SONAR BASED ON PIEZOCOMPOSITE TRANSDUCERS

A.I. MAMMADOV, S.A. MAMMADOV*, R.Z. MEHDIYEVA, B.A. BAYKULOV, R.R. SAFAROV, L.A. ISMAILZADE**

Institute of Physics Azerbaijan National Academy of Sciences, AZ-1143, Baku, Azerbaijan
**MAG-Pi Complex, Baku, Azerbaijan*
National Aviation Academy Baku, Mardakan ave., 30
rafigamehdiyeva@gmail.com

The work carried out in rivers, lakes and at great depths reveals the need for the development and manufacture of various sonar systems for the study of the seabed. The problems solved by such hydroacoustic systems are: search for objects at the bottom and in the bottom soils, monitoring of engineering structures, geological and hydrographic work. The basis of these complexes are sonar, echo sounders, the release of which remains quite laborious and expensive, not only because of the laboriousness of technological operations but also because of the difficulties in measuring and controlling the main electroacoustic parameters.

The work is devoted to the development of hydroacoustic antennas, the mandatory elements of which are effective deep-water transducers based on piezocomposites.

1. INTRODUCTION

Recently, considerable interest has increased in composite polymeric materials (composites), which combine the properties of ceramic and polymeric materials. The filling of polymers with ferroceramic particles significantly modifies their piezoelectric, electrical, and physicomechanical properties: namely, on the one hand, it allows one to use the advantages of ceramic materials by increasing the dielectric constant, the piezomodulus, the electromechanical coupling coefficient *K*, the mechanical quality factor *Qm*, and the piezosensitivity of the polymer-piezoceramic composite. On the other hand, the advantages of the polymer as a matrix, which gives the composite flexibility, strength and the possibility of manufacturing thin piezoelectric elements, uniform in piezoelectric and pyroelectric properties over large areas. Therefore, in recent years, the trend towards the study of polymer composite materials that combine the properties of both a polymer and a composite has been growing, and, consequently, the possibility of their use as an active element for various converters is expanding.

This article discusses the physical and technological features of creating hydroacoustic receiving-transmitting antennas based on piezocomposites. By varying the volume content, structure, characteristics of the components (polymer - piezoceramics), electrical and mechanical properties, polarization conditions, design and characteristics of sealants, transmitting and receiving antennas for studying the seabed and shelf are developed and created, surpassing in many respects similar antennas based on piezoceramics .

2. TACTICAL AND TECHNICAL CHARACTERISTICS OF PIEZOCOMPOSITE TRANSDUCERS OF HYDROACOUSTIC ANTENNAS, REQUIREMENTS FOR THEIR MANUFACTURING TECHNOLOGY

A technology has been developed for the manufacture of piezoelectric transducers based on fundamentally new, more efficient polymer piezocomposite materials for transmitting and receiving hydroacoustic antennas intended for conducting relief studies and profiling the seabed with the following technical characteristics:

- acoustic radiation power: a) 0.5*kW*; b) 2*kW*; c) 10*kW*.
- sensitivity in the reception mode - 200-1000μV/Pa
- operating frequency range: a) (50-200)*kHz*, b) (1-20)*kHz*
- overall dimensions: a)(610x12x15) *mm*, b) (400x400x15) *mm*
- solid and assembled from separate elements
- operation mode pulse *t=2ms*
- excitation voltage *U=500V*
- deepening of transducers up to *1000m*
- storage temperature -30^0 - $+45^0\ C$
- working temperature $+2\ ^0C$ - $+45\ ^0C$
- service life - not less than 10 years

The calculated parameters must be obtained by operating the transducer in conjunction with the acoustic screen and the supporting structure.

The developed piezocomposite elements should be used to create the following transducers:
a) transducer for side-scan sonar antenna;
b) an antenna converter (geolocator);

To meet these requirements, you must conduct:

- selection of the composition (components) of the polymer composition;
- selection of the optimal percentage of components in the composition;
- selection of optimal conditions for obtaining;
- development and production of molds;
- development and manufacture of installation for polarization of samples up to 1.5 *mm* thick;
- development of an installation for polarization of samples up to 15 *mm* thick in a liquid medium;

- development of a high-voltage stabilized source for the polarization of samples up to 15 *mm* thick;
- choice of optimal methods and modes of polarization;
- calculation of parameters of converters;
- development of methods and installations for determining the mechanical properties of piezocomposite materials;
- selection of the composition of the adhesive mass for gluing with an acoustic screen;
- choice of material for the acoustic screen;
- selection of the composition of the compound for pouring (sealant);
- development of optimal methods and conditions for pouring transducers;
- development of an installation for the study of piezoelectric and dielectric characteristics of transducers;
- development of an installation for studying the sensitivity and power of radiation in a given frequency band.

