Elektrostatischer Wandler mit nichtebener konvexer oder konkaver Gegenelektrode

Electrostatic transducer with a non-planar (convex or concave) back plate

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SUMMARY

The electrostatic transducer as a pressure sensor is usually formed by a thin circular or, in the case of silicon microphones, square membrane or plate and a planar back electrode parallel to the membrane. The microphone membrane vibrates under the influence of acoustic pressure and the displacement distribution of a thin circular membrane in fundamental axially symmetric mode (and below it) is approximately parabolic and only the central area of the membrane gives the main contribution to the capacitance changes. For this reason it is possible to make the back plate shape also, e.g., parabolic in convex form (paraboloid of n^{th} order), to preserve the sensitivity of the transducer and simultaneously modify the acoustical impedance of the air gap. The thickness of the air gap, the membrane area, as well as the diameter and position of the holes in the back plate, determines the acoustic impedance of the air-gap and especially the damping of the transducer membrane. Very high damping of the membrane occurs in the transducer with a flat back plate without holes due to viscous losses and the heat conduction in the air gap. For this reason it is necessary to enlarge the distance between electrodes, which unfortunately reduces the pressure sensitivity. We can eliminate this undesirable reduction of the pressure sensitivity by the application of the non-planar back-plate. Probably the first description of the electrostatic transducer having a circular membrane and a non-planar back plate in the convex shape of paraboloid of 2^{nd} or 4^{th} order was presented in [1] and in the subsequent papers [2], [3], [4].

In [5] is proposed the electrostatic transducer which back electrode is shaped as a shallow dish. The electrode is perforated and in [5] is shown that this construction of microphone increases the sensitivity and eliminates the harmonic distortion.

In our paper will be discussed and analyzed both types of this transducer with the convex and concave shape of the back electrode.

ELECTROSTATIC TRANSDUCER WITH CONVEX BACK-PLATE

The membrane has the parabolic deflection ξ (Eq. (1)), where ξ_0 is the central deflection, r is the polar coordinate and R is the membrane radius. The thickness of the air-gap l_e is in Eq. (2), where l_0 is the central distance, α is the shape coefficient and n = 2, 4

$$\xi = \xi_o\left(1-\frac{r^2}{R^2}\right) \quad (1) \qquad \mathbf{l_e} = \mathbf{l}_o\left(1+\alpha^2\frac{r^n}{R^n}\right) \quad (2)$$

In order to obtain the open circuit voltage of the transducer as a microphone of 0^{th} order, we assume that the air-gap is surrounded by a cavity much greater than the volume of the air-gap, the membrane is conductive and vibrating at frequencies below the frequency of the fundamental axially symmetric mode, and the membrane displacement is small with respect to the air-gap thickness. The static deflection of the membrane (due to the electrostatic attractive force) and the influence of the electrical field outside the air-gap are not considered.

From the basic equations of an electrostatic transducer we derived the equation for the output open circuit voltage of the transducer (with constant charge) with respect to the displacement of the diaphragm for n = 2 and $R \geq R_e$

$$u = \frac{U_o\xi_o}{l_o}\left(\frac{\rho^2(1+\alpha^2)}{\left(1+\alpha^2\rho^2\right)\ln\left(1+\alpha^2\rho^2\right)}-\frac{1}{\alpha^2}\right) \qquad (3)$$

where U_0 is the polarization voltage and $\rho = R_e/R$. The output open circuit voltage for the various values of the coefficient α depends on the term in the parentheses of the previous equation (3) noted f (α,ρ). The function f (α,ρ) is the normalized open circuit voltage and for $\alpha = 0$ and $\rho = 1$ is $f(0,1) = 0.5$. The difference of the output voltage levels for $\alpha = 1$ and $\alpha = 0$ is only -1.057dB. For n = 4 and $R \geq R_e$ the output open circuit voltage is as follows:

$$u = \frac{U_o\xi_o}{l_o}\frac{1}{2}\left(1+\frac{\alpha\rho^2(1-\rho^2)}{\left(1+\alpha^2\rho^4\right)\mathrm{arctg}(\alpha\rho^2)}\right) \qquad (4)$$

For n = 4 and $R \geq R_e$ the normalized output voltage is denoted as a function $^{o}f\,(\alpha,\rho)$. The normalized output voltage for ρ=1 does not depend on the shape coefficient α and $^{o}f\,(\alpha,1) = 0.5$. From Eq. (3) or (4) we can derive the optimum ratio of the back plate diameter to membrane diameter to obtain the maximum sensitivity.

