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A. V. DEREPA, *Doctor of Technical Sciences, Senior Researcher*
https://orcid.org/0000-0001-7334-2237
(Central Armed Forces Research Institute of the Armed Forces of Ukraine, Kyiv)

O. G. LEIKO, *Doctor of Technical Sciences, Professor*
https://orcid.org/0000-0002-5588-6449
(National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Kyiv)

O. I. DROZDENKO, *Candidate of Technical Sciences, Associate Professor*
https://orcid.org/0000-0001-6647-1428
(National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Kyiv)

A. O. SVIATNENKO, *Head of Research Department*
https://orcid.org/0000-0002-2084-2243
(State Enterprise «Kyiv scientific research institute of hydrodevices», Kyiv)

Properties of hydroacoustic transducers with internal baffles, depending on the characteristics of the baffles

Frequency and angular characteristics of the amplitudes and phases of the acoustic fields of cylindrical hydroacoustic transducer formed from piezoceramic shell, an elastic medium and an acoustically soft baffle, depending in the size of the baffles and the distance between the long axes of the shell were made. It is established that such technical implementation of transducers significantly enriches the range of resonance emitting by hydroacoustic stations and extends it away in the low-frequency domain compared to the hydroacoustic stations based on transducers without internal baffles. The number of newly generated frequencies of resonance emitting their placement on the low-frequency (0–6000 Hz), resonance (7000–14000 Hz) and high-frequency (more than 14000 Hz) ranges and the amplitude of the acoustic signals at the frequencies of resonance emitting, regulate by the diameters or distance between long axis of the piezoceramic shell and baffle. However, without changing of the size of the transducers in the low-frequency domain, their resonance frequencies can be 2–5 times less, and the resonance emitting of hydroacoustic signals at the same electric field voltage is comparable or much greater relative to the main resonance frequency of the transducers without baffles. Since modern hydro-acoustic stations do not have internal baffles as part of their transducers, the transition in them to the design of transducers with internal baffles should provide an increase in the efficiency of hydro-acoustic stations in terms of the effective implementation of different modes of operation on one hydro-acoustic antenna, increase the energy range of these modes.

Keywords: hydroacoustic piezoceramic transducers, internal acoustic baffle, resonance emitting.

INTRODUCTION

Recently, a number of innovations have been developed in technical hydroacoustic, which have a significant impact on the design of hydroacoustic stations (HAS). In terms of hydroacoustic antennas, these innovations include:

taking into account the antenna theory of the connection of physical fields and processes that take place in the transformation of energy and its formation in the surrounding spaces [1−8];

research in practice of technical realization of antennas of new approaches to the construction of their elements, in particular, hydroacoustic transducers [9, 10].

The latest innovation is the creation of hydro-acoustic transducers in the form of cylindrical piezoceramic structures with internal acoustic baffles. One variant of such a transducers is given in works [8−10] and includes (Fig. 1) a cylindrical piezoceramic shell 1, a cylindrical acoustic soft baffle 2 and an elastic medium 3 in the inner cavity of the transducer.

For physical reasons, it is clear that, given the connection of physical fields and processes in the conversion and formation of energy by the transducer, each of its structural elements plays a significant role in the formation of parameters of the mechanical, acoustic and electric fields of the transducer in the emitting mode. Studies of mechanical and electric fields of such transducers were devoted to work [8 − 10]. From the point of view of HAS requirements, acoustic fields of transducers of this type are of particular interest. It is important to gain new knowledge about the potential of acoustic fields, depending on the specific characteristics of the structural elements of the transducers, namely the composition of the piezoceramics used; physical parameters of the internal elastic environment; the structural dimensions of the shell 1, baffle 2 and the conditions of its placement inside the shell (Fig. 1).

The purpose of this work is to investigate the potentialities of the acoustic properties of cylindrical piezoceramic transducers with internal baffles, depending on the size of the baffle and the conditions of their placement.

