Multi-Diaphragm Micro-Speaker Vs. Single-Diaphragm Micro-Speaker

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Multi-diaphragm Micro-speaker vs. Single-diaphragm Micro-speaker

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ABSTRACT

With wearable devices becoming increasingly popular, there is a foreseeable paradigm shift for small format or miniature audio transducers in the near future. Small single diaphragm micro-speaker transducer no longer meets the new expectations both in low frequency performance and overall sound pressure level. In this paper a new multi-diaphragm micro-speaker is presented. The acoustic performance of the transducer is simulated using finite element method. Furthermore, this paper analyses the low frequency performance between the single diaphragm micro-speaker and the multi-diaphragm micro-speaker.

1 Introduction

Current single diaphragm micro-speaker originated from conventional loudspeaker design with some modifications: in order to save space, the spider was eliminated and surround was changed to diaphragm-surround one-piece design. Therefore, micro-speaker is characterized by its simplicity and size. The small speaker diaphragm cannot move much air so that air loading or in another word, radiation mass is low. An obvious idea is to employ multiple diaphragms and using push-pull mechanism to get maximum air loading. From regular sized loudspeaker to micro-speaker there are two physical quantities that remain roughly unchanged: first is boundary layer and second is motor strength. The boundary layer provides us a possibility of using more narrow slits in the micro-speaker to increase acoustic resistance, and second advantage is small volume magnet can provide similar motor strength as large magnet does, even though somewhat smaller. To increase the sensitivity of the micro-speaker multiple magnets are needed.

2 Design the new micro-speaker

First, we will begin by looking at the conventional micro-speaker. Then we will introduce the new multi-diaphragm micro-speaker.

2.1 Conventional micro-speaker

A typical conventional micro-speaker is consisted of: a coil, a magnetic circuit, diaphragm, surround and frame. The magnetic circuit is consisted of top plate, a magnetic yoke and a magnet. It is assembled as Figure 1.

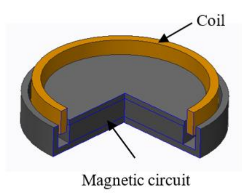

Figure 1. Section view of a typical conventional single diaphragm micro-speaker motor.

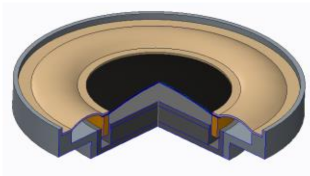

Figure 2. Section view of a typical conventional single diaphragm micro-speaker.

2.2 Design of the new multi-diaphragm micro-speaker

Take a four-diaphragm micro-speaker as an example, Figure 3 presents a cross section view of the new multi-diaphragm micro-speaker.

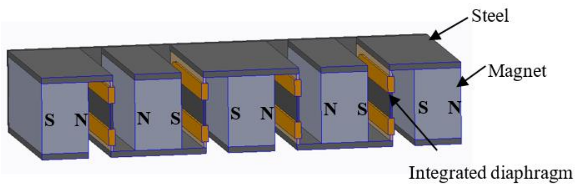

Figure 3. Section view of the multi-diaphragm micro-speaker (For example, four diaphragms.)

In Figure 3, N represents North pole of the magnet, and S represents South pole of the magnet. When planar coils (in yellow color) excited by electrical current the integrated one-piece coil-diaphragm-surround assembly will experience the Lorentz force and move. Selection of the appropriate voltage polarity allows us to have diaphragms face to face motion and therefore results in the sound radiation from the multi-slits of the transducer.

2.3 Coil-diaphragm-surround, one-piece part for the multi-slits micro-speaker

As a key component of the new micro-speaker a new coil-diaphragm-surround one-piece part was invented as shown in Figure 4(each has three components) and Figure 5(three-part assembly).

Figure 4. Three coplanar micro-speaker components.

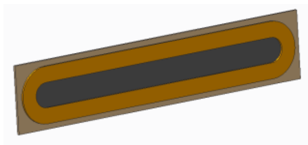

Figure 5. Integrated Coil-diaphragm-suspension, co-molded part for the new micro-speaker.

In Figure 4, the yellow (on the top) color coil is a planar copper (or other conductor such as aluminium, etc.) coil, the middle is diaphragm. It can be any non-magnetic and light weight material. The bottom is the suspension piece, which is made from the easy to co-molded material, such as rubber or polyurethane et cetera. These three parts should be made as a one-piece part as shown in Figure 5 and the suspension edge should be seamlessly fixed to the micro-speaker frame.

