a 30-channel measurement (left) and COMSOL simulation (right).

Figure 7 shows simulated transfer function of the one-layer glass. Different sizes and forms showed almost identical transmission to this.

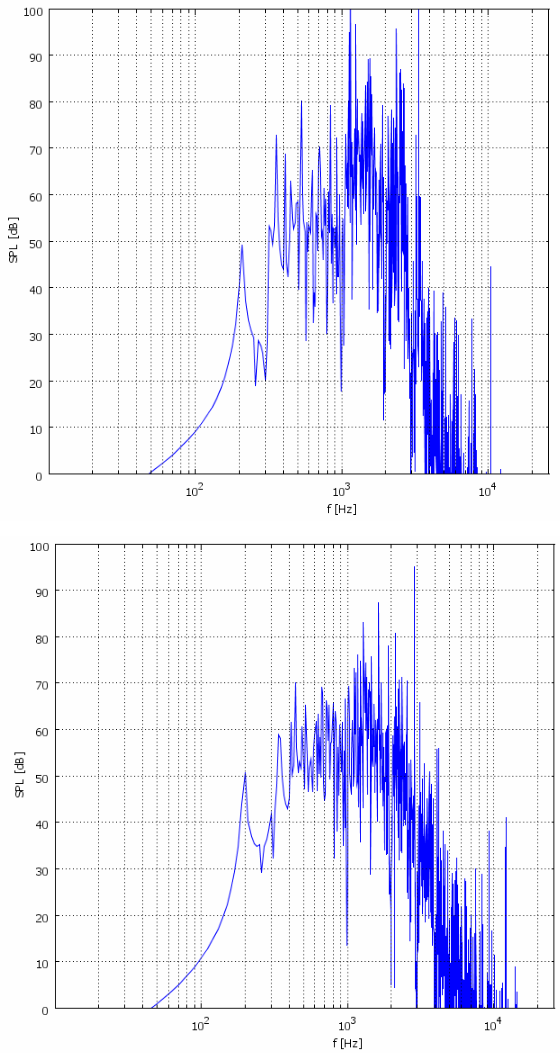

Fig.7. Simulated transfer function of the 50x50x0,6 cm glass (top) and 75x75x0,6 cm glass (bottom). There is no significant energy radiation above 10 kHz.

4.1. Size

Effect of the size of the glass membrane was analyzed based on the directional characteristics. Because this is very time consuming, a 2x1 m rectangle plane and four frequencies were selected for the evaluation.

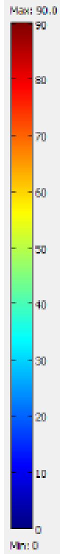

Fig. 8 shows the simulated results of the one-layer plate mentioned above. At 300, 1000 and 3000 Hz it radiates almost uniformly (50-60 dB), but at 10 kHz the SPL is about 20 dB at only 0,3 m from the plate. The color bar shows SPL in dB.

Increasing the size of the glass up to 75x75 cm, the low frequency transmission increases (+25 dB at 300 Hz), other frequencies are not affected (Fig. 9). A 100x100 cm glass has a better middle range, but a decreased low range transmission.

Increasing the thickness has no clear effect either. Doubling the thickness results in reduced middle and high range transmission. 3-times of the thickness caused increment at 3 kHz (10 dB) as long 4-times of the thickness caused increase at 1 kHz. There is no effect of the size on the transmission above 10 kHz.

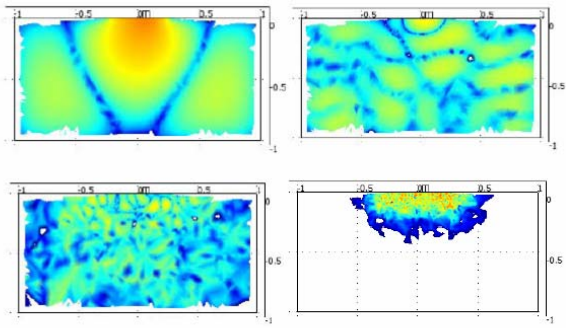

Fig.8. Simulated directional patterns of the 50x50 one-layer glassplate at 300 Hz (top left), 1 kHz (top right), 3 kHz (bottom left), 10 kHz (bottom right).