The studies carried out should enable:

- to recommend the composition of the composition, methods of its preparation and polarization;
- to recommend the optimal design of the converter;
- to recommend material for the acoustic screen;
- to give a recommendation on the composition of the adhesive;
- to recommend compound for pouring (sealant);
- to determine the sensitivity, operating frequency range;
- to determine the heat resistance and cold resistance of the composition;
- to determine the mechanical properties of the composition;
- to determine the piezoelectric coefficients of the composition;
- to determine the dielectric characteristics $(\varepsilon, tg\delta, \rho\upsilon)$ of the composition;
- to determine the electrical strength of the composition *Epr*;
- to conduct full-scale tests in the waters of the Caspian Sea
- to test the electromechanical stability of the receivers over a period of 1000 hours under a pressure of *100atm*.
- strengths (σ) of *PP + PKR-3M* compositions at τ*=1s* from the volume content F of the *PKR-3M* piezo filler.

3. MECHANICAL PROPERTIES OF COMPOSITES IN A STRONG ELECTRIC FIELD

Hydroacoustic transmitting and receiving antennas are always subjected to certain static pressures. Therefore, the determination of the strength properties of composite piezoelectric elements used to create hydroacoustic antennas is one of the important tasks of this work.

Table 1 shows the dependence of the mechanical strength (σ) of the *PP-PKR-3M* compositions at $\tau=1$ on the volume content *F* of the PKR-3M piezo filler.

It can be seen that the mechanical strength of the piezocomposite decreases with an increase in the volume content of the piezophase *F*.

Table 1.

Dependence of the mechanical strength of *PP+PKR-3M* compositions on the volume content of the piezo filler.

F, % об	10	20	30	40	50
σ*, мПа, τ = 1c*	60	50	30	22	8

Experiments on the study of temperature-force dependences of durability have shown that the well-known formula of durability is fulfilled for composites.

$$\tau = \tau_o \exp(\frac{U_o - \gamma_{м\sigma}}{KT}, \qquad (1)$$

where τ_0, U_o and $\gamma_м$ are the coefficients that determine the strength properties of the object under study.

The pre-exponential factor τ_0, is a universal constant, has the dimension of time and corresponds to $(10^{-12}\text{-}10^{-14})$ *s*, which coincides with the period of thermal oscillations of atoms around their equilibrium position in solids. The coefficient U_o is the activation energy of mechanical destruction, the value of which depends on the nature of the breaking bonds. The experimentally found values of τ_0, U_o and $\gamma_м$ for the composition of *PP + 40% vol. RCC-3M* are shown in table 2.

Table 2.

Experimental values of τ_σ,Uo and $\gamma_м$ the composition *PP + 40% vol. PKR-3M*

τ_0*, c*	U_o*, kcal/mol*	$\gamma_м$, kcal/mol *мПа*$^{-1}$	σ, *МПа* *T = 213K*
10^{-12}	24	0,28	22

The effect of a strong electric field on the mechanical durability of polymer composites has been studied. These results are very important in assessing the operating conditions of antennas in the mode of radiation of acoustic waves. in fig. 1a shows the dependence $lg_{\tau oE}=f(\sigma)$ at $E=0(1)$ and with the application of an electric field (2) with a strength of *e=3.2.10V/m*, for the composite *PP+40% vol. RCC-3m*. As can be seen, the application of a strong electric field leads to a decrease in the mechanical durability (strength) of the composition. These studies for composites with different φ showed that the effect of reducing the strength of composites when a strong electric field is applied decreases with increasing volume content of the piezofiller (table 3). the degree of reduction of mechanical durability was defined as it can be suggested that with an increase in the content of piezoceramics in the polymer matrix, the probability of the formation of effective electrons in the composition and their participation in the process of perturbation of molecular targets, and hence in mechanical destruction, decreases. Practically the same results were obtained in the study of the piezocomposition *PVDF+40% vol. PKR-3m* for mechanical strength in a strong electric field (fig. 2b).

