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A. V. DEREPA, *Doctor of Technical Sciences, Senior Researcher*
https://orcid.org/0000-0001-7334-2237
(Central Scientific-Research institute of weapon and military equipment of Armed Forces of Ukraine, Kyev)
O. G. LEIKO, *Doctor of Technical Sciences, Professor*
https://orcid.org/0000-0002-5588-6449
(National Technical University "Igor Sikorsky Kyiv Polytechnic Institute")
O. I. DROZDENKO, *Candidate of Technical Sciences, Associate Professor*
https://orcid.org/0000-0001-6647-1428
(National Technical University "Igor Sikorsky Kyiv Polytechnic Institute", Kyev)
A. O. SVIATNENKO, *Head of Research Department*
https://orcid.org/0000-0002-2084-2243
(State Enterprise "Kiev scientific research institute of hydrodevices", Kyiv)

Properties of electrical fields of hydroacoustic transdusers with internal baffle

The properties of electric fields of hydroacoustic piezoceramic radiators with internal acoustically soft baffels in a wide range of frequencies depending on the size of the baffels have been studied. The studies were carried out taking into account the interaction of physical fields in the process of energy conversion and interaction of the piezoceramic shell and baffel on the acoustic field during the formation of energy in the surrounding space. The analytical relations that describe these physical fields are related to the general solution of three differential equations - the wave equation, the equation of electromechanical oscillations of the electroelastic piezoelectric shell and the equation of state of this piezoelectric shell. The solution of the problem is to solve the problem by means of the known methods of infinite system of linear algebraic equations concerning the unknown coefficients of decomposition of mechanical and acoustic fields of radiation in the Fourier series. The regularities in the frequency behavior of the total capacitive and dynamic currents of electric excitation of the radiators of hydroacoustic stations and the total, active and reactive input electrical resistance of these radiators are established. The complexity of constructing the matching devices for generators and radiators in the radiation devices of hydroacoustic stations is shown. It is established that by selecting the size of internal baffels it is possible to effectively control the parameters of electric fields of shielded radiators in different frequency ranges of hydroacoustic stations operation. At small sizes of internal baffels and preservation of the sizes of hydroacoustic radiators in the field of low frequencies there are new resonant frequencies which are two times less in size, than the basic resonant frequency of the shielded radiator. At the same time, the new resonant frequencies have greater efficiency in converting electrical energy into acoustic energy. The use of these frequencies increases the range of the hydro-acoustic station.

Key words: hydroacoustic piezoceramic radiator, internal acoustic baffel, electrical substitution schemes.

INTRODUCTION

In emitting system of hydro-acoustic stations (GAS), the excitation electronic generator (EG) and the hydro-acoustic sonar array are interconnected and mutually affecting each other. At the same time, for the emitting system, the characteristics of the sonar array, which are determined by the electrical circuit of the emitter replacement, are essential. Such circuits are complex, multi-circuit, and include elements with changing parameters to take more account of the behavior of the emitters under different conditions of use.

Differences in the scheme of replacement of piezoceramic e are particularly difficult.

This is due to the complex interconnection of the electrical, mechanical and acoustic fields that occur in the piezoceramic emitters during their operation due to the inherent piezoceramic environments of the piezoelectric effect. At the same time, simplified single-circuit schemes are usually used for engineering calculations [1]. Their construction is based on the use of the method of equivalent electromechanical circuits [2 - 4]. According to it, the emitter is presented in the form of a multi-circuit, containing electrical and mechanical circuits, which are connected to each other by the so-called electromechanical transformer [5, 6].

Variant of a single-circuit scheme corresponding to the fundamental resonant frequency of the shielded emitter piezoceramic shell is shown in Fig. 1 and contains electrical 1 and mechanical 2 circuits and an electromechanical transformer 3.

Conversion of mechanical circuit 2 to the electrical side 1 of the radiator leads to the fact that the electrical circuit replacement at the resonant frequency of its piezoceramic shell is a parallel connection of two branches (Fig. 2), where M, C, R - are reduced to the electrical side in the form of inductance, capacitance and active load of the support of the mechanical side of the radiator [3],a R_{el} , by virtue of its magnitude, is not taken into account; L_c – compensating inductance.

The first branch describes the static behavior of the emitter. The second branch describes the dynamic behavior of the emitter due to the interaction of its physical fields – electrical, mechanical and acoustic in the process of the emitter. It is in the presence of this interaction and the great mathematical complexity of its description that the main problem is to build adequate circuits for the replacement of piezoceramic emitters.

