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# MODELING ASPECTS OF MINIATURIZED MICROPHONES WITH PERFORATED MOVING ELECTRODES

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## ABSTRACT

Miniaturized electroacoustic transducers whose moving electrodes are perforated for technological reasons have appeared in the literature recently. Since the perforation influences strongly the frequency response of the microphones, particularly at lower frequency range due to the acoustic short circuit, the precise modeling of such devices is of high interest. This contribution presents the analytical modeling aspects and theoretical results using the porosity approach. The effects of viscous and thermal boundary layers and the coupling of the displacement field of the moving electrodes in form of perforated plate (flexible clamped at all boundaries or rigid elastically supported) with the acoustic field inside the device are taken into account. The approximated analytical results are compared to the reference numerical (FEM) ones. The benefits and drawbacks of the analytical method are discussed.

**Keywords:** *Perforated moving electrode, Analytical modeling, Miniaturized microphones*

## 1. INTRODUCTION

Since miniaturized electroacoustic transducers with perforated moving electrodes have appeared in literature in recent years [1–5], the need for the precise theoretical modeling of such devices has increased significantly. Such a model taking into account the coupling of the acoustic pressure inside the transducer with the movement of the moving electrode and with the incident acoustic pressure through the perforation (causing the acoustic short circuit in the lower frequency range) as well as the thermoviscous losses originating in the narrow regions behind the moving electrode has been published recently [6].

Herein, the aspects of the analytical modeling, such as the influence of the precision of calculation of approximated eigenfunction of the perforated plate are discussed.

## 2. THE DEVICE

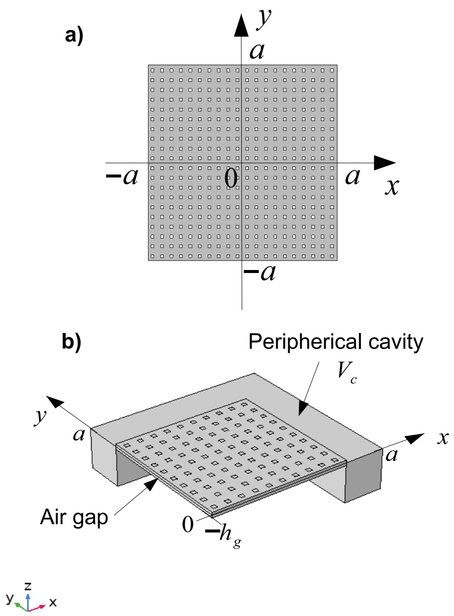


**Figure 1**. Geometry of the transducer: a) the dimensions of the perforated plate, b) 3D cut view of the transducer in the 1st quadrant.

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The device consists of a moving electrode in form of perforated plate loaded by a thin fluid gap and peripheral cavity (see Fig. 1).

## 3. ANALYTICAL MODEL

The displacement of the perforated plate $\xi(x,y)$ (the variable of interest when searching for the acoustic pressure sensitivity of a microphone) is searched for in the form of series expansion

$$\xi(x,y) = \sum_{mn} \xi_{mn} \psi_{mn}(x,y), \quad (1)$$

where $\xi_{mn}$ are the modal coefficients (amplitudes of the modes) and $\psi_{mn}(x,y)$ are the orthonormal eigenfunctions of the perforated plate. Since there is no existing solution for exact analytical expression of such eigenfunctions to our knowledge, the eigenfunctions are approximated using the series expansion [7]

$$\psi_{mn}(x,y) = \sum_{qr} c_{(qr),(mn)} \phi_q(x) \phi_r(y), \quad (2)$$

where the basis functions $\phi_q(x), \phi_r(y)$ are the symmetrical eigenfunctions of 1D beam clamped at both ends, given in [8]. The coefficients $c_{(qr),(mn)}$ are calculated from the numerically calculated eigenfunctions [7].

The acoustic pressure inside the transducer is expressed using integral formulation, solving the wave equation taking into account the thermoviscous losses in the fluid gap and the acoustic short circuit caused by the perforation through the complex wavenumber [6].

The coupling between the acoustic pressure and the displacement field of the perforated plate leads to a system of algebraic equations, solved for $\xi_{mn}$ (see Eqn. (1)).

## 4. NUMERICAL MODEL

The numerical results have been obtained using the Comsol Multiphysics software, version 6.0. The acoustic field inside the transducer (air gap, cavity, holes in moving electrode), calculated using the thermo-viscous formulation contained in the Acoustic module [9] has been coupled with the displacement field of the moving plate, obtained using the Structural Mechanics Module [10], through the velocity continuity boundary condition. The mesh consisted of tetrahedral elements along with layered prism elements near the walls (boundary layer mesh). Depending on the dimensions of perforation of the plate the number of degrees of freedom was in the range from 1 million to 3 million (smaller perforation leaded to finer mesh).

## 5. RESULTS AND DISCUSSION

The acoustic pressure sensitivity of the transducer used as microphone, calculated from the mean displacement of the moving electrode over the surface of the backplate (see [6]) is compared to the complete 3D numerical model calculated using Comsol Multiphysics software. Fig. 2 shows: i) a good agreement between the analytical model and the reference numerical one and ii) very small difference between the analytically calculated curves when using different level of approximation of the eigenfunctions of the perforated plate in Eqn. (2), namely 25 elements of the series (red discontinuous line) and only 1 element of the series (blue line). This result was calculated using only first mode of the silicon plate (1 element of the series in Eqn. (1)) of dimensions $1 \times 1$ mm and thickness of $10\mu$m with 400 square holes of side of $5\mu$m, the airgap between electrodes and the volume of the backing cavity being $10\mu$m and $10^{-10}$m$^3$ respectively.

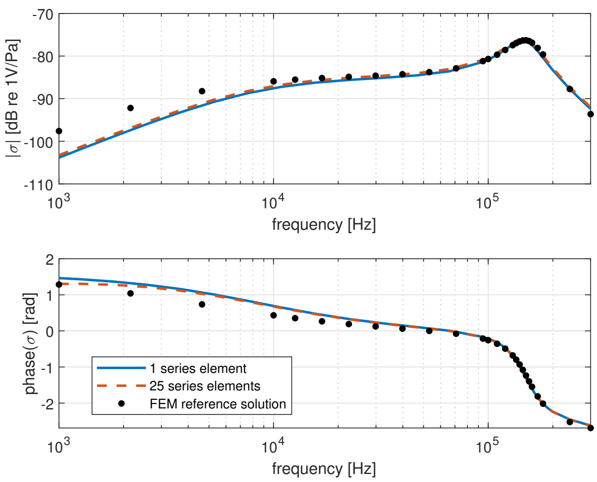


**Figure 2**. Magnitude (upper figure) and phase (lower figure) of the acoustic pressure sensitivity of the transducer calculated using 1 series element (blue line) and 25 elements (red discontinuous line) in present analytical model, compared with reference numerical model (black points).

## 6. CONCLUSION

The analytical model of an electroacoustic transducer with moving electrode in form of perforated plate used as microphone has been examined for the precision of approximation of the eigenfunctions of the plate. It has been shown, that the increasing number of elements of the series has only little effect on the precision of the model and very good agreement between the analytical result and the reference numerical one is preserved even for one element of the series only.

## 7. ACKNOWLEDGMENTS

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