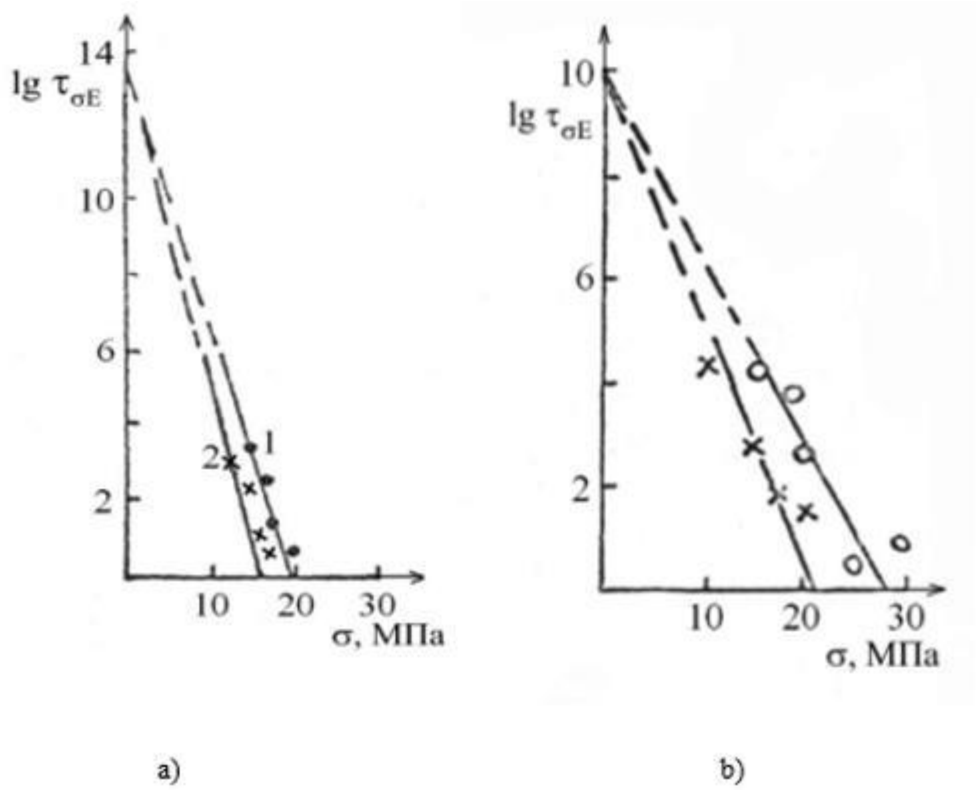

Fig. 1. Change in the mechanical strength of the piezocomposite when a strong electric field is applied.
a) for composite *PP+PKR-3M; Ф=40%* about; *1-E=0; 2-E=3.2x10 V/M*
b) for the composite *PVDF + PKR-3M; Ф=40% vol; 1-E=0; 2-E=3.2x10 V/M*

Table 3.
Decrease in the strength of composites with an increase in the volume content of the piezofiller

F, % об.	10	20	30	40	50
$\Delta\sigma = \sigma - \sigma_E$	10	7,2	5	3,5	1,5

However, it should be noted that the mechanical strength properties of composites at $E=0$ and at $E\neq 0$ are noticeably different. This result is very important when choosing the operating modes of acoustic antennas. Comparison of fig. 6.2a and 6.2b shows that *PVDF*-based composites have higher mechanical properties (Table 4).

Table 4.
Mechanical properties of composites based on *PVDF*

Composites	Mechanical strength $\tau=1c$. $\sigma=МПа$	
	E= 0	$E=3{,}2\times10^{7}$ *B /M*
PP+40% PKR-3M	18	15
PVDF+40% PKR3M	26	20

However, the effect of reducing the mechanical strength under the action of a strong electric field in the case of composites based on *PVDF* is greater. Thus, the analysis of the mechanical strength of composites based on *PP* and *PVDF* shows that composites with a *PVDF* matrix are more efficient for creating acoustic antennas.

4. DEVELOPMENT OF THE DESIGN AND STUDY OF THE CHARACTERISTICS OF HYDROACOUSTIC ANTENNAS

Hydrophones are the main elements of which hydroacoustic antennas for various purposes are completed. In this case, it is piezoelectric transducers that convert electrical energy into the energy of an emitted acoustic signal (and vice versa), and the antenna provides the necessary directionality of radiation (reception). Depending on the purpose of the electroacoustic system, its antenna may include from one to several thousand elementary transducers.

It is known that sound waves can propagate in sea water over very long distances and thus provide underwater location, telemetry, communications and sound vision. Acoustic methods have found wide application in underwater work on the sea shelf during the development of oil fields. A necessary part of any underwater search system is an electro-acoustic station with paths for emitting and receiving sound waves. Therefore, the developed piezoelectric elements must meet the requirements for both wave receivers and emitters of acoustic disturbances [1–11].