The purpose of this work is to study the properties of electric fields of cylindrical piezoceramic emitters with internal baffels considering two types of interaction, namely, the interaction of physical fields in the process of energy conversion and the interaction of the piezoceramic shell and the acoustic field baffel in the formation of energy in the surrounding space.

CALCULATION RELATIONS

Conversion of electric energy into acoustic in a sound emitter (Fig. 3) consisting of a piezoceramic shell 1 of medium radius r_0 with circular polarization, an internal acoustic soft baffel 2 in diameter $2\alpha_0$, and fluid 3, which fills the inner cavity of the shell 1, is characterized by two features.

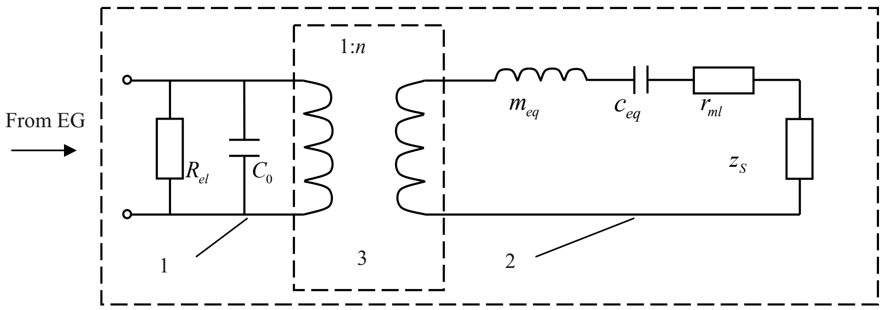

Fig. 1. Single-circuit equivalent electromechanical transducer circuit: 1 – electrical chain; 2 – mechanical chain; 3 – electromechanical transformer; R_{el} – resistance of dielectric losses; C_0 – electrical capacity; n – electromechanical transformation coefficient; c_{eq} – equivalent flexibility; m_{eq} – equivalent mass; r_{ml} – resistance to mechanical losses; z_S – radiation resistance.

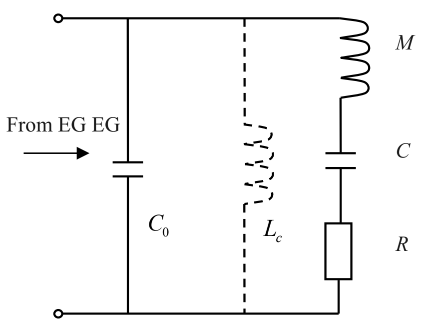

Fig. 2. Wiring diagram of radiator replacement

The first of these is the interconnection of electric, mechanical and acoustic fields in the process of converting to a piezoceramic shell of energy. The second is due to the repeated exchange of sound waves between the shell 1 and the baffel 2, which leads to the interaction of their acoustic fields. Finding analytical relations describing these physical fields is related to the joint solution of three differential equations - the wave equation, the equation of electromechanical oscillations of the elastic piezoceramic cylindrical shell, and the equation of state of this piezoceramic shell. The solution of this problem was carried out in [7] and is reduced by known methods [8] of an infinite system of linear algebraic equations with respect to the unknown coefficients of the decomposition of the mechanical and acoustic fields of a radiator into Fourier series. The parameters of the electric field of the shielded radiator are calculated by the formulas:

