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Influence of the Material Layer on the Frequency Response of the Multimode Converter

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The problem of the sound reception by means of cylindrical transducer in the circular layer is considered in "through" formulation. Electroelastic properties of piezoceramic shell and the transition layer was taken into account in the solution of declared problem.

Features of formation of the amplitude frequency characteristics of multimode piezoceramic receiving transducer with a wave layer are considered for different types of electrodes. In this case the amplitude of the mode components of voltage to frequency characteristics can be adjusted by selecting the type of the electrode and by choosing shielding materials.

Keywords: Shell, Acoustic, Sound, Material layer, Multimode converter, The method of partial regions, The wave layer, Piezoceramic receiving transducer, Electricalelastic properties.

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1. INTRODUCTION

Appliances of information registration include a variety of devices for processing images and sound, usually combined into a single indivisible entity, such as a film, which combines a moving image and sound or television media. There are also devices that record only images, such as photography, printing (newspapers and magazines) or just the sound, such as tape recorders or digital disk recorders [1].

The urgency of the problem is caused by the need to improve understanding of the physical nature of mutual conversion of acoustic, mechanical and electrical energy in the piezoelectric transducers. The design of the sonar transducer, along with an active element, presupposes the existence of wave matching layers. These layers allow to solve a lot of problems as the process (coordination, sealing, electrical insulation, reinforcement) and the wave nature (shielding). In this regard, the actual practical task is to assess the impact of matching layers on the basic physical fields of receiving transducer.

In [2] basis on the developed model of the registration process of contact type receiver of ultrasonic wave has been developed a mathematical model of the transducer, which takes into account the finite size of the disk, the existence of the matching liquid layer, the real values of the electrical load and the existence of the rear acoustic load.

Tasks for determining effects of output piezoelectric transducers are stationary tasks hydroelectric elasticity. The term "electroelasticity" is currently widely used on the design elements conversion [3-5]. "Pass-through" method involves the joint solution of the wave equation and equation fluctuations electroelastic converter, given its shape, characteristics and piezo technology layer, and the type of electrode on the surface of the transducer and the electrical load elements. It is known that the use of electrodes partially covering the surface of the transducer leads to the enrichment of the mode structure of the acoustic field created by the use of higher vibration modes of the electrode surface, for example, the implementation of the first lower three waveforms [5].

Earlier in [6-7], in the framework of traditional approaches to the description of piezoceramic cylindrical transducers using electromechanical analogies method has been proposed taking into account the configuration of the electrodes in the form of the angular dependence of the coefficient of electromechanical transformation. This approach is certainly justified, however, does not allow to fully take into account the interactive features of the higher modal connectivity components fluctuations receiving piezoelectric transducers in the evaluation of the electrical stresses on their loads.

In [8] contains the statement and solution of the problem of the reception of sound waves by electroelastic transmitter enclosed in a closed transition layer. They contain, as well, the study of electromechanical and acoustic fields that arise in process of solving this problem.

In these papers were considered only cases when complete surface of transducer is electrode. We note also that the works devoted to the study of converters with the split electrodes [2, 3, 6, 7], are presented only for the piezoceramic transducers without wave layer.

The solution of this problem in a number of studies [8, 10] presented with the assumption that the mechanical resistance of the piezoceramic transducer shell and radiation resistance are determined using the method of calculation elements converters as a system with lumped parameters.

At the same time, issues of functioning of the receiving transducers in closed and open-ended circular layers described only for the traditional models of converters, not taking into account their electroelastic properties. This is due to insufficient knowledge of electroelastic converters for receiving and emitting shielded systems.

This article continues the research of the amplitude to frequency characteristics (AFC) of multimode oscillating systems.

On the surface of these systems electrodes are applied with a certain angle of aperture. Statement and analytic solution of this problem is presented in [10].

The aim is to further study the amplitude-frequency characteristics of multimode piezoceramic transducer with different types of electrodes placed in the wave layer with varying thickness

2. REFERENCE DATA, CONDITIONS OF CALCULATIONS

The problem of stationary hydroelectricelasticity is studied, which determined by the electrical voltage to the load converter by the known value pressure wave field in the environment. The "through" method was applied to formulating the problem. As a computational model consider a single circular cylindrical piezoelectric receiving transducer (Fig. 1). The solution was obtained by using method of partial domains, Fourier method (expansions in their own forms (multimode property of the "the converter-wave layer" system)), as well as the properties of completeness and orthogonality of cylindrical wave functions and of functions $e^{i\omega t}$.