Analysis of results of acoustic field calculations

To quantify the parameters of the acoustic fields of cylindrical transducers with internal baffles, we use the analytical ratios given in [8−12]. We begin by exploring acoustic fields to determine the effect of baffle sizes and the nature of their placement relative to the piezoceramic shell. Numerical experiments for this purpose were performed for the following parameters and characteristics of the transducers: the piezoceramics of the composition of ZTBL-3 (zirconate-tintanate barium lead); circular polarization; $r_0 = 0,068\,m$; $h = 0,008\,m$; $\alpha_0 = 0,2r_0$; $0,5r_0$; $0,9r_0$; $l_{0'0} = r_2 - \alpha_0 - 0,003\,m$; $\theta = 0^\circ$; $\psi_0 = 200\,V$; $\rho c = \rho_1 c_1 = 1,5 \cdot 10^6\,kg/m^2 s$. The frequency range ranges from 0 to 20000 Hz. The amplitudes and phases of the external acoustic field were calculated at a point on the surface of the transducer with internal baffle with coordinates $(r_1, 0)$. The results of the calculations are presented in Fig. 2−6.

Analysis of the frequency and phase dependences of the acoustic pressure amplitudes when resizing the acoustic baffle and the constant distance (0.003 m) between the

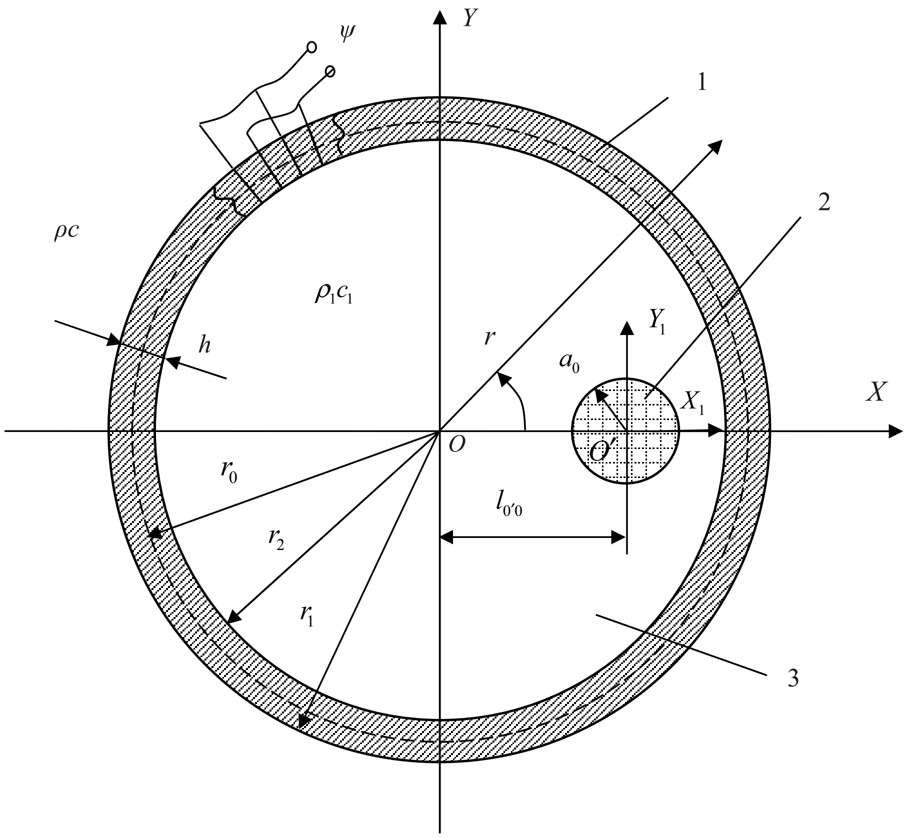

Fig. 1. Normal cross section of the transducer with the internal baffle

surfaces of the piezoceramic shell and the baffle shows this. Asymmetrical placement of the baffle in the inner volume of the piezoceramic shell causes a significant number of amplitude bursts (Fig. 2). Most of these bursts have amplitudes that are comparable to, or greater than (and significantly), the amplitude of the pressure on the self-resonance of the piezoceramic shell. The number of such amplitude bursts is greatest at maximum values $l_{0'0}$ and small values α_0, that is, at maximum loss of radial symmetry of transducer construction. It is interesting that, in small values α_0, the shielded transducer generates amplitude pressure bursts in the low-frequency range. The frequencies of these bursts are 1.3–6 times lower than the natural frequency of the piezoceramic shell. The dimensions of the shielded transducer remained unchanged. Analysis of the frequency-phase dependences in this domain (Fig. 3) shows that not all of these amplitude bursts are resonant. This is important to know because it is at resonance frequencies of the burst amplitude several orders of magnitude higher than at nonresonant frequencies.