In this paper, we consider the design of one of the most common piezoelectric transducers, which is a cylindrical transducer of a power structure. The active element of this transducer consists of a set of simple piezoelectric elements connected to each other with glue. The fastening of the active element to the housing is carried out with the help of elastic layers of polymeric or metallic materials. The electrical insulation of the active element of the converter is provided by layers of solid electrical insulating materials located between the active element and the converter housing or the operating environment. Sealing of the active element is carried out using combinations of vulcanize or glued layers of sealing materials. The mechanical strength of all elements is ensured by an appropriate choice of material parameters and dimensions of parts. The mechanical strength of the active element, if necessary, can be increased by imposing on it special compressive stresses created by the reinforcement elements. Layers of materials with high sound reflection coefficients in water are used as sound-reflecting screens.

A hydroacoustic antenna is a device that, together with the electrical circuits that control its characteristics, provides a given spatial selectivity of radiation or sound reception in an aquatic environment. The physical reasons for the existence of an antenna's spatial selectivity are interference and diffraction of acoustic waves on it. According to the method of creating the spatial selectivity of a hydroacoustic antenna, it is possible to subdivide fixing, horn, parametric and interference antennas.

The hydroacoustic antenna developed by us mainly consists of the following main parts:

a) hydroacoustic transducers that convert electrical energy into sound energy and vice versa;

b) sound-reflecting or sound-absorbing screens that ensure unidirectional sound emission (reception);

c) electrical switching lines connecting the converters with the circuits for the formation and control of directional characteristics;

d) a supporting structure that provides the necessary spatial arrangement of the transducers;

e) elements of sound - and vibration isolation of the antenna from the noise of the carrier object.

Depending on the geometric shape of the antenna, its size, mode of operation, the number of elements included in it, as well as the method of its mechanical connection with the carrier object, there are several varieties of antenna design.

So, linear receiving antennas based on piezocomposite elements are performed:

a) in the form of vertically or horizontally oriented chains of cylindrical or plate receivers, fixed together with electrical communication lines on rigid rods or flexible cables that act as a supporting structure.

b) in the form of a chain of cylindrical receivers placed together with electrical communication lines inside a sound-transparent sealed hose filled with an electrically insulating liquid.

As already noted, the disadvantages of existing piezoceramic antennas include their increased weight and dimensions, low sensitivity in the receive mode, relatively low physical and mechanical (brittleness, low mechanical strength under static pressure) and electrical (electrical strength, especially at resonance) properties.

To eliminate these shortcomings, a design of hydroacoustic transceiver antennas based on a piezo-sensitive composite material was developed. Piezoelectric hydrophones both based on piezoceramics and piezocomposite have a wide range and various applications: measuring, seismic, underwater communications, medical, etc. [1-10], while the dynamic pressure range is from *10-3 Pa to 1010 Pa* in the frequency range from *0.1Hz* to *107Hz*. A large number of hydrophones are designed to measure rapidly changing pressures and pulse pressures, liquid media in underwater pipelines, pneumo-hydraulic systems of machines and mechanisms, nuclear reactors and submarines. In accordance with the task, it was required to develop an antenna with the following characteristics: $f_p = 20kHz$, $W_a = 2kW$ (acoustic power of the antenna), $\gamma_p = 800\text{-}1000 \mu V/Pa$, $U \leq 800V$.

To achieve the required value of the power and frequency of the antenna, the design of the rod converter is the most acceptable. This design has minimal weight and dimensions and a relatively simple execution technology. Three-component rod transducers with two different overlays increase the efficiency of one-way receiving radiation.

The resonant frequency of such a system is related to the wave size ili and the resistance iCi of each section by the following relation:

$$\frac{\rho_1 C_1 S_1}{\rho_2 C_2 S_2} tg \frac{2\pi l_1}{\lambda_1} + \frac{\rho_3 C_3 S_3}{\rho_2 C_2 S_2} tg \frac{2\pi l_3}{\lambda_3} + tg \frac{2\pi l_2}{\lambda_2}$$

where indexes 1, 2, 3 correspond to sections of the transducer: 1-radiating overlay; 2-active material; 3-back pad.

We choose titanium as the radiating overlay, aluminum as the back, and composite as the active material. The main constants of these materials, which are used in the calculation of the antenna, are given in table 5.

Table 5.