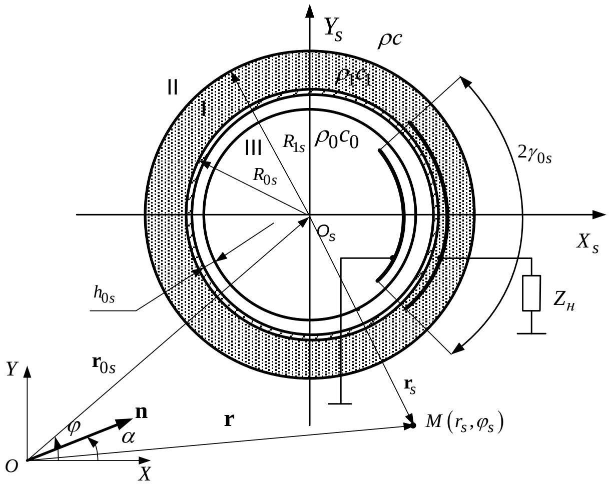

Fig. 1 – Piezoceramic receiving transducer with disconnect electrode and the coordinate system

The converter with closed wave ring layer is of infinite length and is located in an ideal incompressible fluid (density $\rho = 1000$ (kg/m^3) and speed of sound $c = 1500$ (m/s)). Inside the converter is a vacuum. Parameters transducer:

– the diameter $2R_{0S} = 135 \cdot 10^{-3}$, m;
– material piezoceramic shell – lead zirconate titanate-barium;
– the thickness of the piezoceramic shell $h_{0S} = 6 \cdot 10^{-3}$, m;
– the wave thickness layer $h_S = \lambda/4$ in the material of the layer relative to the operating frequency $f = 5$ kHz.

It is assumed that material layer does not resist shear deformations, and its acoustic properties are characterized by density and speed of sound. Calculations are performed for the layer made of a rubber stamp (density $\rho = 1500$ (kg/m^3) and speed of sound $c = 1575$ (m/s)), and polyurethane foam (density $\rho = 300$ (kg/m^3) and speed of sound $c = 1180$ (m/s)).

On the surface of the transducer electrode are located with an angle of aperture 2γ. In the general case electrodes of transducers not electrically connected and loaded into separate electrically independent (in general complex) resistance. Calculations were performed in the frequency range (10-50000) Hz for these conditions.

In the oscillating system falls flat sound wave angle $\alpha = 0°$. Acoustic field are considered for linear approximations of classical acoustics.

Thus the effect of elastic and inertial properties of the technological elements of piezoelectric transducers in the amplitude frequency characteristics of the oscillating system is investigated. The problem was solved with use of algorithm finding the unknown coefficients of expansions of acoustic, mechanical and electrical fields for a system consisting of one converter. Thus, the amplitudes of the voltage on the active respective load electrode modal numbers $n = 0, 1, 2, 3, 4$ at the frequencies of the range is considered.

The solution is carried out using [5, 6, 8, 9]:

– state equations for piezoelectric ceramics, which are linearly, linked to each other components of stress, strain, tension and electrical induction;
– equations of motion of a mechanical vibratory element transducer system;
– relations Cauchy, which are connect the components of the strain tensor and displacement vector;
– equations of forced electrostatics.

The joint solution of these equations determines the inverter characteristics, taking into account the three main fields - electrical, mechanical and acoustic.

3. RESULTS OF CALCULATIONS

The formation features of amplitude frequency characteristics of the piezoceramic receiving transducer with wave layer are examined. Fig 2-4 shows the amplitude frequency characteristics of the piezoceramic receiving transducer with wave layer for various materials layers and for different types of electrodes piezoceramic shell. In [10] frequency characteristics for quarter-wave thickness layer relatively to the operating frequency $f = 8.2$ kHz are investigated.

Let us analyze the results of calculations using the example as a layer – rubber. A variety of electro-active modes for different types of electrodes transducer has been established. Thus for different angles of aperture of the electrode, the calculation results show the high degree of relatedness waveforms.

AFC for the aperture angle $2\gamma = 180°$ of the electrode indicates the presence of zero and all the odd waveforms, while amplitude of the mode components of the "1" and "3" modes practically coincides.

The increase in the layer thickness leads to insignificant changes in the amplitudes of the mode components of the frequency dependence of the electric field strength in comparison with [10].

Mode for the number "3" shows the change in the width of the resonance curve. Maximum width of the resonance curve is characterized by AFC zero mode converter without a layer. The presence layer leads to significant changes in the resonance frequency of the zero modes. Thus, the first and third forms show an increase in the voltage amplitude compared to the amplitude of the electric voltage at a frequency of zero waveform. In other words, the amplitude of the zero modes is ten times less than the amplitude of the other existing modes.

