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A model for an electrostatic ultrasonic transducer with a grooved backplate

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Abstract. A model has been constructed for an electrostatic ultrasonic transducer with a uniformly grooved backplate. The membrane and the groove pattern of the transducer was divided into individual elements, and each element was treated as a Helmholtz resonator. The resonant frequency of the transducer can be calculated using one single resonator element. The calculated resonant frequencies were compared with experimental results.

1. Introduction

The electrostatic transducer is commonly used as an airborne signal transmitter and a receiver. The traditional electrostatic ultrasonic transducer consists of a light membrane metal coated on one side, and a backplate, which is for instance sandblasted or grooved. The plastic membrane lies on the backplate and is in contact with only the ridges of the pattern.

In the traditional way, the electrostatic ultrasonic transducer has been treated as a capacitor microphone. The resonant frequency of the capacitor microphone depends on the diameter of the transducer as well as on the tension and the mass per unit area of the membrane. However, the contacts on the backplate divide the air volume of the transducer. And, because of this, in the following study the electrostatic ultrasonic transducer has been considered as a combination of individual resonators.

When a narrowband transducer is required, all individual resonators should have the same resonant frequency. The cross section profile of the backplate was in the shape of a triangular pattern to make the resonator elements similar. Backplates of this kind are simple periodic and besides, they are easy to cut on circular discs by turning. In the following, transducers whose grooves are as regular as possible are studied both in theory and in experiment. The transducers were measured using back reflected bursts (figure 1).

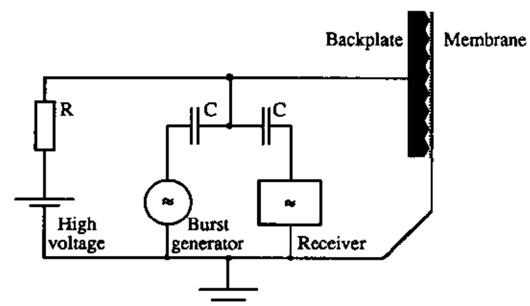

Figure 1. Schematic diagram of an electrostatic ultrasonic transducer.

2. The Helmholtz resonator and the resonator element

A simple example of a lumped acoustical element is the Helmholtz resonator. We assume that it can be applied to resonators with different forms and dimensions if the wavelength is longer than all dimensions. The Helmholtz resonator consists of a rigid-walled cavity of volume V with a neck of area S and length L (figure 2). The resonant frequency of the Helmholtz resonator is [1]

$$f = \frac{c}{2\pi}\sqrt{\frac{S}{LV}} \tag{1}$$

where c is the speed of sound.

The Helmholtz resonator model is applied to part of the V-grooved backplate and membrane. In this case

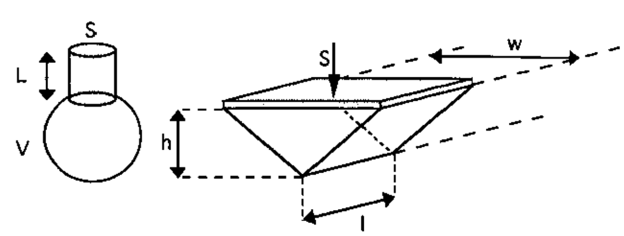

Figure 2. The Helmholtz resonator and the real resonator element.

it is assumed that the mass of the fluid in the neck corresponds to the mass of the membrane.

The cavity as described in figure 2 is limited by the two brass walls of the backplate, and two virtual end faces, which are common with the previous and subsequent resonator elements. On top there is the membrane. Electrostatic force at the membrane is in the same phase over the whole groove. That is why the pressure is at the same phase along the groove, and there are no forces in the groove direction. So the forces, which affect the end face of the resonator, can be considered equal in both directions, and thus the end face acts as a rigid wall.