Basic material constants that are used in the calculation of the antenna

Parameters	Radiant pad	Active Material, piezocomposite	Overlay
ρ, кГ/м	4500	1700	2600
C, м/с	5250	2000	5240
Y, Па	-	2 × 10	-
ε	-	150	-
d33 , P·C/n	-	150	-

The wavelengths at $\lambda = 20kHz$ in these materials are respectively equal to:

$$\lambda_1 = 262.6mm;\ \lambda_2 = 100mm;\ \lambda_3 = 262mm.$$

Based on practical considerations and solving the above relations, we obtain the geometric dimensions of these sections:

l_1 =3mm, l_2=36mm, l_3=30mm, D_1=56mm, D_2=500mm, D_3=54mm
d_2 =16mm, d_3=16mm.

where *l* is the length; *D*-outer diameter; *d* is the inner diameter of the respective sections. To calculate the excitation voltage and sensitivity using electromechanical analogies, it is necessary to calculate the electromechanical transformation coefficient of a sectioned rod [10]:

$$h = d_{33}Y_{ю}\frac{S}{s} = d_{33}Y_{ю}\frac{\pi(R^2 - r^2)}{l}N$$

where *s* is the distance between the electrodes;
N - number of sections;
R and *r* are, respectively, the outer and inner radius of the piezoelectric element.

$$n = 150 \cdot 10^{-12} \cdot 2 \cdot 10^{10}\frac{\pi(25^2 - 8^2)N}{36 \cdot 10^3} = 0{,}15N$$

The antenna is assembled from 18 transducers.
Thus, the acoustic power of one transducer will be equal to

$$Wa^1 = \frac{Wa^1}{m} = \frac{2000}{18} \approx 110$$

Let us calculate the voltage required to excite such a power [10]:

$$U = \frac{\sqrt{2R_s Wa^1}}{n\eta_{am} \cdot \cos\kappa_1 l_1 \left[1 + \sqrt{\frac{(\rho cS)_2^2 + (\rho cS \cdot tg \cdot \kappa l)_1^2}{(\rho cS)_2^2 + (\rho cS \cdot tg \cdot \kappa l)_3^2}}\right]}$$

where η_{am} -acoustic-mechanical efficiency $\approx$*0,6;*
R_s –radiation resistance at large wave sizes $R_s = (\rho c)_в \cdot S_1$

$$(\rho cS) = 5\ 10^3\ 2\ 10^3\ 561\ \pi\, 10^{-6} = 5610\pi$$

$$(\rho cS) = 4{,}5 \cdot 10^3\ 5{,}25\ 10^3\ 784\pi\, 10^{-6}\ tg^2\frac{\pi^3}{262{,}5} = 1331{,}6\pi$$

$$(\rho cStg\kappa S)_3 = 2{,}7 \cdot 10^3 \cdot 5{,}24 \cdot 10^3 \cdot 665\pi \cdot 10^{-6}\ \lg\frac{2\pi \cdot 36}{262} = 8213{,}85$$

$$R_s = (\rho c)S = 1{,}5 \cdot 10^6 \cdot 784\pi \cdot 10^{-6} = 3698{,}6$$

$$(\cos\kappa l)_1 = \cos\frac{2\pi \cdot 3}{262{,}5} = 0{,}997 \approx 1$$

$$U = \frac{\sqrt{2 \cdot 3698{,}6 \cdot 110}}{0{,}15N \cdot 0{,}6 \cdot l\left[1 + \frac{5610^2 + 1331{,}6^2}{5610^2 + 8213{,}8^2}\right]} = \frac{813692}{0{,}15N \cdot 0{,}948} = \frac{6343}{N}$$

The number of sections is chosen from the condition *U ≤500 V*.
Then at *N=18, S=2 mm*:

$$U = \frac{6343}{18} = 360B$$

The sensitivity at the resonant frequency is determined by the formula:

$$\gamma_p = \frac{d_{33}Y_{ю}\delta\eta_{am}}{lwp(\rho c)b}(\cos\kappa l)_1\left[1\sqrt{\frac{(\rho cS)_2^2 + (\rho cStg \cdot \kappa \cdot l)_1^2}{(\rho cS)_2^2 + (\rho cStg \cdot \kappa \cdot l)_3^2}}\right], A = \frac{\nu}{\varepsilon\varepsilon_0}$$

where ν-diffraction coefficient (ν=2)

$$\gamma_p = \frac{2 \cdot 150 \cdot 10^{-12} \cdot 2 \cdot 10^{-3} \cdot 0{,}6}{150 \cdot 8{,}85 \cdot 10^{-12} \cdot 36 \cdot 10^3 \cdot 2\pi \cdot 20 \cdot 10^3 \cdot 1{,}5 \cdot 10^6} \times \cos\frac{2\pi \cdot 3}{262{,}5} \times \left[1 + \sqrt{\frac{5610^2 + 1331{,}6^2}{5610^2 + 8213{,}8^2}}\right] = -1{,}0\,MB/Па$$