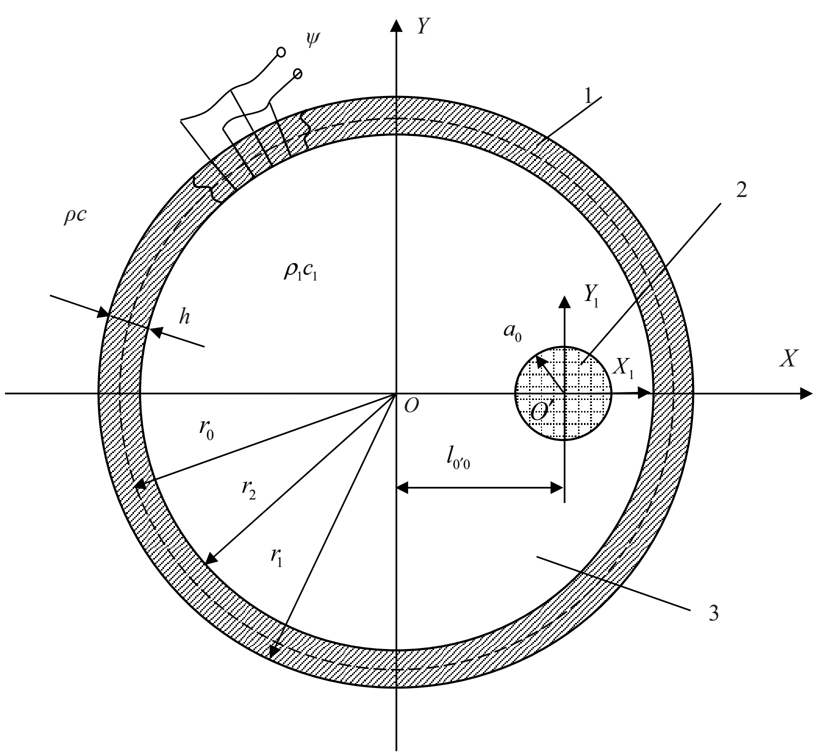

Fig. 3. Normal cross-section of the radiator with the inner baffel

− electric excitation current

$$J=-i\omega S_{el}\left\{\varepsilon_{33}^{0}\frac{\psi_0 M^2}{2\pi r_0}+\frac{e_{33}}{r_0}\sum_{j=1}^{M}\left[\sum_n in u_n e^{\frac{in2\pi}{M}j}+\sum_n w_n e^{\frac{in2\pi}{M}j}\right]\right\};$$

− electric field strength in the piezoceramics of the emitter at surround polarization

$$E_{\varphi}=\frac{-\psi_0 M}{2\pi r_0};$$

− the input electrical resistance of the emitter, its active R_{in} and reactive X_{in} components

$$Z_{in}=R_{in}+iX_{in}=\frac{\psi_0}{J},$$

where ω – circular excitation frequency; S_{el} – the area of the electrodes of the piezoceramic prisms of the radiator shell; M – the number of prisms in the shell; ψ_0 – excitation voltage; ε_{33}^{0} and e_{33} – dielectric constant and constant piezoceramics of the shell; u_n, w_n – coefficients of decomposition of the mechanical field of the shielded converter into Fourier series.

The analysis of the above relations shows that the total current J of the excitation of the radiators is the sum of the capacitive (first addition) and dynamic (second addition) currents. This is evidenced by the electrical circuit replacement (Fig. 2). Availability of capacity $C_0=\frac{\varepsilon_{33}^{0}S_{el}M^2}{2\pi r_0}$ leads to the consumption of a large capacitor current from the electric generator. This current overloads the generator and all electrical lines of communication. To eliminate this deficiency or reduce its impact capacity C_0 compensate for artificially created compensating inductance L_c, shown in Fig. 2 dashed lines. But, as practice shows, this approach does not exhaust the problem of matching the generator with the emitter. This is due to the presence in the scheme of substitution (Fig. 2) of the right dynamic branch. Even if the emitter is operating at the frequency of its mechanical resonance, when the reactive load of its dynamic, branch approaches zero, the parameter R_l is not once and forever a fixed constant.

The above applies to the variant of construction of the emitter in the form of a single-mode oscillating system. For multimode systems, which are shielded emitters [7], a single-circuit equivalent electromechanical circuit of the emitter is converted into a multi-circuit [3]. In this case, each circuit corresponds to its fashion and describes the behavior of the emitter at the resonant frequency of its fashion. It will also be natural for several electrical circuits to replace the emitter to match their modes with their dynamic branch parameters.

RESULTS OF NUMERICAL EXPERIMENTS

We determine the behavior of the electric fields of piezoceramic cylindrical radiators with internal baffels, depending on the size of the baffels.

Calculations of the parameters by the above formulas will be carried out for the following values of the characteristics of the emitters: $r_0=0,068$ *м*; $h=0,008$ *м*; M=48 piezoceramics of ZTBS-3 composition (lead barium zirconate): $\alpha_0=0,2r_0$; $\alpha_0=0,5r_0$; $\alpha_0=0,9r_0$; $\rho c=\rho_1 c_1=1,5\cdot10^6$ *кг/м²с*; $\psi_0=200$ *В*; $r_0-h/2-\alpha_0-l_{0'0}=0,003$ *м*.

