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Experimental Study of the Dynamic Behavior of Pulses Emitted by a Linear System of Electromechanical Transducers

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A significant difference between electrical impulses, used for stimulation of elements of the acoustic location systems, and acoustic pulses, emitted by the systems, that occurs in the systems during their operation, has been discovered experimentally. Physical reasons for the appearance of these differences, for linear systems of electromechanical piezoceramic transducers, are transients in electromechanical oscillatory systems of transducers and spatial spread of the systems. It is shown that the first reason is caused by the inertia of the transducers and the second – by the delay in the wave front when it propagates along the system.Typical dynamical changes in acoustic pulses, depending on the causes of their occurrence, were discovered. It is shown that the inertia of the mechanical oscillatory systems causes smooth increases and decreses, of the front and rear edges of acoustic pulses, respectively, in the directions of main and side lobes of the directivity of the system.It was discovered that typical dynamic changes in acoustic pulses caused by the delay in the front edge of the emitted wave, for the directions that are distant from the main and side lobes and interference zeros of the directivity, led to significant increase of their length, compared to electric ones and to the emergence of dips in the pulses' amplitudes between their edges and their long sound after the end of the electrical stimulation of the systems' transducers. Displayed dynamic changes in the emitted acoustic pulses compared to electrical stimulation pulses significantly worsen the parameters of location systems evaluated by the parameters of electrical impulses. Therefore, they must be considered when designing such systems.

Keywords: Acoustic pulses, Piezoceramic transducer, Linear system.

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1. INTRODUCTION

Most modern sonar devices operate in pulse modes [1-3]. At the same time, as electromechanical energy converters, they use devices of various geometric shapes, formed from elastic media with a piezoelectric effect [4, 5]. These devices are characterized by several features [3, 6-9].

First of these is the mutual relationship between electrical, mechanical and acoustic processes in the energy conversion inside piezoceramic bodies on the one hand and the processes of acoustic energy formation during the propagation of sound waves in the elastic media surrounding both these bodies and the systems of bodies, on the other hand.

The second feature is that the studied electromechanical devices have two sides of the load - electrical and acoustic, and each of them is characterized by a variety of options for both electrical and acoustic loads. Therefore, features of the acoustic load of piezoceramic devices through mechanical processes significantly affect the electronic processes in them, that are, the characteristics of electric load. At the same time, discovered relationship between mentioned physical processes accompanying emitting and receiving of the sound by piezoceramic devices and systems of them affect electrical and acoustic load of these devices.

Variety of features of electrical and acoustic load of piezoceramic transducers and systems of them caused the need of quantitative assessment of the influence of described relationships on physical fields of the devices. New knowledge on them was obtained [2, 3, 6-9] for the conditions of continuous stimulation of transducers by a monochromatic harmonic electrical signal. At the same time, the electrical stimulation of transducers with a pulsed signal significantly different from the situation with continuous signal because of the emergence of several new physical factors leading, due to the nonstationary stimulation, to the occurrence of transients in electromechanical devices [10]. These differences and underdevelopment of calculational methods for the physical fields of piezoceramic transducers and the systems formed from them, considering mutual relationship of the fields in situations of nonstationary stimulation, that are the main reason for the need of experimental study of electrical, mechanical and acoustic fields of the transducers in these modes of operation.

The purpose of the article is to obtain and analyze experimental data of the dynamic properties of pulsed signals of electrical and acoustic load of piezoceramic transducers when they work as part of a linear system.

2. ABOUT THE FEATURES OF CONVERSION OF ELECTRICAL PULSES INTO ACOUSTIC PULSES WHEN EMITTING SOUND BY THE SYSTEMS OF ELECTROMECHANICAL TRANSDUCERS

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As known [4, 11] electromechanical transducers have two components – electrical and mechanical, and therefore, two components of load – electrical and acoustic.

So, the physical processes arising in electromechanical transducers and systems formed from them, when emitting pulsed signals, are characterized by fundamental differences in each of the components. These differences are caused by the fact that speed of propagation of electromagnetic waves in the electrical part of electromechanical transducer is in several orders higher than the speed of propagation of sound waves in the mechanical part of the same transducer. Therefore, in real time, usual for sound processes, the electrical part of the transducers does not show signs of transient.