For optimal reception-radiation, it is necessary to match the electrical impedance of the converter in the receive mode with the input impedance of the amplifier, in the radiation mode with the output impedance of the generator. The electrical impedance is calculated from the individual components at the resonance frequency. Converter capacity:

Active mechanical resistance:

$$R_{мр} = \frac{R_s}{4n^2\eta am(\cos\kappa l)_1^2\left[1+\sqrt{\frac{(\rho cS)_2^2+(\rho cStg\cdot\kappa\cdot l)_1^2}{(\rho cS)_2^2+(\rho cStg\cdot\kappa\cdot l)_3^2}}\right]}$$

$$R_{мр} = \frac{3693}{4\cdot(0{,}15N)^2\cdot 0{,}6\cdot 1\cdot 1{,}56} = 133{,}5 Ом$$

Capacitance:

$$Y_c = \frac{1}{iwpc} = \frac{1}{2\cdot 20\cdot 10^3\cdot 2\pi\cdot 2{,}16\cdot 10^{-8}} = i\cdot 368{,}6$$

Total electrical resistance (impedance):

$$Z_n = \frac{R_м\cdot Y_c}{R_м + Y_c} = \frac{133{,}5\cdot 368{,}6}{133{,}5+368{,}6} = 118+42{,}8$$

Electrical Impedance Module:

$$|Z_n| = \sqrt{118^2+42{,}8^2} = 125{,}5$$

6. DESIGN OF PREMIUM-TRANSMITTING ACOUSTIC ANTENNAS

The design of the sonar antenna is shown in fig. 2, 3. All antenna elements are attached to a rectangular base along the edges of which there are 6 holes for attaching the antenna and to the carrier. The antenna is assembled from 18 separate transducers (pos.14), which form a flat radiating surface in the form of a circle. The side wall 13 of the antenna is made of sheet aluminum and is attached to the base with brackets.15. The antenna is a compensation type structure and the entire free internal volume is filled with polyurethane. One-sided reception and radiation provide a screen 17 of the foam.

The entire antenna is divided into 2 groups, which allows you to vary the tactical and technical indicators of the antenna (power, directivity, etc.). 7 transducers in the center of the antenna form group I and 12 transducers around the circumference on the outside of the antenna form group II. All transducers within a group are electrically connected in parallel.

The oscillatory system of the transducer consists of a piezoceramic package 2, glued from 18 separate plates, a radiating titanium lining 1 and a rear aluminum lining. Both linings are also glued to the ends of the piezoelectric package. All plates of the piezoelectric package are electrically connected in parallel. The converter reinforces with a stud 2 and two nuts 12, to eliminate distortions during reinforcement, a spherical washer 11 is used. The piezoelectric package is isolated from the stud with an ebonite insert. With the same stud and special nut 10, the converter is attached to the base 8 of the antenna. Rubber acoustic rings decouple the transducer from the base of the antenna.

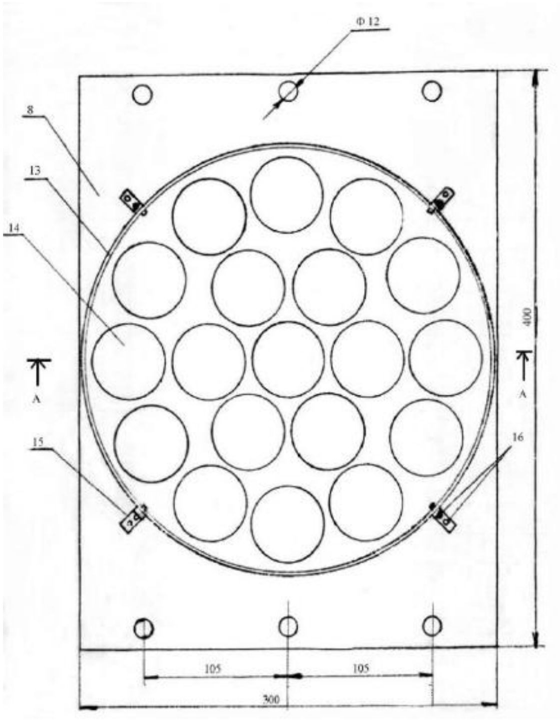

Fig.2. The design of the sonar antenna

A separate element of the piezoelectric package is a washer (fig. 3) with metallized surfaces, the washer is made by hot pressing, after which it is subjected to mechanical processing; a hole is drilled, poses are turned for electrical terminals-petals. Petals are made of brass 60 microns thick. The tinned petal is inserted into the groove and pressed with a soldering iron for 3-

5 seconds. After that, with a small file, remove the remnants of solder from the surface of the washer and degrease it in acetone. Fat-free washers are collected in a special cassette of 6 pieces and electrodes are applied by vacuum deposition. Glue 100-150 microns thick is applied to the previously degreased surfaces of the washers to be glued and tightly pressed against each other. In this position, the glued bag dries within 24 hours.