2.4 Assemble the sample micro-speaker

Figure 6 shows the multi-diaphragm micro-speaker assembly. Under the frame there are four diaphragms, which radiate sound from four slits openings from the front of the speaker.

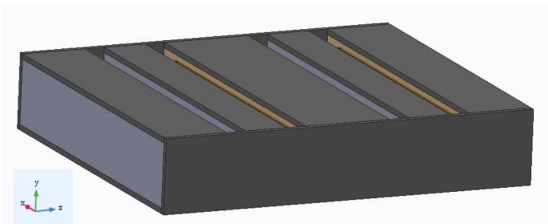

Figure 6. The micro-speaker assembly (18mm x 15mm x 3.5mm).

3 FEA simulation of the micro-speakers

3.1 Magnetic circuit and Lorentz force

Simulation and optimization of the static magnetic field in air gap is considered the first step to design a multi-diaphragm transducer. Second is to calculate Lorentz force applied to each coil. As in Figure 7 below magnetic flux lines indicate flux density B field direction and magnitude.

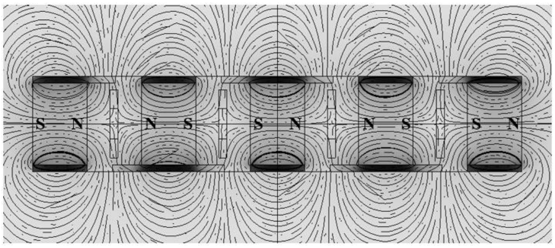

Figure 7. Magnetic flux density B field in the air gap of the multi-diaphragm micro-speaker.

BL, is the single coil force factor and its value is magnetic flux density B multiplying coil wire length L. For this specific case coil is in 40 turns and coil wire diameter is 0.07mm. Based on finite element analysis, BL is 0.32Wb/m.

The coil in Figure 4 has an inductance L_b curve:

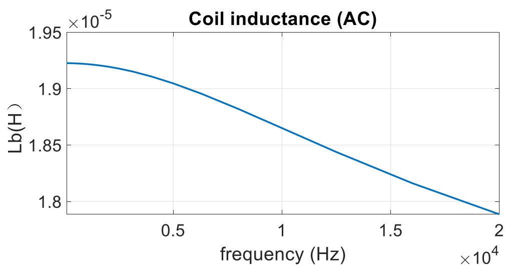

Figure 8. Coil inductance vs. frequency

And the coil resistance R_b curve:

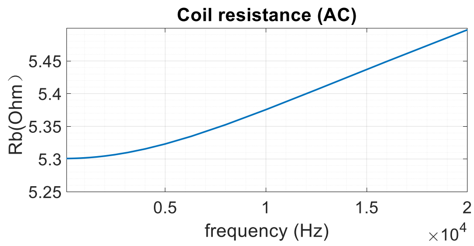

Figure 9. Coil resistance vs. frequency

Therefore, blocked coil impedance:

$$Z_b = R_b(freq) + 2\pi i * freq * L_b(freq) \quad (1)$$

Suppose each coil velocity is v_i (using Comsol denotation),

$$v_i = aveop\_i(solid.u\_tZ) \quad (2)$$

For this special case $i = 1,2,3,4$.

Assuming applied voltage is $V0$, for each coil, Lorentz force is:

$$F_i = BL * (V0 - BL * v_i)/Z_b \quad (3)$$

For this special case $i = 1,2,3,4$.

In Figure 6, y-axis is in vertical direction all the F_i is in xz-plane. Also, here choose +z-axis from left to right of the micro-speaker in Figure 6.

3.2 Sound pressure frequency response of the multi-diaphragm micro-speaker

In order to obtain the sound radiation from the micro-speaker, a signal voltage (for example, 2.83 volts) is applied to each coil. In this simulation model four forces in the form of equation (3) are applied to each terminal of the four coils. Also, to optimize the sound radiation the polarity of each voltage is considered. All these can be implemented in Comsol Solid Mechanics module.

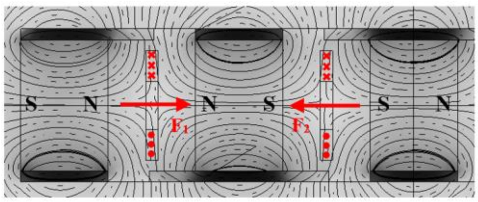

Figure 10. Lorentz force is applied to each coil (Only coil1 and coil2 are demonstrated).

