Program Digest, 2019 IEEE International Ultrasonics Symposium (IUS)
Glasgow, Scotland, October 6-9, 2019

The influence of metal film, placed near a piezoelectric lateral electric field resonator on its characteristics

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***Abstract*—The effect of a thin metal film on the characteristics of a piezoelectric resonator with a lateral electric field is studied theoretically and experimentally. We studied two resonators based on PZT piezoceramic plates 3.56 and 4.46 mm thick with a resonant frequency of ~ 96 kHz. It was found that with an increase in the gap between the free side of the piezoelectric resonator and a thin aluminum film, the parallel resonance frequency and the maximum value of the real part of the electric impedance increase and reach saturation. In this case, the relative change in these values with a change in the gap width from 0 to 0.3 mm increases with decreasing resonator thickness. As for the frequency of the series resonance and the maximum value of the real part of the electrical admittance, they practically do not change. The experimental results are in good agreement with theoretical data. The change in these values with a temperature change in the range of 25-50C was measured. As a whole the possibility of development a micro displacement meter in the range 0–0.3 mm is shown, and the possibility of compensating the temperature deviation of the frequency of parallel resonance is analyzed.**

Keywords—Piezoceramics PZT, piezoelectric resonator with lateral electric field, electrical boundary conditions, frequencies of parallel and series resonances, conducting film, electrical impedance and admittance, finite element analysis, termal deviation of parameters, meter of micro displacement.

I. INTRODUCTION

In recent years, piezoelectric resonators with a lateral exciting electric field have attracted the attention of researchers and are used as sensors of various types [1–7]. Since the electrodes of such resonators are located on one side of the piezoelectric plate, the electric field of acoustic wave penetrates outside the plate. Therefore, a change in the electrical boundary conditions near the free side of the resonator leads to a change in its characteristics. Therefore, based on such resonators, the sensors were developed for measuring the electrical conductivity and permittivity [1-7] of liquids. The effect of the conductivity of a film located near the free side of the X-cut resonator of lithium niobate on its characteristics was also investigated [8, 9]. The results showed the possibility of developing gas sensors and mechanical displacement sensors in the range of 0.2 - 2 mm for continuous monitoring of deformations and cracks in buildings, bridges, etc.

The aim of this paper is experimental and theoretical study of the influence of a thin metal film located near a piezoelectric resonator with a lateral electric field based on PZT ceramics. This choice is due to the fact that PZT ceramics has a higher value of the electromechanical coupling coefficient compared to lithium niobate [10]. The effect of films with different conductivity located near a resonator with a lateral electric field based on PZT ceramics on its characteristics near a resonant frequency of 96 kHz was studied in [10]. It was found that a change in the resonance characteristics occurs when the gap between the free side of the resonator and the conductive film changes in the range of 0.01 - 0.3 mm. Such a narrow gap variation interval opens up not only the possibility of creating a micro displacement meter in the range of 0.01 – 0.3 mm, but also shows the way to compensate for thermal deviations of the frequency of parallel resonance. Therefore, the paper also presents data on the effect of temperature on the frequencies of parallel and serial resonances. The possibility of compensating of the thermal drift of the parallel resonance frequency by changing the width of the gap between the resonator and the conducting plane is estimated.

II. EXPERIMENTAL STUDY

A. Description of the Resonators and Method of Mesurement

Two resonators with a lateral electric field were fabricated on plane-parallel PZT piezoceramic plates 3.56 and 4.46 mm thick (Fig.1). The shear dimensions of each resonator were 18x20 mm. On one side of each plate two electrodes 9 mm wide and with a gap between them of 2 mm were set. An electric voltage applied to the electrodes led to the appearance of an electric field whose tangential component was parallel to the polar axis of the piezoelectric. To measure the frequency dependences of the real and imaginary parts of the electrical impedance and admittance, the resonator was connected to