A systematic analysis of the results of extensive numerical experiments for radiators with internal baffels, depending on the baffel sizes, is presented in Fig. 4 and 5. Note that when performing all these calculations, the minimum distance between the shell and baffel surfaces was kept constant.

The analysis of the given dependences of the currents in the external circuit of the shielded emitter (Fig. 3) shows the following. For all baffel sizes, the capacitive current, as it should be, varies equally and in proportion to the frequency. This is due to the fact that the piezoceramic shell of the radiator is not subject to any changes.

The dynamic component of full current behaves differently. Its frequency behavior is completely determined by the size of the baffel. For the little ones ($\alpha_0\sim0,2r_0$) baffel sizes (рис. 4a) and, as a result, significant violations of the radial symmetry of the emitter construction result in different behavior of current amplitudes in different frequency ranges. In the low-frequency pre-resonance region (0−8 kHz) There are several significant narrowband bursts whose amplitudes exceed or greatly exceed the current amplitude at the resonance frequency of the piezoceramic shell. The frequencies of these bursts are more than half the natural frequency of the shell. The resonant region of the piezoceramic shell and the appearance of several very narrow band bursts characterize the resonant region (8−14 kHz) of the emitter. Their amplitudes are smaller than the current amplitude at the shell's own resonance, and the frequencies of these bursts are located above the shell frequency.

In the high-frequency post-resonance region (above 14 kHz), the current amplitude decreases significantly and amplitude dips occur to zero.

Increasing the size of the baffels ($\alpha_0=0,5r_0$) causes significant changes in the frequency dependences of the dynamic current amplitudes (Fig. 4b). In the low-frequency pre-resonance region, the resonant bursts of amplitudes disappear and there is a gradual increase in the amplitude of the dynamic current close to the direct proportionality. The resonance region undergoes significant changes. The natural frequency of the piezoceramic shell decreases and its resonance band decreases. New resonant surges are emerging in this area. Their amplitudes are comparable to the current amplitude at the natural frequency of the piezoceramic shell, and the resonance bands are narrower compared to the resonance band of the shell, but much larger than such resonance bands at small baffel sizes (Fig. 4a).

In the high-frequency post-resonant region, the current amplitude decreases significantly (more than an order of magnitude). At the same time, very narrow-band bursts of current amplitudes of different magnitude occur at separate frequencies. The placement in the inner volume of the shell of a large cylindrical baffel radiator ($\alpha_0\sim0,9r_0$) fundamentally changes the above-described patterns in the behavior of dynamic current (Fig. 4c).

Multi-resonance in all frequency ranges is disappearing. Dynamic current has only one resonance burst at the natural resonance frequency of the piezoceramic shell of the radiator. It is interesting that at different baffel sizes, the amplitude of the dynamic electric current of the emitter remains almost unchanged at the natural resonance frequency of the piezoceramic shell.

Let us now consider the frequency regularities of the behavior of the full excitation current of a shielded emitter. As noted, full current is an algebraic sum of capacitive and dynamic currents. Analysis of curves in Figs. 5 indicates that, in different frequency domains, these components have different effects on full current. And this influence, in turn, depends on the size of the baffel. In the low-frequency region at medium and large sizes of the inner baffel, the capacitance component controls the regular behavior of the full current. With small baffel sizes in this frequency range, the dynamic component is also connected to this control. In the resonant region, the total current is almost completely, except for the upper frequencies of this range, determined only by the dynamic current.

Finally, at high frequencies, the regular behavior of the full current is determined by its capacitive component at all sizes of internal baffels.

The established patterns of behavior of dynamic and full currents have their physical nature. This nature is determined by the interconnection of physical fields in the conversion of energy in a piezoceramic emitter, and is related to the changes that occur in its mechanical field under the influence of the interaction of the acoustic fields of the shell and the baffel in the internal volume of the emitter [9−12].

Indeed, with radially symmetric electrical excitation of the piezoceramic shell, energy is pumped into the emitter at the zero mode of oscillation of the shell. Repeated exchange of sound waves emitted by the shell and reflected waves from the baffel and the shell and asymmetrical placement of the baffel inside the shell destroy the radial symmetry of the internal acoustic field of the radiator. This led to fundamental changes in the mechanical field of the emitter, which consists in the generation of new, following the zero, modes of oscillations and the emergence, under certain conditions, standing waves of zero mode oscillations.