6. CHARACTERISTICS OF THE SEALANT OF HYDROACOUSTIC ANTENNAS

Currently, epoxy and polyurethane resins are mainly used for sealing and electrical insulation of piezoelectric transducers. Epoxy resin-based compositions have good cohesion and adhesion to various materials. They are well processed in a variety of ways, have good electrical and mechanical properties, and are resistant to various solvents, water, and aggressive media. A significant disadvantage of epoxy compounds is toxicity, a short "life" period, and a large dependence of electrical characteristics on temperature.

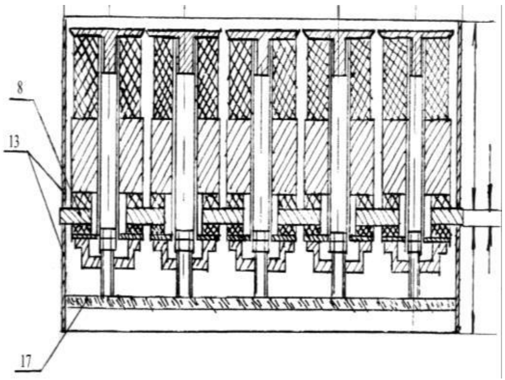

Fig. 3. A separate element of the piezo package.

Polyurethanes are polymers containing macromolecules of the urethane group - HN - CO - O- in the main chain. Depending on the type of starting compounds, in addition to urethane groups, macromolecules may contain amide, urea, and ether groups. However, the main characteristics of polyurethanes are determined by the presence of urethane groups in the macromolecules. Currently, methods have been developed for the production of linear and cross-linked polyurethanes. Linear polyurethanes are obtained by the interaction of diisocyanates with glycols:

$$nOCN–R–NCO+nHO–R'–OH \rightarrow [-OCHN–R–NHCO–OR'O-]n$$
$$n\ Cl\ CO\ -ORO\ -COCl + n\ H2N\ -R'-\ NH2 \rightarrow [-CO\ -ORO\ -CONH\ -R'-NH\ -]n$$

Crosslinked polyurethanes are prepared from difunctional compounds using chain extension and crosslinking reactions. To do this, all the components that make up the recipe (oligoester, diisocyanate, catalyst, etc.) are mixed simultaneously and cured.

The degree of cross-linking is controlled by changing the ratio between the number of insulating groups and the total number of active hydrogen atoms. A trifunctional agent may be added to the reaction system to achieve the desired degree of crosslinking. When obtaining polyurethanes, the following are used as starting materials: diisocyanates, glycols, simple or complex oligoethers, diamines. The use of various classes of compounds for the synthesis of polyurethane causes a wide variety of structures and properties of this polymer. The properties of polyurethane significantly depend on the nature, number and distribution of intermolecular bonds (hydrogen and van der Waals). The spatial network of cross-linked polyurethanes is highly mobile and can be rebuilt upon heating or mechanical action. Due to the relative ease of destruction and subsequent restoration of the network of physical bonds, cross-linked polyurethanes are capable of “self-healing” defects during deformation and can be used to seal acoustic systems.

To select a polyurethane formulation and sealing technology for hydroacoustic antennas, studies were carried out with four representatives of the diisocyanate class:
3,3I - dimethyl - 4,4I - diphenylmethane disocyanate;
4,4I - diphenylisopropylidene diisocyanate;
2,4 - toluene diisocyanate;
3,3I - dimethyl - 4,4I - tolicine diisocyanate.
Glycol is used as a hardener. Curing was carried out at a temperature of $80 + 30^0C$, time 10 hours.

Physical-mechanical and acoustic properties of cross-linked polyurethanes are determined, see table 6.

Table 6.