As the baffle sizes increase to medium $\alpha_0 \approx 0,5\, r_0$, the resonant bursts of amplitudes in the low-frequency region (Figs. 2b and 3b) disappear, and their number in the resonant region of the shielded transducer increases. The amplitudes and resonant frequency bands on newly generated resonances are significantly increased. The inherent resonance frequency of the piezoceramic shell of the transducer with such an internal baffle shifts to the lower (5–7%) frequency range. Almost all the frequencies of the newly generated amplitude bursts are resonant. In the high-frequency region, almost all newly generated amplitude bursts are resonant. With a further significant increase in the size of the baffles $\alpha_0 \approx 0,9\, r_0$ in the frequency dependences of the amplitudes (Fig. 2c) and phases (Fig. 3c), the acoustic pressure remains only one resonance. Other bursts of amplitudes are no longer generated. In this case, the resonance frequency of the shielded transducer coincides with the natural resonance frequency of the piezoceramic shell. The presence of fluid in the gap between this shell and the acoustic baffle does not manifest itself.

The results above show that choosing the right inner baffle sizes can solve different practical tasks. Let us now consider how the frequency dependences of the acoustic pressure amplitudes of a shielded transducer change as the distance $l_{0'0}$ between the longitudinal axes of the piezoceramic shell and the inner baffle and the constant baffle and shell dimensions change. For this purpose, numerical calculations were made for the parameters of the converters above with the following changes: $\alpha_0 = 0,2\, r_0$; $l_{0'0} = 0$; $l_{0'0} = r_2 - \alpha_0 - 0,003\, m.$ The results of the calculations are shown in Fig. 4. In general, the placement of a constant-sized inner baffle at different distances from the center of the piezoceramic shell ensures the generation of many resonant bursts of acoustic pressure. Nevertheless, the frequency ranges in which they are placed, and their number in these ranges, are determined by the value of magnitude $l_{0'0}$.

Analysis of the frequency dependences of the amplitudes and phases of the acoustic pressure as the distance $l_{0'0}$ changes shows (Fig. 2a, 4) the resonant nature of these dependences. In general, placement of the internal baffle of constant size, but at different distances $l_{0'0}$ from the center of the piezoceramic shell generates many resonant bursts of acoustic pressure. But the frequency ranges in which they are placed, and their number in these ranges, are determined by the values of magnitude $l_{0'0}$.

The highest number of resonant bursts of acoustic pressure amplitudes and their presence in all the studied frequency regions – low-frequency, resonant and high frequency, are observed at maximum distance values.

In addition, as already noted, the particular practical importance is the fact that without increasing the overall dimensions of the transducers and the small size of the internal baffles in the low-frequency region generates a significant number of resonant emitting frequencies with amplitudes of acoustic pressure, greater or significantly greater than the amplitude of the amplitude of the ceramic sheath of the transducer. This creates the potential for a significant increase in the efficiency of the transducers.

The physical reasons for the creation of such possibilities are, first, a significant violation of the radial symmetry of the construction of the baffle transducer and, secondly, the appearance in the inner space of the piezoceramic shell of standing waves due to the presence of an acoustic baffle in it.

Moving the acoustic baffle closer to the center of the piezoceramic shell (Fig. 4a) significantly changes the picture described above. In the low-frequency region, the number of newly generated resonant bursts of acoustic pressure amplitudes decreases significantly, and their amplitudes decrease. At the same time, both the number of newly generated resonant emissions and their amplitudes are increasing in the resonant region of the shielded transducer.

Placing the acoustic baffle in the center of the piezoceramic shell of the transducer (Fig. 4b) again significantly changes the frequency dependences of the acoustic pressure of the transducer. This is due to the fact that such a shielded cylindrical transducer again restores the radial symmetry of its construction and the physical causes of the appearance in its mechanical field of modes following the zero mode, no [8]. Hence the absence in the acoustic spectrum of such a shielded transducer of new resonant frequencies.

At the same time, one newly generated resonant frequency remains in the low-frequency region of the acoustic field. This inherent resonance of the shielded transducer is due to other physical causes. They consist in the appearance of this frequency in the inner space of a fluid-filled, piezoceramic shell of a standing wave. Its appearance is because the wavelength of the gap $l_{0'0}$ between the inner surface of the shell and the outer surface of the inner baffle is in the region of 0.25. This standing wave is caused by the interaction of the direct wave emitted by the shell and the wave reflected by the acoustic baffle. Under these conditions, a sharp increase in acoustic pressure is created on the inner surface of the shell.