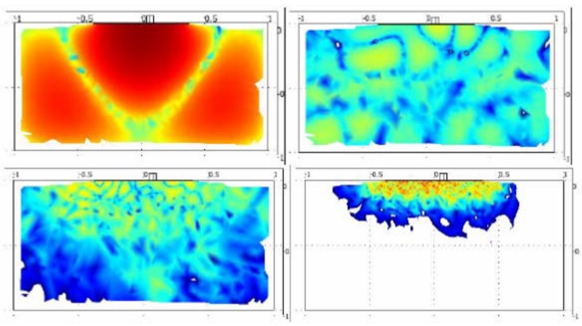

Fig.9. Simulated directional patterns of the 75x75 one-layer glassplate at 300 Hz (top left), 1 kHz (top right), 3 kHz (bottom left), 10 kHz (bottom right).

4.2. Geometry

Geometry and shape of vibrating plates can influence the transmission [4, 13]. For simulating different geometries we used circle-shape glass with 25 cm and 50 cm radius as well as an ellipse (2:1 axis ratio). The 25-cm radius circle has decreased transmission of about 5-6 dB at 1 kHz, and 8-10 dB increment at 3 kHz in contrast to the 50x50 cm rectangle. The 50-cm radius circle has a better low frequency transmission, but less improvement at 3 kHz. The ellipse has almost the same transmission as the 4-times thicker glass rectangle, only 20 dB better at 1 kHz. Increasing the side-ratio of the rectangular shape results in no significant difference. Figure 10 shows vibration plots computed by COMSOL.

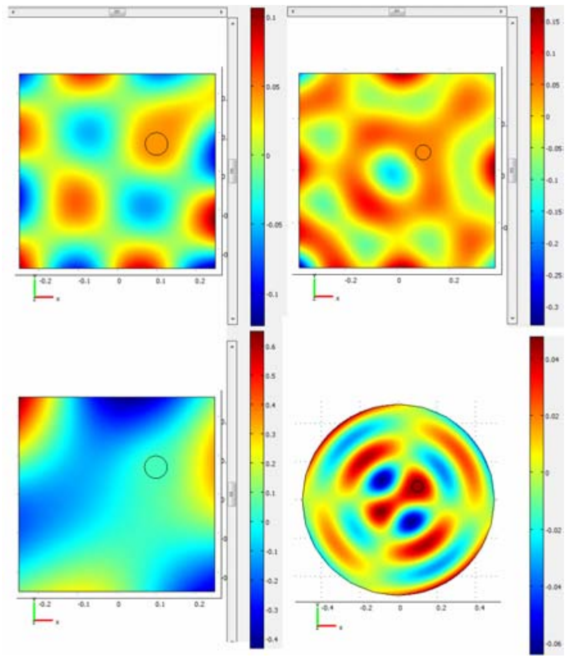

Fig.10. Vibration plots [1 kHz, m/s^2] of the 50x50x0,6 (top left), 75x75x0,6 (top right), 50x50x2,4 (bottom left), r = 50 cm circle (bottom right) membrane.

4.3. Material

Other materials for the simulation were: beech tree, steel and marble with the size 50x50x0,6 cm. Surprisingly, there was no difference in the directional characteristics, only the vibration modes were somewhat different.

5. DISCUSSION

Based on the measurement results, the FEM model simulation is capable to estimate acoustic behavior of the vibrating plate. This includes vibration modes and computed transfer functions and directional characteristics. The transducer was placed in a non-symmetrical way on to the plate and the resonance frequencies were determined. Transmission between 200 Hz and 10 kHz can be maintained almost independently of size and material. Sensitivity and reproduced SPL is relatively low, however, directional characteristics show almost plane wave propagation. The use of a supplementary subwoofer system is recommended. Table 1 lists the SPL levels (sensitivity) for different sizes based on the simulation.