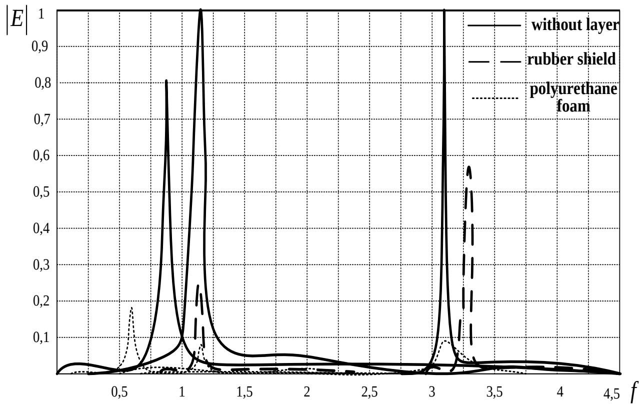

Fig. 2 – Amplitude frequency characteristics of the oscillating system without layer and with a layer which is made of a rubber shield, polyurethane foam for the electrode angle aperture $2\gamma = 180°$

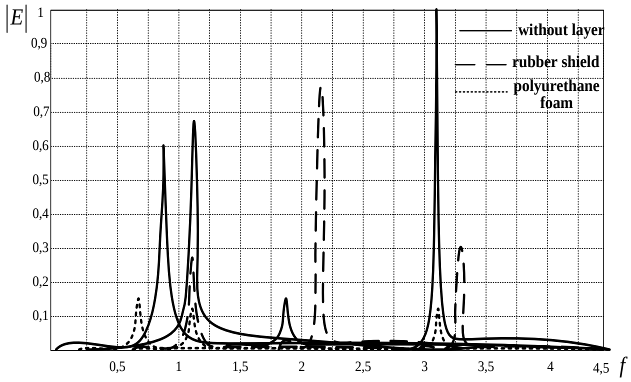

Fig. 3 – Amplitude frequency characteristics of the oscillating system without layer and with a layer which is made of a rubber shield, polyurethane foam for the electrode angle aperture $2\gamma = 90°$

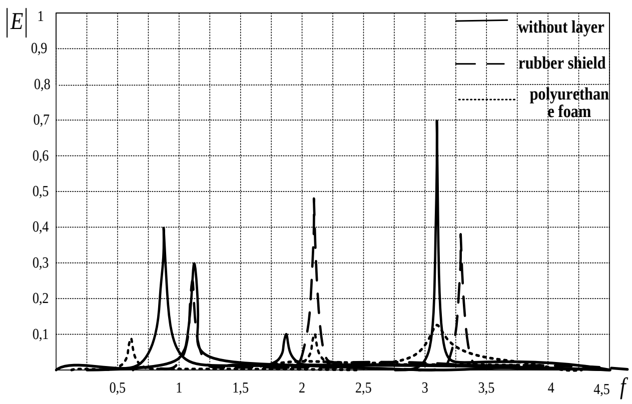

Fig. 4 – Amplitude frequency characteristics of the oscillating system without layer and with a layer which is made of a rubber shield, polyurethane foam for the electrode angle aperture $2\gamma = 45°$

When using the matching layer which made of a rubber shield, the contribution of mode makes up for aperture angle of the electrode $2\gamma = 180°$ is considerably reduced and amounts to 3-10 dB (Fig. 2). The level of the amplitude of the zero modes is substantially small as compared to the higher order modes (up to 30 dB). The results show the frequency shift of the third oscillation mode. Note that for this material layer is a general decrease in the amplitude values of the modes components and change width of the resonance curve as compared to the AFC without a layer that indicates an increase in the quality factor for the higher forms.

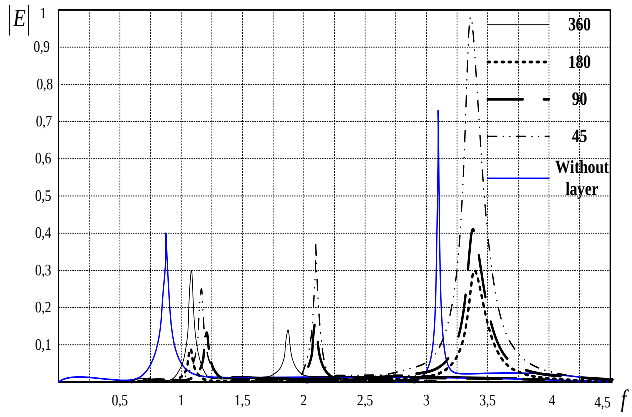

Fig. 5 – Amplitude frequency characteristics of the oscillating system without layer and with a layer which is made of a rubber shield for different type electrodes

It also corresponds to the fact that with increasing number of modes, damping near the vicinity of the higher frequency becomes large and the broadband contributions of higher modes – less.