At the same time, the mechanical part of the transducer and the elastic medium connected to it have several physical properties, that create transients when emitting acoustic pulses [2].

For a single electromechanical transducer, these physical properties and their accompanying consequences were the subject of detailed consideration in the work [10]. It was discovered that the main causes of transients are significant inertia of the mechanical resonant oscillatory system of the transducer and the inertia of the elastic medium that creates its acoustic load. Presence of transients cause the appearance of distortions in emitted acoustic pulse signals compared to electrical pulse signals, that stimulate transducer. They include smooth increase in the front edge of the acoustic pulse, a decrease in its' rear edge and the appearance at the beginning and at the end of the pulse short sharp "bursts" in acoustic pressure amplitudes. For a single transducer, discovered transients are associated only with the process of energy conversion in it.

When placing an electromechanical transducer in the system, its second function plays a significant role, the essence of which is the process of forming acoustic fields in the surrounding elastic media. The physical feature of this process for transducers' systems is the appearance of multiple transducers, emitting sound waves, reflection of these waves from all transducers and interaction of all these waves with each other. In this way, in the system of transducers, interaction of acoustic fields of all transducers of the system arises during the formation of its acoustic field. Analysis of the materials given in the works [2, 3, 6-9] shows that in the stationary radiation mode, the quantitative effect of acoustic interaction on the emitted acoustic signals depends on many physical factors. They include configuration of the transducers' system and its wave dimensions, frequency characteristics of transducers and their ratio to the signal frequency, type of oscillatory system of the transducer and its wave dimensions and others. In stationary mode, results of acoustic interaction of transducers in the system are different acoustic load of transducers, which leads to significant changes in their oscillatory speeds and mechanical resonant frequencies; dependence of these characteristics on the location of the transducers in the system; transition of transducers from the mode of radiation of sound energy to the mode of its receiving from the surrounding and return of electrical energy to the generator device.

Same physical features are caused by the acoustic interaction of transducers in the system should be expected in non-stationary modes of radiation. Naturally, this should lead to the emergence of new differences in the emitted acoustic pulses compared to transducers' stimulation electrical impulses.

Pay attention to several circumstances. First, the distances between transducers in the system and the acoustic pulses have finite lengths in space, that, depending on the time duration of the pulses, are comparable to each other. Second, for any direction in space, the acoustic pulses emitted by the systems' transducers into the distant field of the system, where their superposition takes place, pass different wave paths. In this regard, their addition in each direction is carried out with its own phase raids for pulses from each transducer of the system. Therefore, in a system of converters for each direction in space, acoustic pulses will differ from each other. At the same time, transducers' stimulation electrical impulses in the system do not undergo such changes.

The above physical reasons that led to changes in electrical impulses during their transformation into acoustic ones in the process of non-stationary stimulation of transducers in the system have not yet been described in the form of analytical expressions that allow to obtain the necessary data. Therefore, to provide design work, they can only be obtained experimentally.

3. EXPERIMENTAL STUDIES AND THEIR RESULTS

We will perform an experimental evaluation of transients in the system of piezoceramic transducers during its pulse load on the example of a linear cylindrical hydroacoustic system.

Studied sample of the system is formed from cylindrical piezoceramic electromechanical transducers (Fig. 1) and includes 7 transducers with an outer diameter of 96 mm and a height of 330 mm.

Fig. 1 – The studied sample of the linear system.

Resonant frequency of mechanical oscillations of the system at zero mod of its oscillations is $f_0 = 14{,}3\ kHz$ at a time constant $\tau_0 = 0{,}115 \cdot 10^{-3}\ s$. Transducers are in the system at the same distance $d = 100\ mm$ from each other. At a frequency $f = 7{,}5\ kHz$, $d/\lambda = 0{,}5$. The electronic part of the measuring stand is shown in Fig. 2. The electrical stimulation of the system was carried out by a rectangular radio pulse with unmodulated filling. The pulse duration was $0.1 \cdot 10^{-3}$ s and was limited by the size of the measuring pool. The frequency of repetition of pulses was chosen in the range of 10^{-20} Hz, which practically ensured complete attenuation of transients in the system before the start of each new impulse.