The mass of the fluid in the neck of the Helmholtz resonator is replaced by a membrane with the same mass. The mass of the membrane is obtained by $m=\sigma S$, where σ is the mass per unit area and S is the area of the membrane. In this case the length of the neck is obtained by $L=\sigma/\rho_0$ where ρ_0 is the density of the air. When studying a transducer with dimensions small compared with wavelengths the loading of the active individual resonator by the external air could be considered as a Helmholtz resonator with a flanged outer end. However, this effect is small compared with the mass loading of the neck. Considering the whole active transducer the loading by the external air is reduced because the adjoining resonator elements are vibrating in the same phase over the whole transducer. Consequently, the flange correction factor can be omitted. The cross sectional area of the cavity is obtained by $A=\frac{1}{2}hw$ where the volume of the cavity is $V=\frac{1}{2}hwl$. Thus the resonant frequency of the resonator element is [2]

$$f_0=\frac{c}{\pi}\sqrt{\frac{\rho_0}{2\sigma h}}. \qquad (2)$$

This shows that the resonant frequency of the resonator element is a function of the depth of the groove, the mass per unit area, the speed of sound and the density of air. The width or length of the cavity has no influence on f_0, i.e. the ridge angle has no influence. There is no parameter for the tension of the membrane, because the tension is small compared with the acoustical force generated by the resonator element. However, the mechanical and electrical tensions together will modify the dimensions of the cavity to a small degree. So the above argument is limited to the case where the membrane is light and not stiff.

3. Experiment

The relation between groove depth and resonant frequency was studied for nine series of transducers with backplates whose ridge angles varied from 30 to 150 degrees. Over each series the mass of the membrane was 8.96 g m^{-2}. The depth of the grooves varied from 0.10 to 0.50 mm and the width from 0.05 to 3.73 mm. The diameter of the round backplates was 38 mm. A characteristic example of the measured resonant frequencies together with the calculated curve is shown in figure 3(*a*). The measurements confirm relation (2) where the resonance in this configuration depends on the depth of the groove but not on the ridge angle.

One series of transducers with a 105° backplate had different membranes. The mass per unit area of mylar films was 2.66, 4.31, 6.14, 8.96 and 11.28 g m^{-2} and the corresponding values for kaptan films were 13.77 and 18.75 g m^{-2}. The thickness of these membranes varied from 2 to 13 μm. The measured resonant frequencies and the calculated curve are plotted in figure 3(*b*). The measurements showed that the influence of the membrane mainly depends on its mass as in relation (2). The deviation of the mass per unit area has been uneven in some cases also causing deviations of the resonant frequency.

When clearly irrelevant values (4 out of 52 cases) were omitted the relative deviation from calculated values was within 16 per cent. The few omitted cases occurred when the attachment of the membrane was not successful or there were faults in the backplate caused by a broken cutting tool. The standard deviation was 7.8 per cent.

4. Conclusion

The resonant frequency of the electrostatic transducer can be calculated by defining the successive unit res-

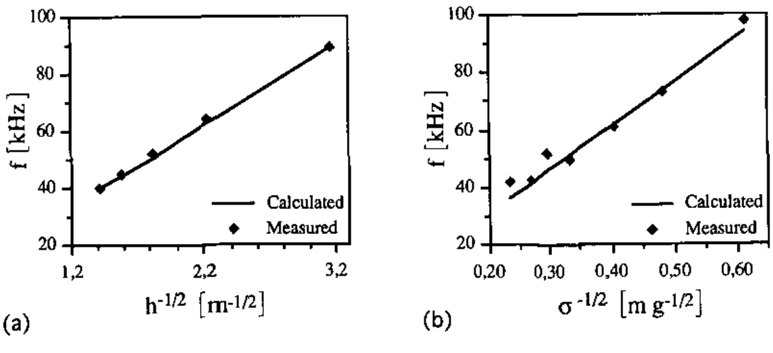

Figure 3. The resonant frequency as a function of (*a*) the depth of the groove ($h^{-\frac{1}{2}}$) and (*b*) the mass per unit area ($\sigma^{-\frac{1}{2}}$).

onator of the membrane–backplate combination. The model might be applied to many different geometries. In the case of a V-grooved transducer it is sufficient to know the depth of the groove and the mass per unit area of the membrane. In terms of groove depth, the valid range is at least from about 0.1 to 0.5 mm.

References

[1] Kinsler L E, Frey A R, Coppens A B and Sanders J W 1982 *Fundamentals of Acoustics* 3rd edn (New York: Wiley)

[2] Hietanen J 1992 Kapasitiivisen anturin mallintamisesta *MSc thesis* University of Helsinki