A 3-D Comsol model for sound pressure calculation is created. A Perfect Matching Layer (PML) is considered and the mesh is created to meet maximum analysis frequency to 10kHz: maximum element size is chosen as 342m/s /10kHz/5.

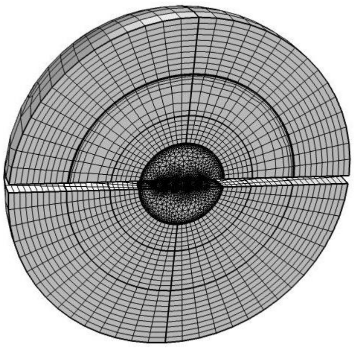

Figure 11. 3D model for free field sound pressure calculation of the micro-speaker

In this model: Pressure Acoustics, Frequency Domain (acpr), and Solid Mechanics (Solid) two modules are included. In Multiphysics node: Pressure Acoustic (acpr) and Solid Mechanics (Solid) are coupled together.

In Figure 12, at one moment, the diaphragms face to face vibrated in xz-plane and the sound radiated in + y-axis(up); same time the diaphragm back side surfaces breathed air from -y-axis(down), vice versa. From Figure 12 also, the diaphragm vibrations can be monitored and see if the system works properly.
In Figure 13, the baffled free field sound radiation at certain frequency of the multi-diaphragm transducer is presented.

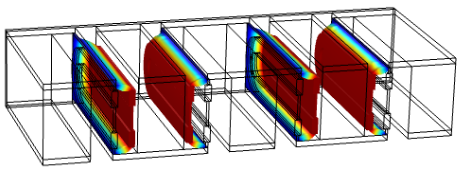

Figure 12. Diaphragm vibrations of the micro-speaker

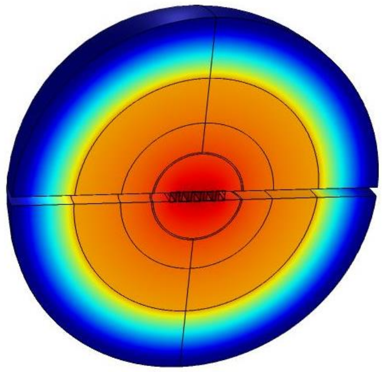

Figure 13. Free field Sound Pressure Level of the multi-diaphragm micro-speaker

At 2.83 volt and 1 meter from acoustic center (here is geometric center) on axis, half space, sound pressure level frequency response is:

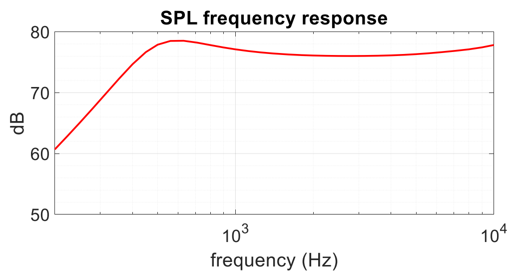

Figure 14. Sound pressure level frequency response of the multi-diaphragm micro-speaker

3.3 Sound pressure frequency response of a single-diaphragm micro-speaker

Consider a typical conventional micro-speaker as shown in Figure 2. We choose the right dimensions and magnet circuit to make it the same force factor BL and same occupying space as the multi-diaphragm micro-speaker. Also Coil DCR, moving mass and radiation surface are same as the multi-diaphragm micro-speaker, too. We call it as the “equivalent” single diaphragm micro-speaker. Then we will compare the acoustic performance difference between the “equivalent” single diaphragm micro-speaker and multi-diaphragm micro-speaker.

For the "equivalent" single diaphragm micro-speaker, a 3-D Comsol model for sound pressure calculation is created. Mesh is created to meet maximum analysis frequency to 10kHz: maximum element size is chosen as 342m/s /10kHz/5.

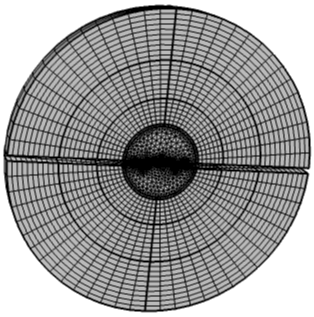

Figure15. 3D model for sound pressure calculation of the "equivalent" single diaphragm micro-speaker

Some FEA results present below in Figure 16 and Figure 17.