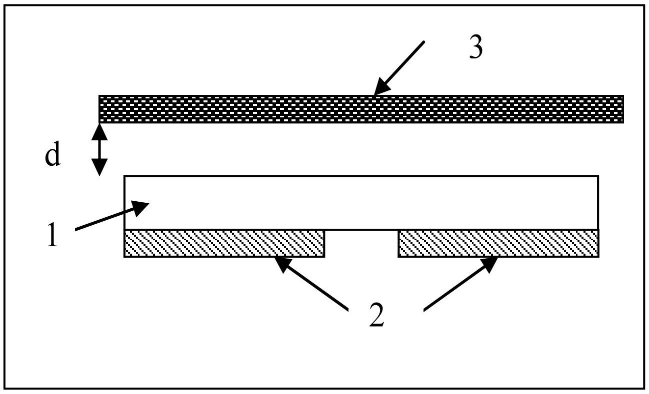

Fig. 1. Draft of the investigated resonator with a lateral electric field: 1-plate of PZT ceramics, 2-electrodes, 3-conducting film.

meter of LCR parameters 4285A (Agilent, United States). The measurements were carried out in the range of 75-120 kHz. The specified gap between the free side of the resonator and the glass plate with an aluminum film was provided by a micrometric device with an accuracy of 0.01 mm [8, 9]. The frequency dependences of the real and imaginary parts of the electrical impedance/admittance were measured at various values of the width of gap between the resonator and aluminum film. These dependences allowed to find the frequencies of parallel and series resonances, as well as the maximum values of the real parts of the impedance and admittance.

B. Results and Discussion

Experimental dependences of the frequencies of parallel and series resonances, as well as the maximum values of the real parts of the electrical impedance and admittance on the gap width for resonators with a thickness of 3.56 and 4.46 mm, respectively, were constructed. These experimental dependences are shown in Figs. 2-5 by dotted lines. It can be seen that the frequency of parallel resonance and the maximum value of the real part of the impedance increase with increasing gap width d and reaches saturation (Figs. 2-3). In this case, the main change in the indicated values is observed when the gap width changes from 0.01 to 0.1 mm. From Figs. 4-5 it follows that the frequency of the series resonance and the maximum value of the real part of the admittance vary insignificantly and remain almost constant.

Theoretical Analysis

C. Problem Setting

A theoretical analysis of the influence of a perfectly conducting plane on the characteristics of a resonator with a lateral electric field based on PZT piezoceramics was also performed by the finite element method [11]. The geometric dimensions of all elements of the analyzed resonators exactly corresponded to the experimental samples, with the exception of the shear size perpendicular to the polar axis of the piezoelectric. In this direction, the structures were considered infinite. The distribution of the components of the mechanical displacement inside the piezoelectric plate was found, as well as the distribution of the electric potential inside the piezoelectric plate and in the surrounding vacuum. It has been found that from the side of the free surface, the electric field penetrates into the vacuum to a depth substantially less than the thickness of the resonator and does not exceed a value of 0.3 mm. An ideally conducting film located near the resonator was described by a plane with zero electric potential. The characteristics of parallel and series resonances were studied for one type of plate vibrations with a parallel resonance frequency of ~ 96 kHz. The frequency dependences of the real and imaginary parts of the electrical impedance and admittance were calculated for a fixed value of the gap width between the resonator and the conducting plane. The gap width varied between 0 - 0.3 mm. Figs. 2–5 show by solid lines the dependences of the frequencies of parallel and series resonance, as well as the dependences of the maximum values of the real parts of the electrical impedance and admittance on the width of the indicated gap. It can be seen that with an increase in the width of the gap, all of the indicated values monotonically increase and reach saturation.