Naturally, under the influence of these factors, which behave differently at different frequencies, the frequency dependence of the zero mode of oscillation changes significantly compared to the radially symmetric acoustic load of the cylindrical emitter. And since the chosen scheme of the organization of the electric excitation of the emitter energy is "pumped" into its mechanical field only at the zero mode of oscillation, the frequency changes in the behavior of the zero mode are reflected in the frequency dependences of the exciting electric current. This is confirmed by comparing the graphs in Fig. 4 with graphs in Fig. 3 works [10]. As we can see, for all baffel sizes, there is a complete coincidence of the frequency dependencies of the amplitudes of the oscillatory velocity of the emitter at the zero mode of oscillation and the dynamic component of the total current.

As already noted, electric current characterizes the efficiency of electromechanical energy conversion. The ability of the converter's electric field to effectively absorb electrical energy from an electronic generator is determined by its input electrical resistance. The analysis of its frequency dependences (Fig. 5) shows that the influence of the dimensions of the inner baffel on them is essential only in the regions of pre-resonance and resonance frequencies. In the field of post-resonant frequencies, the input electrical resistances of the shielded emitters have stable values, with a tendency to decrease these values as the excitation frequency of the emitter increases. At low values (Fig. 5a), the low-frequency region of the shielded emitter is characterized by large values of the total input electrical resistance and inversely proportional to its decrease with increasing excitation frequency.

At the same time, attention should be paid to the appearance: first, of frequencies where this resistance acquires small values, and, secondly, of two frequency ranges of 1.5−1.8 octaves with unchanged and relatively small input impedance. The resonance region at such values α_0 has two frequency ranges with sharply different (more than an order of magnitude) but stable in frequency in these ranges values of full input electrical resistance. These are the features of frequency behavior $|Z_{in}|$ significantly improve the ability of the electronic generator to match the emitter.

Increasing the baffel size to average $\alpha_0 \sim 0,5r_0$ significantly changes the frequency dependence of the input electrical resistance of the radiator (Fig. 5b). In the low-frequency pre-resonance region, the value is $|Z_{in}|$ it varies inversely with the frequency and has several features that have been set for small values α_0 (Fig. 5a). These features move to the resonant region and are at low levels of values $|Z_{in}|$ a number of narrowband bands appear in this area, where the magnitude of the full resistance increases significantly (3−5 times).

Go to large baffle ($\alpha_0 \sim 0,9r_0$) causes the disappearance of all previously established features in the behavior of full electrical resistance (Fig. 5b). There is only one resonant burst of magnitude in the resonant region $|Z_{in}|$.

Analysis of the frequency behavior of active components of full resistance shows its small values for baffels of all sizes, with the exception of two features. The first is that in the resonant region there is a resonant burst of active resistance, the frequency of which decreases with increasing size α_0 baffle. The second feature indicates that the active resistance in the low-frequency region is lower than in the high-frequency region.

Analysis of the frequency dependences of reactive electrical resistance indicates that it is it that determines the frequency behavior of full resistance. Almost the entire test frequency range for all baffel sizes has a reactance of capacitive character. The exceptions are the narrow frequency ranges in the low-frequency and resonant regions for small and medium-sized baffels (Figs. 5a, 5b). In these ranges, the capacitive nature of the resistance changes to inductive.

CONCLUSIONS

The results of electrical field studies of hydroacoustic piezoceramic radiators with internal baffels allow us to draw conclusions that are important for the construction of the GAS radiating paths.