Figure16. Diaphragm vibration of the "equivalent" single diaphragm micro-speaker

The baffled free field sound radiation of the single-diaphragm transducer is presented in Figure 17.

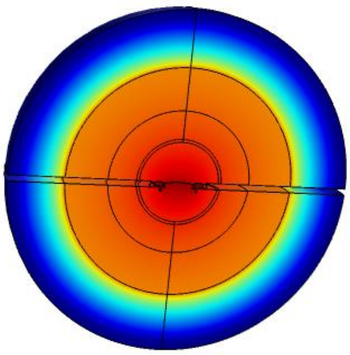

Figure 17. Free field sound pressure level simulation of the "equivalent" single diaphragm micro-speaker

At 2.83 volt and 1meter from acoustic center on axis sound pressure level frequency response is:

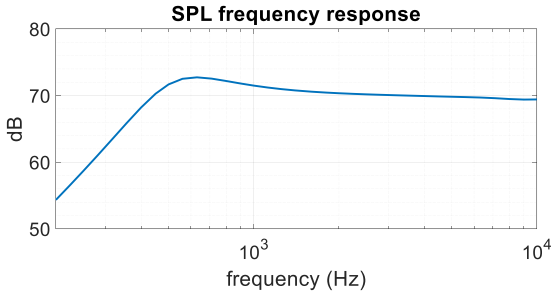

Figure 18. Sound pressure level frequency response of the "equivalent" single micro-speaker

3.4 Sound pressure frequency response comparisons of the two micro-speakers

Figure 19 represents both Figure 14 and Figure 18 graphically. The "equivalent" single micro-speaker frequency response curve shown in Figure 19 is in dotted line. Both speakers have a very closed fundamental resonance frequency F_o, which is about 500Hz. But single diaphragm speaker SPL response curve is lower than the red (solid line) curve, which is multi-diaphragm speaker SPL frequency response, both in lower and high frequencies.

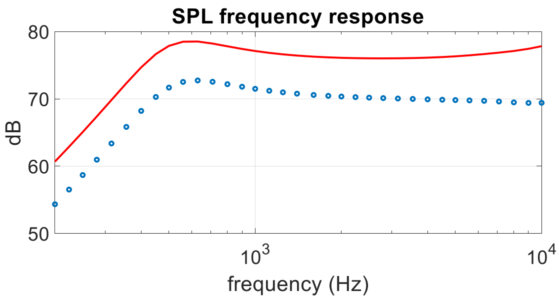

Figure19. Sound pressure level frequency response of the two kinds micro-speakers in half space.

3.5 Qualitative Interpretation of the differences

In the wavelength vs. frequency curve (Figure 20), under 10kHz it is impossible to hold a quarter of a wavelength between two diaphragms in the multi-diaphragm micro-speaker. This means that the sound pressure is evenly distributed in the slit. The compression of the air in the slit cavity provides stiffness.The reaction force on the diapragm is greater than that in free field condition. Since radiation impedance is defined as reaction force divided by diaphragm velocity, therefore, the radiation impedance is increased. The imaginary part of the radiation impedance is responsible for radiation mass. So radiation mass increase results in F_o decrease. With respect to the real part of the radiation impedance, the compression of the air in the slit makes the air density increase so that increase the sound radiation efficiency. These explain that why compare to multi-diaphragm micro-speaker, single diaphragm micro-speaker underperforms.

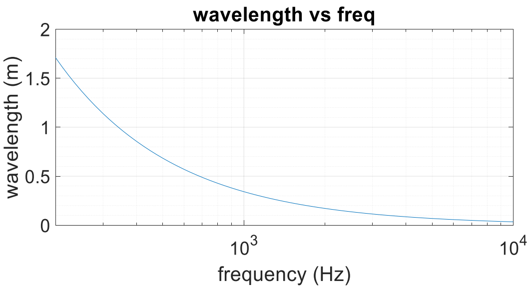

Figure 20. The wavelength vs. frequency curve in the air.

4 Conclusions

The outlined analysis from fundamental magnetic circuit to sound pressure frequency response of the multi-diaphragm micro-speaker have been presented. The finite element analysis shows that if under similar conditions, such as space, radiation surface, moving mass, BL and applied voltage the multi-diaphragm micro-speaker has higher sound pressure level, therefore, better performance. It may pave the way for a generation of small format audio transducers in the near future. The shortcomings are that, it is difficult to manufacture and more expensive compare to single diaphragm micro-speaker.

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