ELECTROSTATIC TRANSDUCER WITH CONCAVE BACK-PLATE

In the case of transducer with concave shaped back plate we start from Eqs. (2), (3) and (4) in which we replace the shape coefficient α by the coefficient a

$$\alpha^2 = -a^2 \qquad \alpha = i\,a$$

where the new coefficient a < 1. For n=2 the open circuit voltage is as follows:

$$u = \frac{U_o \xi_o}{l_o}\left(\frac{\rho^2(1-a^2)}{\left(1-a^2\rho^2\right)\ln\left(1-a^2\rho^2\right)}+\frac{1}{a^2}\right) \qquad (5)$$

and for n=4

$$u = \frac{U_o \xi_o}{l_o}\frac{1}{2}\left(1+a\rho^2\,\frac{1-\rho^2}{1-a^2\rho^4}\,\frac{1}{\frac{1}{2}\ln\frac{1+a\rho^2}{1-a\rho^2}}\right) \qquad (6)$$

Similarly as in previous notation the normalized output voltage is in Eq. (5) denoted $\varphi(a,\rho)$ and in Eq.(6) $^o\varphi(\alpha,\rho)$ The normalized output voltage for n = 4 and for ρ=1 does not depend on the shape coefficient α and $^o\varphi(\alpha,1) = 0.5$. The difference of output voltage levels for n = 2, ρ = 1 and a = 0.707 and a = 0 is 0.942 dB. In Fig.1 are the graphs of normalized output voltages for n = 2 and $\rho = 1/\sqrt{2}$ as a function of α and a.

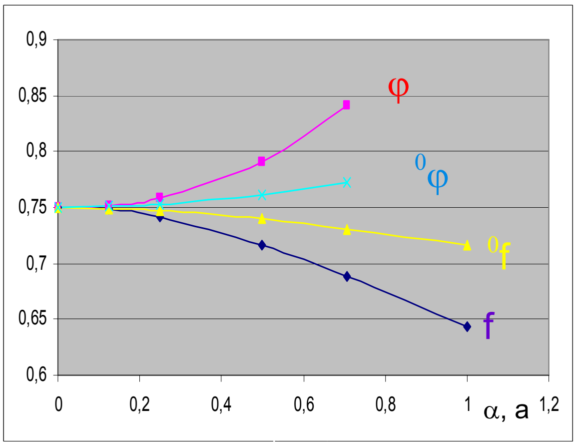

Fig.1 Normalized output voltage as a function of the shape coefficient

HARMONIC DISTORTION

The second harmonic distortion of the transducer with the convex or concave back electrodes for ρ = 1 and n=2, 4 has been described and the result is presented in Fig.2 where are shown the graphs of the normalized distortion k/η as a function of shape coefficients α and a and k is harmonic distortion and η is the ratio of the central membrane displacement to the central electrodes distance.

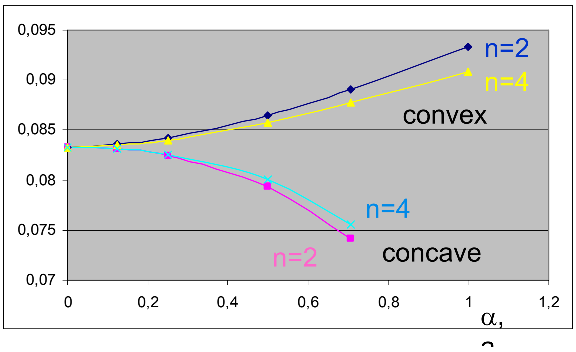

Fig.2 The harmonic distortion of the transducer with a convex or concave shape of the back electrode

DISCUSSION

In the contribution is presented the analytical description and comparison of electrostatic transducers as microphones with a thin circular membrane and a non-planar convex or concave back electrode. For the transducer with a concave back electrode there is a small increasing of the sensitivity and a small decreasing of harmonic distortion but the construction needs the perforation of electrode. For the transducer with the convex shaped back electrode we consider the small decreasing of the sensitivity with respect to the increasing of the shape coefficient and the small increasing of the harmonic distortion. The main advantage of the transducer with convex electrode is the possibility to construct the electrode without holes as has been suggested and proved in previous works (1), (2), (3), (4) and this transducer construction is applicable for classical and micromechanical technologies.

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