Object [cm]	SPL @ 1 kHz, 1 m
50x50x0,6 glass	38
75x75x,0,6 glass	67
100x100x0,6 glass	41
50x50x1,2 glass	46
50x50x1,8 glass	42
50x50x2,4 glass	32
25x50x0,6 glass	33
25x75x0,6 glass	22
r=25 circle, glass	18
r=50 circle, glass	30
ellipse, glass	50
50x50x0,6 steel	38
50x50x0,6 marble	38
50x50x0,6 wood	38

Table 1. Simulated SPL values at 1 kHz, 1 metre from the membrane (symmetry axis).

These systems are not able to replace conventional loudspeakers if high audio quality is needed. On the other hand, "invisible audio" solutions, designer applications with acceptable quality of musical and speech transmission can benefit from this technology. Installations, exhibitions, conferences, commercials (shop windows), architectural applications can use this hidden loudspeaker technology.

6. SUMMARY

The SolidDrive SD1g resonator with membranes of different size, geometry and material were measured and analyzed based on FEM models using the COMSOL software. The simulation focused mainly on glass membranes. The sound quality is moderate, there is no energy radiated below 200 Hz and above 10 kHz and sensitivity is also relatively low (below

50 dB). Size, geometry (form) and material do not influence simulation results significantly. Decreased directivity suggests applications where plane waves are required and the localization of the sound source is not relevant. Future works includes further simulations to determine the effect of placement of the transducer, mounting of the plate and sensitivity measurements. Listening tests are planned to verify the STI and subjective impressions of sound quality.

7. REFERENCES

[1] A. A. Piacsek, and R. T. Muehleisen, "Using COMSOL multiphysics software to investigate advanced acoustic problems," *J. Acoust. Soc. Am.*, vol. 130, no. 4, pp. 2363-2363, 2011.

[2] M. Karjalainen, V. Ikonen, P. Antsalo, P. Maijala, L. Savioja, A. Suutala, and S. Pohjolainen, "Comparison of Numerical Simulation Models and Measured Low-Frequency Behavior of Loudspeaker Enclosures," *J. Audio Eng. Soc.,* vol. 49, no. 12, pp. 1148-1166, 2001.

[3] S. Zhang, Y. Shen, X. Shen, and J. Zhou, "Model Optimization of Distributed-Mode Loudspeaker Using Attached Masses," *J. Audio Eng. Soc.,* vol. 54, no. 4, pp. 295-305, 2006.

[4] C.-F. Liu, and Y.-T. Lee, "Finite Element Analysis of Three-Dimensional Vibrations of thick circular and annular Plates," *Journal of Sound and Vibration*, vol. 233, no. 1, pp. 63-80, May 2000.

[5] W. Klippel, and J. Schlechter, "Dynamic Measurement of Transducer Effective Radiation Area," *J. Audio Eng. Soc.,* vol. 59, no. 1/2, pp. 44-52, 2011.

[6] J. Christophorou, "Low-Frequency Loudspeaker Measurements with an Accelerometer," *J. Audio Eng. Soc.,* vol. 28, no. 11, pp. 809-816, 1980.

[7] A-M. Bruneau, "Amplitude and Phase Measurements of Vibrations of Radiating Surfaces in Order to Determine the Emitted Sound Field," *J. Audio Eng. Soc.,* vol. 31, no. 12, pp. 907-913, 1983.

[8] http://www.soliddrive.com/

[9] http://www.feonic.com/

[10]http://www.powerview.com/GlassResonator.html

[11] D. D. Rife, and J. Vanderkooy, "Transfer-function measurements with maximum-length sequences," *J. Audio Eng. Soc.,* vol. 37, no. 6, pp. 419-444, 1989.

[12] http://www.comsol.com/

[13] F. Tornabene, "Free vibration analysis of functionally graded conical, cylindrical shell and annular plate structures with a four-parameter power-law distribution," *Computer Methods in Applied Mechanics and Engineering*, vol. 198, no. 37-40, pp. 2911-2935, August 2009.