Based on the above, let us pay attention to the following two facts. The first of these is that the standing wave is formed by the zero mode of oscillation. Moreover, since the conversion of the electric field energy into the energy of the mechanical and then acoustic fields is carried out only on the zero mode of oscillations, its change must be reflected in the electric field of excitation of the shielded transducer. The second fact is that at all values $l_{0'0}$ the frequency of zero mode remains unchanged. Therefore, for different values $l_{0'0}$ of magnitude, there will always be such distances between the shell and the baffle, which will be in the region of 0.25 λ and when the frequency changes, and therefore the values of λ, the given condition may correspond to other distances between the surfaces of the shell and the baffle. This is evidenced by the frequency dependencies of Fig. 2a, 3a, 4a.

In the study of the mechanical fields of transducers with internal baffles [8] their interesting features were established. They consist in the fact that two physical factors are involved in the formation of these fields, which are caused by the repeated exchange of sound waves between the piezoceramic shell and the acoustic baffle in the internal volume of the transducer. The first of them is related to the finite size of this volume, so that when it propagates zero mode, only which is emitted by the piezoceramic shell when selected in the scheme of its electrical excitation, it produces acoustic fields of standing waves at certain frequencies, which are defined as the natural frequencies of this volume.

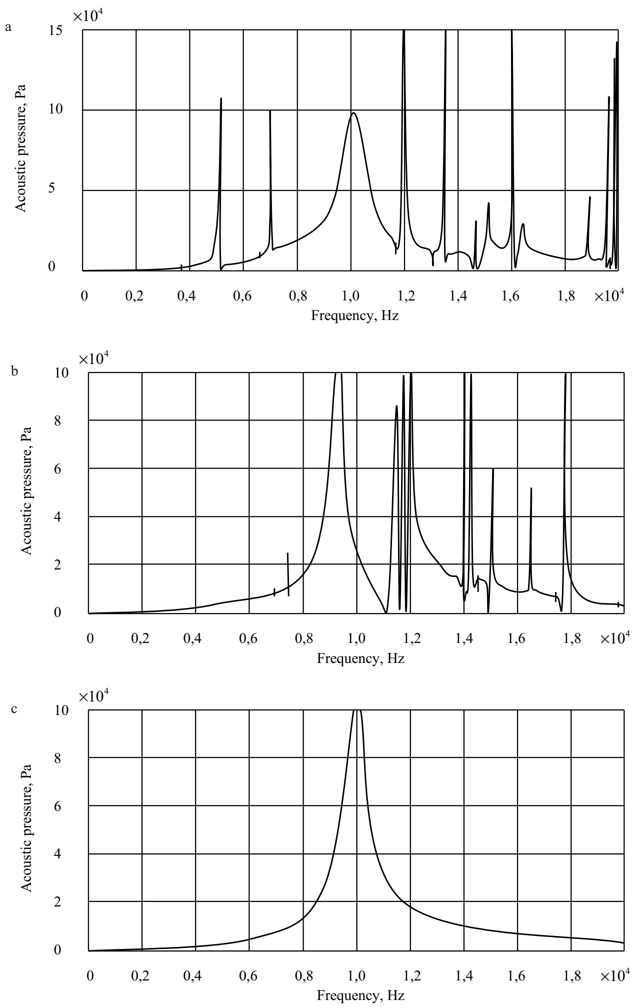

Fig. 2. Frequency dependences of acoustic pressure amplitudes on the surface of the transducer with internal baffle at $\alpha_0 = 0,2\, r_0$ (a); $\alpha_0 = 0,5\, r_0$ (b); $\alpha_0 = 0,9\, r_0$ (c)

The second of these physical factors is that the asymmetric placement in the piezoceramic shell of the inner baffle