D. Comparison of Theoretical and Experimental Results

A comparison of the results of the theoretical and experimental studies of the effect of a thin metal film located near a piezoelectric resonator with a lateral electric field based on PZT piezoceramics on its characteristics showed their qualitative correspondence. However, theoretical and experimental results differ quantitatively. The discrepancy between these data is due to the following factors. First, a simplified two-dimensional resonator model was used in theoretical analysis. Secondly, the material constants of piezoceramics [10] used in the calculation may differ from their real values. Thirdly, the discrepancy between experimental and theoretical data is also due to the fact that in the experiment it is impossible to maintain perfect plane parallelism of the gap between the side of the resonator and the conducting film.

III. Temperature Measurements

As already noted, a change in the resonance characteristics of the resonator due to approaching the conducting plane to resonator opens the possibility of compensating the thermal drift of the resonant frequency. So, the effect of temperature on the resonance characteristics of resonator based on PZT piezoceramics was experimentally investigated. The resonator under study was placed in a special thermostat, which allows changing the temperature in the range of 25–50C. For the selected temperature, the frequency dependences of the electric impedance/admittance were measured and the frequencies of parallel and series resonances were determined. It has been found that with increasing temperature the values of the resonant frequencies decrease, which is associated with a decrease in the velocity of the acoustic wave. Changing the temperature by 25C reduced the frequencies of parallel and series resonances by about 1%. It is obvious that a synchronous increase in the gap width with increasing temperature can compensate the thermal drift of the frequency of parallel resonance. The experiment has shown that such change in the gap width is equal 0.01 - 0.1 mm. According to the theory, the necessary change in the gap is 0.01 - 0.02 mm.

The work was carried out with financial support from the Russian Scientific Foundation grant № 15-19-20046-P.

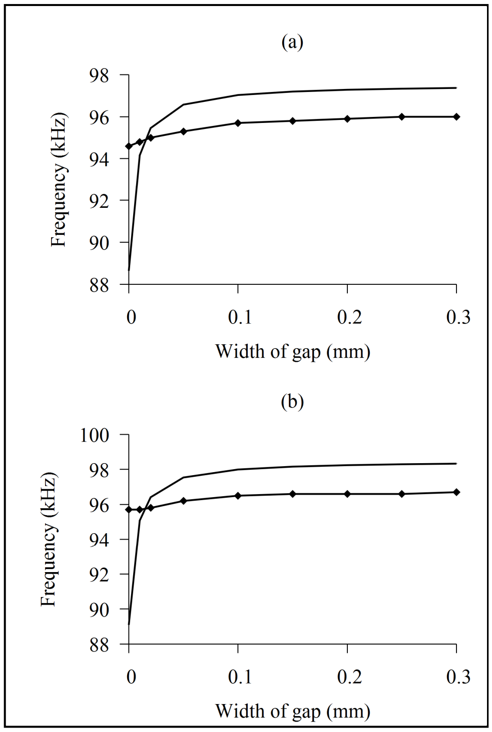

Fig. 2. Experimental (dotted line) and theoretical (solid line) dependencies of parallel resonant frequency on the width of gap "resonator–conducting film." The resonator thickness = 3.56 mm (a) and 4.46 mm (b).

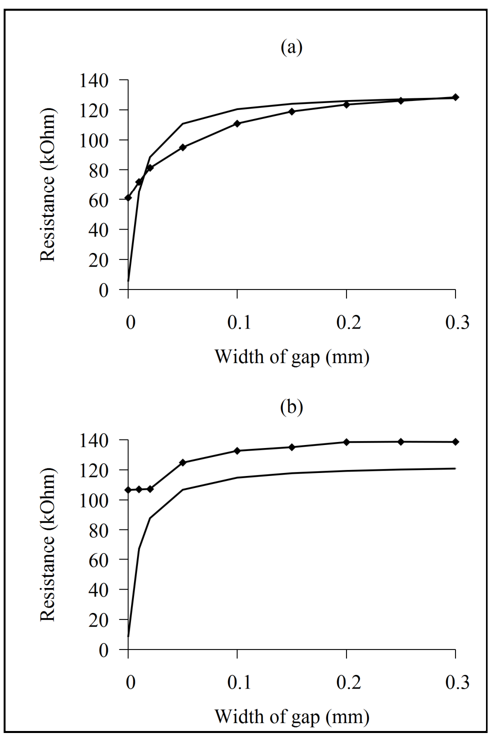

Fig. 3. Experimental (dotted line) and theoretical (solid line) dependencies of maximum value of resistance on the width of gap "resonator–conducting film." The resonator thickness = 3.56 mm (a) and 4.46 mm (b).