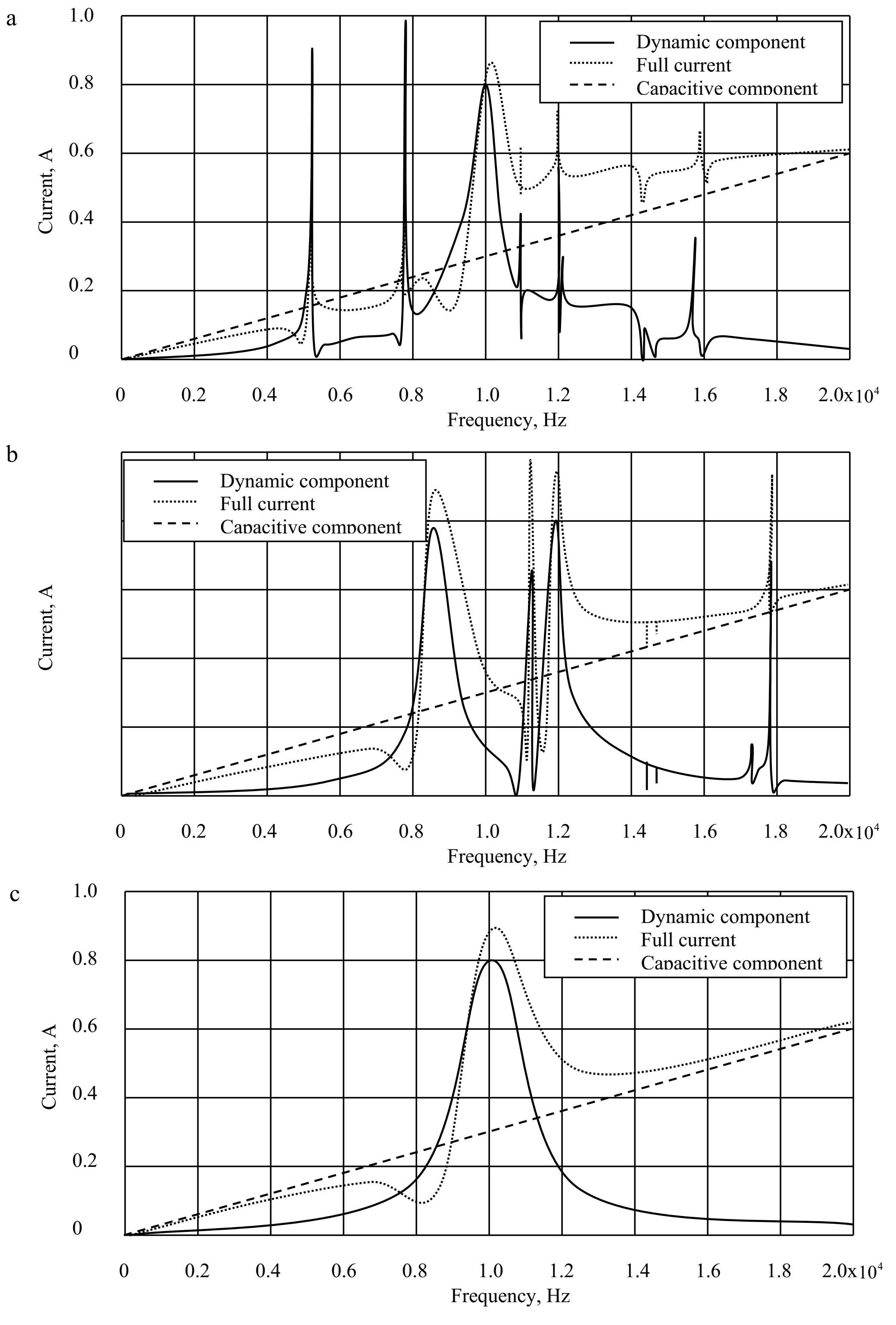

Fig. 4. Frequency dependencies of the amplitudes of the capacitive and dynamic components and the total current shielded emitter at baffel sizes:a) $\alpha_0 = 0,2r_0$; b) $\alpha_0 = 0,5r_0$; c) $\alpha_0 = 0,9r_0$