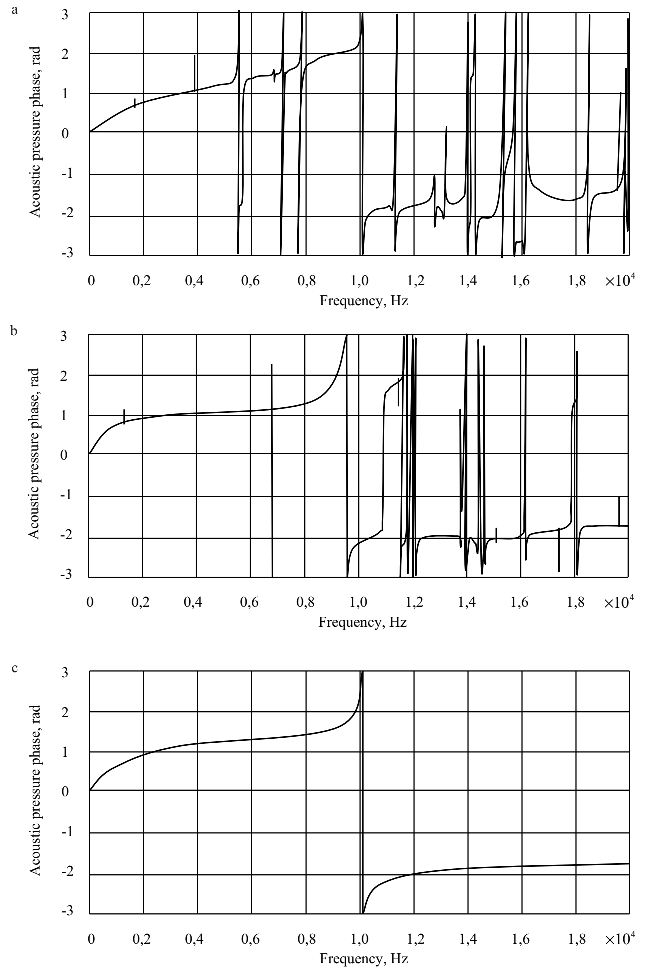

Fig. 3. Frequency dependences of acoustic pressure phase on the surface of the transducer with internal baffle at $\alpha_0 = 0,2\, r_0$ (a); $\alpha_0 = 0,5\, r_0$ (b); $\alpha_0 = 0,9\, r_0$ (c)

violates the radial symmetry of the mechanical oscillatory system of the transducer. While maintaining the radial symmetry of the electrical excitation of the piezoceramic shell of the transducer, this asymmetry of its mechanical oscillatory system causes the generation of new zero-oscillation modes in it. They have different energy efficiency due to the redistribution of zero-mode energy between all modes of the oscillating system of the shielded transducer. In this case, each fashion has its own resonant frequency.

Since each of the described modes of mechanical oscillation forms in its environment its own components of the acoustic fields, the full acoustic fields of the shielded transducer represent a superposition of all these components. The above dependences of the amplitudes and phases of the acoustic fields on the outer surface of the transducer indicate this.

It seems appropriate to identify the roles that qualitatively and quantitatively influence the formation of the acoustic fields of shielded transducers the above factors. This is important to know for two reasons. The first is knowledge of the energy efficiency of each of the mode components of the acoustic field in different frequency domains. The second reason is the determination of the angular distributions of acoustic fields created by a shielded transducer at

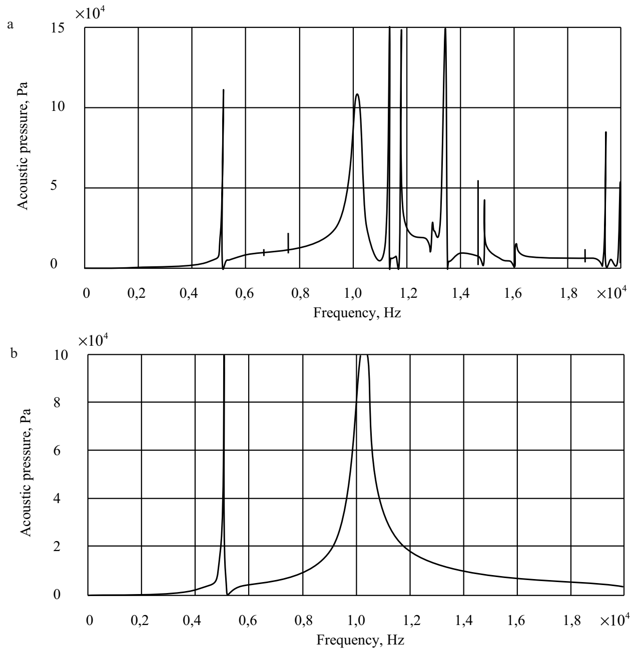

Fig. 4. Frequency dependences of the acoustic pressure amplitudes on the surface of the transducer with internal baffle at $l_{0'0} = 2a_0$ (a); $l_{0'0} = 0$ (b)