Physical, mechanical and acoustic properties of cross-linked polyurethanes

№	Speed of f sound, *m/s*	Density *Kg/m*	Diisocyanate	Tensile strength *MN/m²*	Relative extension, %	Elastic modulus *MN/m2*	Tear strength *kN/m*
1	1920	958	4,41-diphenyl-isopropylidene-diisocyanate	25,0	700	2,0	20
2	2200	961	3,31-dimethyl-4,4-diphenylmethane diisocyanate	37,0	500	4,0	10
3	1810	946	2,4 toweelanddiiso-cyanate 3,31-dimethyl-4,41-tolidine diisocyanate 25.0	32,0	600	2,5	30
4	2015	950		28,0	400	16,0	30

As can be seen from the table 6. polyurethane synthesized on the basis of 2,4-toluene diisocyanate has a better combination of mechanical properties and is acoustically consistent with the environment compared to other representatives of this series

In this regard, an industrial oligodiene polymer (product *10-000 TU 84-566-75*) containing toluene diisocyanate was used as an organic base to prepare a polyurethane potting compound for sealing hydrophones.

Prepolymer 10-000 is the product of the interaction of toluene diisocyanate with the product *PDI-1K*, taken in a molar ratio of 2:1.

The proposed compound contains:

Diameter X 417.0 *m.h.*

Laprol 3203-80 1000 *m.h.*

Lapromol 294 28 *m.h.*

Characteristics of the properties of the compound are given in table.7.

Table 7.

Characteristics of the properties of the compound

№	Indicator name	Unit of measurement	Meaning
1.	Density uncured cured	*g/cm3*	0,946 0,960
2.	Gelatinization time	hour	1,2
3.	Operating temperature range	*K*	223 – 323 -50 ÷ 50°C
4.	Peel bond strength with piezoceramic with titanium with polymethyl methacrylate with brass	*kg/cm*	 4,0 10 4,0 10
5.	The dielectric constant		3,2
6.	Dielectric loss tangent		$35{,}10^{-3}$

7. CONVERTER TEST PROCEDURE AND RESULTS

The measurement of the Total conductivity modulus of a separate transducer in the frequency range from *1kg* to 1000*kHz* was carried out by the method of amplitude-phase measurements according to the scheme shown in fig.4.

The device for amplitude-phase measurements contains a generator of harmonic oscillations, a measuring quadripole, a voltage meter and a phase meter. If the converter impedance module is much larger than R and the shunt capacitance C does not have a noticeable effect, then with a stable output signal of the generator, the voltage measured by the voltmeter is proportional to the complex conductivity module ρ of the converter, and the phase difference measured by the phase meter determines the conduction phase.

The total conductivity modulus is determined by the values of active and reactive components:

$$G = \frac{\alpha(\cos\varphi - \alpha)}{R(1+\alpha^2 - 2\alpha\cos\varphi)};$$

$$B = \frac{\alpha\sin\varphi}{R(1+\alpha^2 - 2\alpha\cos\varphi)}$$

where α is the ratio of the voltage at the output of the four-band to the input voltage;

φ- measured phase shift angle;

G, *B* are active and reactive components, respectively.

The graphs of the total conductivity of all converters, as shown in fig.5, lie between curves 1 and 2. The curves have the form of an exponential (the scale is logarithmic along the frequency axis), from which we can conclude that the conductivity modulus is almost purely capacitive in nature.

Thus, comprehensive studies have been carried out to determine the effect of the volume content and structure of the filler, polarization conditions, high static pressures on the main electrophysical, piezoelectric, and physicomechanical properties of polymer-ferroelectric composites. It is shown that compositions based on a thermoplastic polymer matrix (*PVDF*, *PP*) filled with particles of rhombohedral piezo-sensitive ceramics have the highest values of the piezoelectric coefficient and piezosensitivity.

Based on piezocomposites, hydroacoustic receiving-transmitting antennas have been created. The storage temperature and service life of the antennas have been determined.

The composition of the adhesive mass was chosen for gluing individual elements with an acoustic screen.

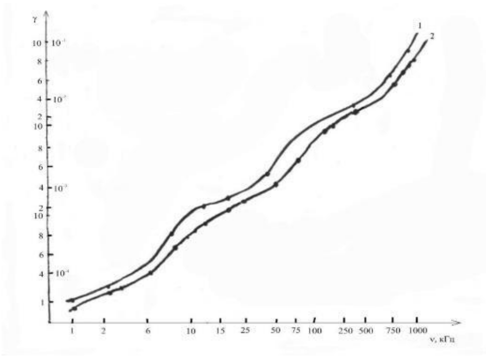

Fig.4. Frequency dependences of the transducer total conductivity modulus.

The optimal compositions of the casting compound are determined, and the influence of various properties of the compound on the characteristics of the antenna is investigated. The achieved parameters for hydroacoustic antennas are primary results that can be the basis for further development of more efficient piezocomposite transceiver antennas for various purposes.

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