Fig. 2 – The electrical part of the measuring stand.

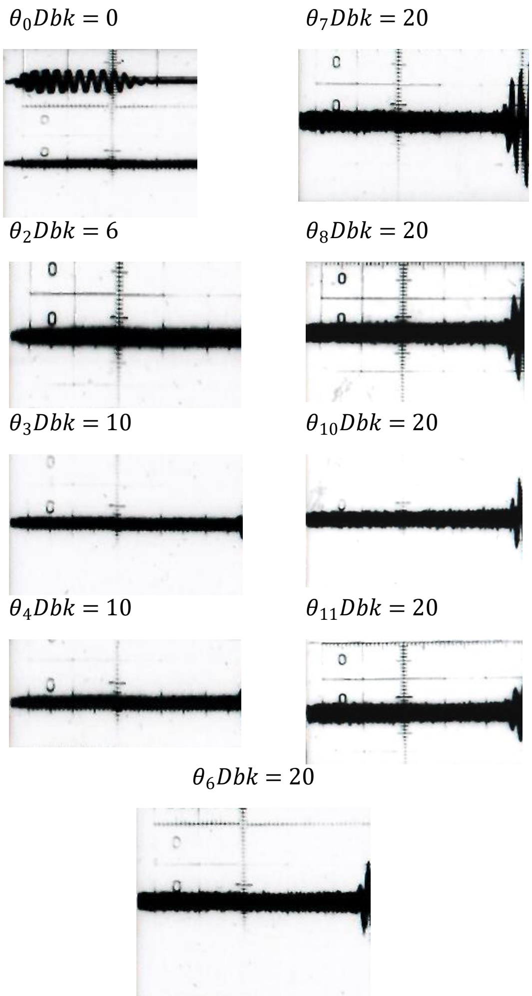

Fig. 3 – Dependence of the systems' response form the angle of incidence of the wave with $\omega/\omega_0 = 0{,}5$

Experimental studies were carried out in a measuring hydroacoustic pool with dimensions of 8×4×5 m according to the measurement scheme given in the work [10]. The purpose of the research was an experimental assessment of changes in the shapes of two pulsed signals – electrical, stimulating a linear electromechanical system, and acoustic, emitted by this system into the environment.

In the process of research, the frequency of filling the electrical stimulation pulse changed and were taken equal to $\omega/\omega_0 = 0{,}5$ and $\omega/\omega_0 = 1{,}0$, where ω_0 is the circular frequency of the mechanical resonance of the transducers in the system. Acoustic measurements in the pool were carried out in accordance with the regulated requirements in hydroacoustic [12]. In this case, the RMS error was 0.08 with a confidence level of 0.95.

Results of measurements of the dependence of amplitude shape of acoustic response of the system from the angle θ of radiation of acoustic wave are shown in Fig. 3 ($\omega/\omega_0 = 0{,}5$) and Fig. 4 ($\omega/\omega_0 = 0{,}5$). Here, θ_0 – θ_9 are angles of the maximum values of the main and additional lobes of the directivity characteristics of the system in the plane of its longitudinal axis, and θ_{10} – θ_{13} – angles of dips (interference zeros) of the directivity characteristic between the corresponding lobes; k – coefficient of amplification of acoustic response of the system.