The results illustrates the dependence amplitude waveforms of the electrode area (in this case - from the angle of aperture) (Fig. 3-4). As seen from the results of amplitude frequency characteristics of oscillatory system with a layer, which is made of a rubber shield, increasing the mode number is a general increase in the amplitude values of the modal components.

When the thickness of the layer for the oscillatory system changes, than the zero mode of the matching layer, which is made of PPU-10 material, is activated.

Using constructive polyurethane foam material causes a change in the sound transparency layer of the oscillating system. The layer behaves as a soft object, the pressure which is virtually zero, because of this incident sound wave is almost absorbed, which illustrates the AFC for all examined types of electrodes (Fig. 2-4).

However, an increase in the thickness of the layer leads to an increase in the levels of the zero, first modes and to a decrease in the amplitude of the second and third modes.

Thus, together with the wave layer electrode serves as not only a kind of filter, which retains or eliminates some, or other vibration modes, and the device regulating amplitude output electrical signals. In this case the filter depends on the angle of aperture of the electrode.

As can be seen from the results of the calculation for the aperture angle $2\gamma = 90°$ of the electrode is suppressed mode "4". In comparison aperture angle of the electrode $2\gamma = 180°$ activated the "2" mode. For the aperture angle $2\gamma = 45°$ of the electrode 45 in the total electrical signal are present all modes except "5" mode.

The change in the thickness of the layer leads to an increase in the amplitude of the second harmonic and to a decrease in the third mode of oscillation

Also an analysis of the calculation results indicated shift (± 10÷15 %) of amplitude components AFC of a change in electrode area. These results demonstrate the enrichment of the modal composition with a decrease in the angular aperture of the electrode. Thus, obtaining of mode with the largest amplitude components involves selection electrode with a certain angular aperture, and the material layer. For every calculated problem, there are situations inhibition and activation of a particular mode, changes mode in amplitude and frequency shift. The result allows predicting the degree of use some form of oscillation with its amplitude in the formation of the sum signal to the load electrode.

CONCLUSIONS

In the framework of solution problem for receving sound of the cylindrical thin-walled electroelasticity receiver in a wide frequency range for different types of electrodes were calculated.

It was concluded that the use of split electrode leads to a modification of the amplitude frequency characteristics of multimode transducer oscillating system which are defined sound transmission system.

It is shown that the amplitude of the mode components of the frequency characteristics of the voltage can be controlled by means of the type of electrode, as well as the choice of shielding materials.

These results demonstrates the enrichment of the modal composition with a decrease in the angular aperture of the electrode. Thus, obtaining of mode with the largest amplitude components involves selection electrode with a certain angular aperture, and the material layer.

Влияние материала слоя на частотные харатеристики многомодового приемника

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В «сквозной» постановке рассматривается проблема приема звука с помощью цилиндрического преобразо-вателя в кольцевом слое. При решении поставленной задачи учитываются электроупругие свойства пьезокерамической оболочки и переходного слоя.

Рассмотрены особенности формирования амплитудно-частотных характеристик многомодового пьезокерамического приемного преобразователя с волновым слоем для различных типов электродов.

При этом амплитуду составляющих мод напряженности электрического поля частотных характеристик можно регулировать, выбирая тип электрода и экранирующих материалов.

Ключевые слова: Оболочка, Акустика, Звук, Слой материала, Многомодовый преобразователь, Метод частичных областей, Волновой слой, Пьезокерамический приемный преобразователь, Электроупругие свойства.

Вплив матеріалу шару на частотні характеристики багатомодового приймача

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Розглядається проблема прийому звуку за допомогою циліндричного перетворювача в кільцевому шарі в «наскрізній» постановці. При цьому враховувались електропружні властивості п'єзокерамічної оболонки та перехідного шару.

Особливості формування амплітудних частотних характеристик багатомодового пьезокерамічного приймального перетворю-вача з хвильовим шаром розглядається для різних типів електродів.

При цьому амплітуду компонентів напруги частотних характеристик можна регулювати шляхом вибору типу електроду та екрануючих матеріалів.

Ключові слова: Оболонка, Акустика, Звук, Шар матеріалу, Багатомодовий конвертер, Метод часткових областей, Шар хвилі, Пьезокерамичний приймальний перетворювач, Електропружні властивості.

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