resonant frequencies due to various physical factors. Analysis of the results of the calculations shown in Fig. 5, indicates the following. In the formation of acoustic fields of shielded transducers, the main energy contribution is made by the zero mode of their mechanical vibrations. It provides energy to the acoustic fields not only at the natural frequency of the piezoceramic sheath of the transducer, but also at all the natural frequencies of this mode in the internal volume of the transducer associated with the emergence of standing waves. In particular, it causes the appearance of an effective acoustic field, albeit in narrow resonance bands, in the low-frequency region at frequencies that are 1.3−2 times smaller than the natural frequency f_0 of the shell in vacuum. It also provides the "pumping" of acoustic energy into the resonant emissions of the acoustic field at the natural frequencies of the newly generated oscillation modes (Fig. 5a).

In this case, the forms of resonant emissions of acoustic fields repeat the forms of the corresponding mode components of the mechanical field [8].

Practically important is the knowledge of the angular distribution of the acoustic field of the shielded transducer at its resonant frequencies. This is because it is a superposition of the acoustic field components with their amplitudes and phases at appropriate frequencies. In particular, at the lowest resonant frequency of the shielded transducer, the acoustic field is formed only by the zero mode of oscillation of its mechanical field, and therefore, it must have a non-directional character (Fig. 6, curve 1). The acoustic field of the transducer must have the same character of angular distribution at all frequencies, where the contribution of its component due to the zero mode of oscillation of its piezoceramic shell is the main one.

This angular distribution of the acoustic field must have another character at the resonant frequencies caused by the

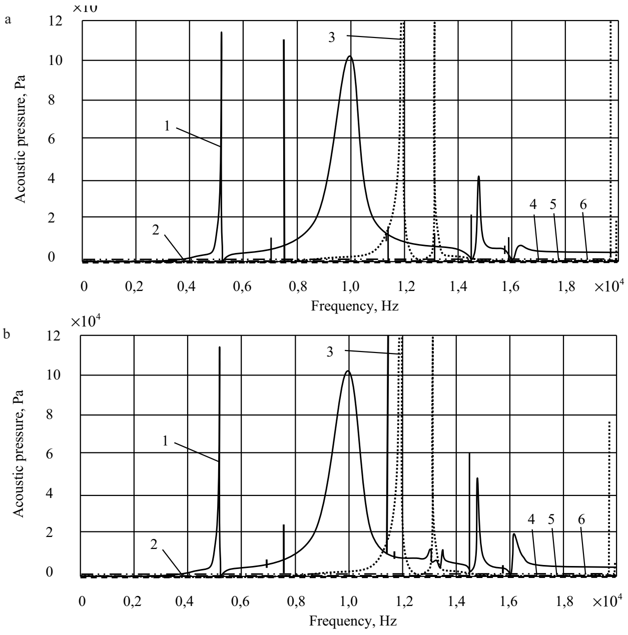

Fig. 5. Frequency dependencies of the amplitudes of the mode components of acoustic pressure on the surface of a shielded emitter at $\alpha_0 = 0,2\,r_0$; $l_{0'0} = r_2 - a_0 - 0,003\,m$ (a); $l_{0'0} = 2a_0$ (b); n=0 (curve 1); 1 (curve 2); 2 (curve 3); 3 (curve 4); 4 (curve 5); 5 (curve 6)

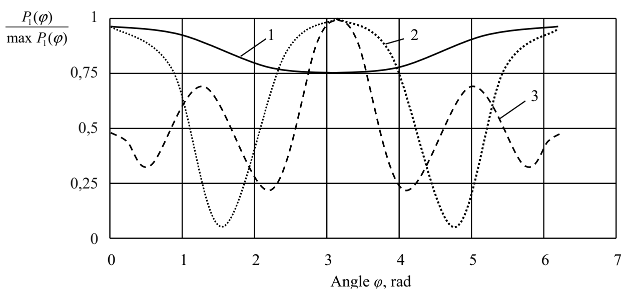

Fig. 6. Angular dependencies of the normalized acoustic field amplitudes $\frac{P_1(\varphi)}{\max\, P_1(\varphi)}$ in the far area emitter at frequencies 3800 Hz (curve 1), 6925 Hz (curve 2), 13140 Hz (curve 3)

appearance of other modes of oscillation (Fig. 6, curves 2, 3). This character ranges from bidirectional (curve 2) to predominantly unidirectional (curve 3).