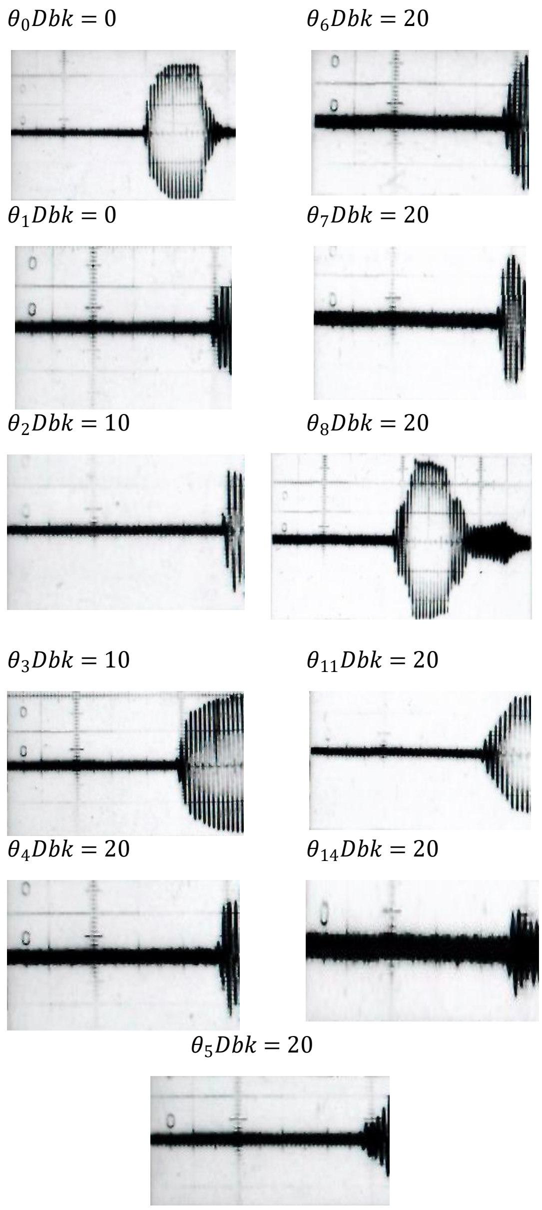

Fig. 4 – Dependence of the systems' response form the angle of incidence of the wave with $\omega/\omega_0 = 1{,}0$

Analysis of the above results indicates the following.

As already mentioned, with the same electrical load of all transducers in the system in the formation of their acoustic load, the interaction of transducers in the system by the acoustic field plays a significant role. This interaction causes a significant difference in the shape of the acoustic pulses emitted by the system. Physically, these changes are caused by two factors – the inertia of the electromechanical transducers of the system and the delay of the edge of acoustic wave during its propagation along the system.

As shown in the above results, changes in the shape of acoustic pulses due to the first factor are decisive for the angles that coincide with the directions of the main and additional lobes ($\theta_0, \theta_1 - \theta_4$, Fig. 4) of the directivity characteristic. In these spatial angles there are typical distortions, usual for pulses that have passed through mechanical resonant systems [11]. These distortions cause smooth rise of the front edge and decrese of the rear edge of the pulse. At the same time, degree of remoteness of frequencies of the harmonic filling of pulses from the frequency of mechanical resonance of transducers (Figs. 3, 4) creates insignificant, but different features in the forms of acoustic pulses emitted in these directions. Thus, the analysis of the above figures indicates that with an increase in the emission angle of the sound wave, the duration of the transient process due to the propagation of the sound wave along the studied transducers' system increases. This leads to the fact that when emitting acoustic pulses in the directions of the distant lobes (θ4 –θ8, Fig. 4) and the dips between them ($\theta_{11} - \theta_{14}$, Fig. 4), forms of acoustic pulses become complex and differs from each other after transducers' stimulation electrical impulse finishes. This takes place throughout the entire interpulse time interval and consists in a significant increase (3-5 times compared to the length of the electrical pulse) of the length of emitted acoustic pulse, the smooth rise and fall of the pulses' edges, the appearance of significant dips in the amplitude of pulses between the edges and the long sound of acoustic pulses after the rear edge. Described above process is physically caused by the multiple exchange of sound waves between transducers of the system through the media.

Analysis of graphs in Fig. 3 and Fig. 4 indicates that the distortion of acoustic pulses due to the inertia of the electromechanical transducers of the system takes place only in the directions of the axes of the main and near additional lobes of the spatial directivity characteristics.