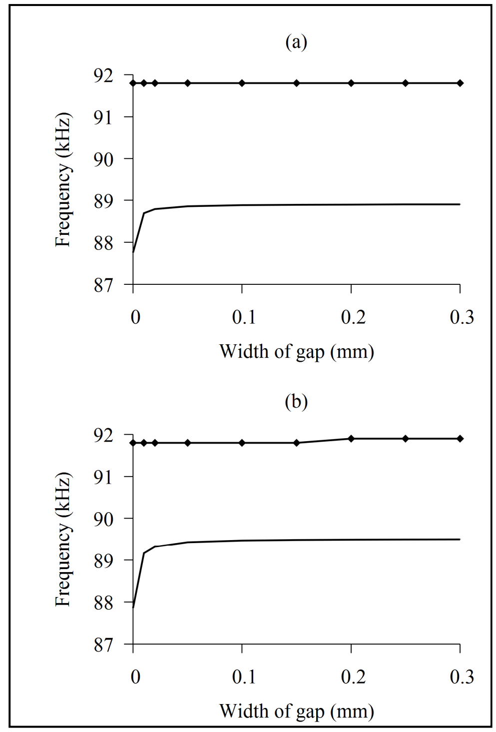

Fig. 4. Experimental (dotted line) and theoretical (solid line) dependencies of series resonant frequency on width of gap "resonator–conducting film." Resonator thickness = 3.56 mm (a) and 4.46 mm (b).

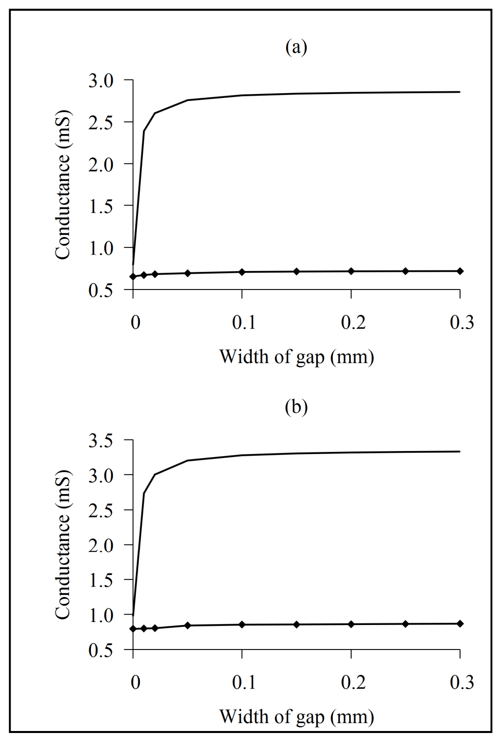

Fig. 5. Experimental (dotted line) and theoretical (solid line) dependencies of maximum value of conductance on width of gap "resonator–conducting film." The resonator thickness = 3.56 mm (a) and 4.46 mm (b).

The indicated dependence of the temperature change in the width of the gap to stabilize the frequency of parallel resonance can be achieved by choosing a material with a given coefficient of thermal expansion for fastening the conductive plate. As for the frequency of the series resonance, it is practically independent on the width of the gap between the resonator and the conductive film. Therefore, it is impossible to stabilize the frequency of the series resonance and it will change with temperature. This temperature dependence of the frequency of the series resonance can be used to determine the temperature.

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