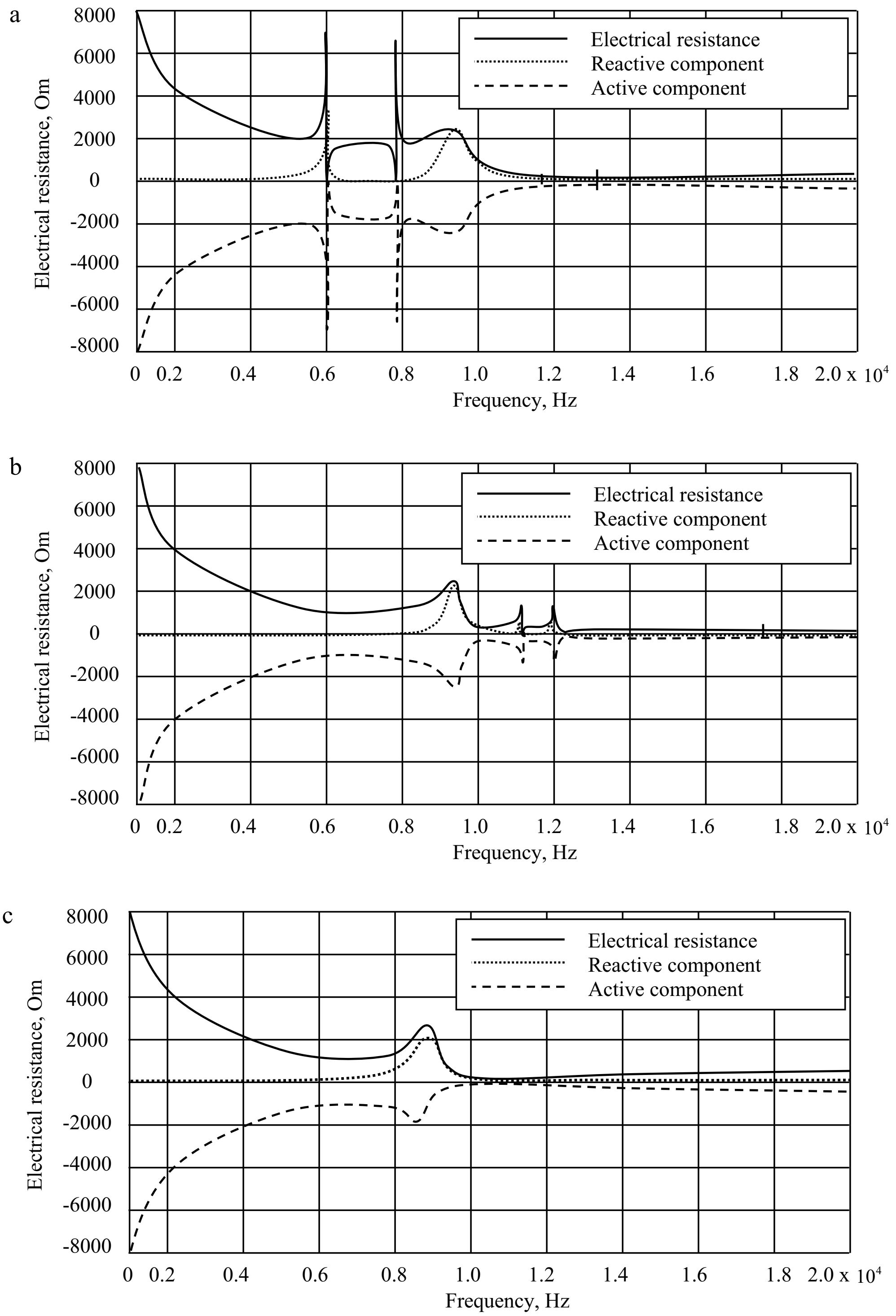

Рис. 5. Frequency dependencies of active, reactive and full input electrical resistances shielded emitter at baffel sizes: a) $\alpha_0 = 0,2r_0$; b) $\alpha_0 = 0,5r_0$; c) $\alpha_0 = 0,9r_0$

First, by selecting the sizes of the internal baffels, you can effectively control the parameters of the electric fields of the shielded radiators in different frequency ranges of the GAS operation.

Secondly, with the small size of the inner baffels and maintaining the size of the acoustic emitters in the low frequencies, new resonant frequencies arise, which are 1.5–2 times smaller in value than the main resonant frequency of the shielded emitter, but with greater efficiency (by 10–50 %) conversion of electrical energy into acoustic. The use of these frequencies increases the range of the GAS.

Third, with all sizes of interior baffels throughout the frequency range, except for a few narrow areas, the capacitive excitation current of the emitters significantly exceeds its dynamic current. This requires that measures be taken to protect the GAS radiative tract and overhead lines.

Fourth, the complex frequency nature of the behavior of the reactive component of the input electrical resistance of the shielded emitter complicates the technical implementation of the chains of coordination of the electronic generator GAS with its loading hydroacoustic emitter. This is due to the need to build harmonization devices with complex frequency dependence of their characteristics.

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Відомості про авторів:

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

Лейко Олександр Григорович
доктор технічний наук
професор
професор кафедри акустики та акустоелектрорніки Національного технічного університету України «Київський політехнічний інститут імені Ігоря Сікорського»
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»
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»
https://orcid.org/0000-0002-2084-2243
e-mail: sviatnenkoa@gmail.com

Information about the authors:

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

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”
https://orcid.org/0000-0002-5588-6449
e-mail: Alexander_leiko@ukr.net

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

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

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