In other directions, the second physical factor acts – the delay of the acoustic wave edge during wave propagation along the transducers' system. This factor is decisive for angles that are distant from the main lobe of the directivity characteristic ($\theta_4 - \theta_8$, Fig. 4), and for angles θ that coincide with the directions ($\theta_{11} - \theta_{14}$, Fig. 4) of the interference zeros of spatial characteristic. At the same time, there is both rise of quantity of dips in the directivity characteristic and a significant decrease in the level of amplitudes of the emitted acoustic pulses.

4. CONCLUSION

The dynamic changes that occur in the acoustic pulses emitted into the media by linear systems of piezoelectric electromechanical hydroacoustic transducers, compared to the electrical pulses that stimulate these emitters, have been experimentally discovered.

It was discovered that these dynamic changes are the result of the emergence of transients in the studied linear systems, both in electromechanical oscillatory systems of transducers, and in connection with the spatial extent of the systems under study. It is shown that the first physical cause of distortion of the emitted acoustic pulses is the inertia of the emitters, the second is the delay in the wave edge during its propagation along the linear system.

It has been established those typical distortions of acoustic pulses emitted by the system, due to the inertia of the transducers, are a smooth increase in the front edge of acoustic pulses and decrease in the rear edge. These changes in the shape of acoustic pulses are usual for the directions adjacent to the axes of the main and adjacent side lobes of the spatial directivity characteristic of the system.

It has been established these typical distortions of acoustic pulses, due to delays in the edge of the emitted wave, consist in a significant (3-5 times compared to an electrical pulse) increase in the length of acoustic pulses, a smooth increase and decrease in pulse edges, the appearance of significant dips in the amplitudes of pulses between the edges and the long sound of pulses after the rear edges. These changes in the shape of the acoustic pulses emitted by the system are decisive for the angles of spatial directivity characteristics, which correspond to the directions of the additional lobes that are distant from the main lobe, and the directions of the interference zeros of the spatial characteristic.

The distortions of acoustic pulses emitted by the linear location system of electromechanical sonar transducers given in the work significantly worsen the parameters of this system compared to their values, estimated only by the parameters of stimulation electrical impulses. Therefore, the above results must be considered when designing such location systems.

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Експериментальні дослідження динамічної поведінки імпульсів, що випромінюються лінійною системою електромеханічних перетворювачів

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Експериментальним шляхом встановлена суттева відмінність, що виникає в акустичних локаційних системах при їх роботі між електричними імпульсами, що збуджують елементи систем, і акустичними імпульсами, що випромінюються цими системами. Для лінійних систем, утворених із електромеханічних п'езокерамічних перетворювачів, фізичними причинами появи цих відмінностей є виникнення перехідних процесів в електромеханічних коливальних системах перетворювачів та просторова протяжність лінійних систем. Показано, що перша причина обумовлена інерційністю перетворювачів, друга – запізненням фронту хвилі при поширенні її вздовж системи.

Встановлені типові динамічні зміни акустичних імпульсів в залежності від причин їх виникнення. Показано, що інерційність механічних коливальних систем перетворювачів обумовлює в напрямках головної і прилеглих до неї бокових пелюсток просторової характеристики направленості лінійної системи, плавні наростання і спадання відповідно переднього і заднього фронтів акустичних імпульсів.

Встановлено, що для напрямків віддалених від головної і додаткових пелюсток та інтерференційних нулів просторової характеристики направленості, типові динамічні зміни акустичних імпульсів, викликані запізненням фронту випромінюваної хвилі, полягають в суттєвому збільшенні довжини їх порівняно з електричними, появі провалів амплітуд імпульсів між їх фронтами та довгому їх звучанні після закінчення електричного збудження перетворювачів системи. Наведені динамічні зміни випромінених акустичних імпульсів порівняно з електричними збуджуючими імпульсами, суттєво погіршують параметри локаційних систем, оцінених за параметрами електричних імпульсів. Тому їх необхідно враховувати при проектуванні таких систем.

Ключові слова: Акустичні імпульси, П'езокерамічний перетворювач, Лінійна система.