CONCLUSIONS

The results of the research presented in the paper allow us to draw a number of conclusions, important in terms of increasing the efficiency of the HAS, the composition of hydroacoustic antennas which include cylindrical transducers with internal baffles.

First, the introduction of cylindrical transducers of the inner baffles significantly enriches the spectrum of the resonant HAS radiation. In addition, since the efficiency of the HAS in the mode of radiation of the acoustic signals is ensured by their work only in the resonant regions, it allows to implement several modes of operation of the HAS in one hydroacoustic antenna and thus to provide the transformation of the HAS into hydroacoustic complexes.

Second, the use of cylindrical transducers with internal baffles in the construction of hydroacoustic HAS antennas allows to extend the range of resonant frequencies into the low frequency range without changing the overall dimensions of the antennas and transducers. In this case, the frequencies of the resonant radiation are reduced by 2−5 times relative to the resonant frequencies of such transducers without baffles, and the amplitudes of the hydroacoustic signals are comparable or significantly higher at the low frequencies of the amplitudes of the latter. This allows one to expect a significant increase in the energy range of the HAS.

Third, changing the diameter of the baffles at a constant distance between the surfaces of the baffles and the piezoceramic shells, or changing the distance between the longitudinal axes of the baffle and the shell at constant dimensions of the shell and baffle can be controlled as an enrichment of the spectrum of the resonant radiation of hydroacoustic antennas, and often of diaphragm antennas the enrichment of the spectrum is mainly concentrated. This allows you to control the performance of the HAS, using either the energy range criterion or the accuracy criterion for determining the coordinates of the object, depending on the set requirements.

Fourth, it is possible to dynamically control the parameters of the HAS, using electromechanical devices to change both or diameter the internal baffle, or the location of the baffle in the internal volume of the design of the transducers of the corresponding acoustic antenna. Examples of possible technical implementation of HAS with such antennas are given in patents.

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Дерепа А.В., Лейко О.Г., Дрозденко О.І., Святненко А.О.

ВЛАСТИВОСТІ ГІДРОАКУСТИЧНИХ ВИПРОМІНЮВАЧІВ З ВНУТРІШНІМИ ЕКРАНАМИ В ЗАЛЕЖНОСТІ ВІД ХАРАКТЕРИСТИК ЕКРАНІВ

Проведено дослідження частотних і кутових характеристик амплітуд і фаз акустичних полів циліндричних гідроакустичних випромінювачів, утворених із п'єзокерамічної оболонки, пружного середовища і акустично м'якого екрану, в залежності від розмірів екранів і відстані між поздовжніми вісями оболонки та екрану. Встановлено, що така технічна реалізація випромінювачів суттєво збагачує спектр резонансного випромінювання гідроакустичних станцій і далеко поширює його в низькочастотну область порівняно з гідроакустичними станціями на основі випромінювачів без внутрішніх екранів. Кількість заново генерованих частот резонансного випромінювання, їх розміщення по низькочастотному (0−6000 Гц), резонансному (7000−14000 Гц) і високочастотному (більше 14000 Гц) діапазонах та амплітуди гідроакустичних сигналів на частотах резонансного випромінювання регулюють вибором розмірів діаметрів або відстані між поздовжніми вісями оболонки та екрану. При цьому без змін розмірів випромінювачів в низькочастотній області їх резонансні частоти можуть бути в 2−5 разів меншими, а резонансні випромінювання гідроакустичних сигналів при однаковій електричній напрузі збудження порівняними або значно більшими відносно основної резонансної частоти випромінювачів без екранів. Оскільки сучасні гідроакустичні станції не мають внутрішніх екранів у складі своїх випромінювачів, то перехід в них до конструкції випромінювачів з внутрішніми екранами повинен забезпечити збільшення ефективності гідроакустичних станцій в частині ефективної реалізації різних режимів роботи на одній гідроакустичній антені, збільшення енергетичної дальності та точності виявлення об'єктів на цих режимах.

Ключові слова: гідроакустичний п'єзокерамічний випромінювач, внутрішній акустичний екран, резонансне випромінювання.

Дерепа А.В., Лейко А.Г., Дрозденко А.И., Святненко А.О.

СВОЙСТВА ГИДРОАКУСТИЧЕСКИХ ИЗЛУЧАТЕЛЕЙ С ВНУТРЕННИМИ ЭКРАНАМИ В ЗАВИСИМОСТИ ОТ ХАРАКТЕРИСТИК ЭКРАНА

Выполнены исследования частотных и угловых характеристик амплитуд и фаз акустических полей цилиндрических гидроакустических излучателей, образованных из пьезокерамической оболочки, упругой среды и акустически мягкого экрана, в зависимости от размеров экранов и расстояния между продольными осями оболочки и экрана. Установлено, что такая техническая реализация излучателей существенно обогащает спектр резонансного излучения гидроакустических станций и далеко распространяет его в низкочастотную область по сравнению с гидроакустическими станциями на основе излучателей без внутренних экранов. Количество заново генерируемых частот резонансного излучения, их размещение в низкочастотном (0−6000 Гц), резонансном (7000−14000 Гц) и высокочастотном (более 14000 Гц) диапазонах и амплитуды гидроакустических сигналов на частотах резонансного излучения регулируют выбором размеров диаметров или расстояния между продольными осями оболочки и экрана. При этом без изменений размеров излучателей в низкочастотной области их резонансные частоты *могут быть в 2–5 раз меньше, а резонансные излучения гидроакустических сигналов при одинаковом электрическом напряжении возбуждения сопоставимыми или значительно больше основной резонансной частоты излучателей без экранов. Поскольку современные гидроакустические станции не имеют внутренних экранов в составе своих излучателей, то переход в них к конструкции излучателей с внутренними экранами должен обеспечить увеличение эффективности гидроакустических станций в части эффективной реализации различных режимов работы на одной гидроакустической антенне, увеличение энергетической дальности и точности обнаружения объектов на этих режимах.*

Ключевые слова: гидроакустический пьезокерамический излучатель, внутренний акустический экран, резонансное излучение.

Дерепа Анатолій Войткович
доктор технічний наук
старший науковий співробітник
провідний науковий співробітник науково-дослідного відділу розвитку морських озброєнь науково-дослідного управління розвитку морських озброєнь та техніки Військово-Морських Сил Центрального науково-дослідного інституту озброєння та військової техніки Збройних Сил України,
м. Київ, Україна
https://orcid.org/0000-0001-7334-2237
e-mail: derepaan@i.ua

Derepa Anatolii
Doctor of Technical Sciences
Senior Research
Leading researcher of the Scientific Research Department Navy Armament of the Scientific Research Management Navy Armament and Equipment Research Directorat of the Central Scientific Research Institute of Armament and Military Equipment of the Armed Forces of Ukraine.
Kyiv, Ukraine
https://orcid.org/0000-0001-7334-2237
e-mail: derepaan@i.ua

Лейко Олександр Григорович
доктор технічний наук
професор
професор кафедри акустики та акустоелектрорніки Національного технічного університету України «Київський політехнічний інститут імені Ігоря Сікорського»
м. Київ, Україна
https://orcid.org/0000-0002-5588-6449
e-mail: Alexander_leiko@ukr.net

Leiko Oleksandr
Doctor of Technical Sciences
Professor
Professor of the Chair of Acoustics and Acoustoelectronics of the National technical university of Ukraine “Igor Sikorsky Kyiv polytechnic institute”
Kyiv, Ukraine
https://orcid.org/0000-0002-5588-6449
e-mail: Alexander_leiko@ukr.net

Дрозденко Олександр Іванович
кандидат технічний наук
доцент
доцент кафедри акустики та акустоелектроніки Національного технічного університету України «Київський політехнічний інститут імені Ігоря Сікорського»
м. Київ, Україна
https://orcid.org/0000-0001-6647-1428
e-mail: drozdenko@i.ua

Drozdenko Oleksandr
Candidate of Technical Sciences
Associate Professor
Associate Professor of the Chair of Acoustics and Acoustoelectronics of the National technical university of Ukraine “Igor Sikorsky Kyiv polytechnic institute”
Kyiv, Ukraine
https://orcid.org/0000-0001-6647-1428
e-mail: drozdenko@i.ua

Святненко Андрій Олегович
начальник науково-дослідного відділу
Державного підприємства «Київський науково-дослідний інститут гідроприладів»
м. Київ, Україна
https://orcid.org/0000-0002-2084-2243
e-mail: sviatnenkoa@gmail.com

Svyatnenko Andriy
Chief of Scientific Research Department
State Enterprise «Kyiv Scientific Research Institute of Hydrodevices»,
Kyiv, Ukraine
https://orcid.org/0000-0002-2084-2243
e-mail: sviatnenkoa@gmail.com

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