ON THE POSSIBILITY OF THE CREATION OF PIEZOCOMPOSITE RADIATORS FOR MEDICAL DEVICES

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It is experimentally established that electroacoustic converters of the medical purpose may be created by the change of the polarization conditions, physico-mechanical characteristics, the configuration and geometric sizes of piezocomposite elements.

The modern medicine is inconceivable without piezoelectric diagnostic devices, operating in the ultrasound range [I]. They are necessary for the visuality of deep structures of body and internal organs for the investigation of tissues structure and the control of parameters of the moving medium and structures, for example, at the research of the blood circulation and heart work. The physiotherapical ultrasound piezoelectric technique is successfully applied at various diseases treatment, in particular, breath organs with the application of the aerosoltherapy method [2]. The main criterion, determining aerosol penetration in structural elements of lungs, is the size of aerosol particles [2]. So, for example, it is experimentally proved that particles with the radius r<5 mcm penetrate the lungs alveolus. The dispersion of the medicinal substance and its transfer in the aerodispersional system is realized by piezoelectric sprays.

It is shown in [2], that the radius (r) of aerosol particles reduces by the increase of the resonance frequency of the piezoelectric spray. It is known, that the resonance frequency of the piezoelement is determined as $f_r = \frac{\vartheta}{2d}$, where ϑ - is the sound spreading velocity, d is the piezoelement thickness. In the case of the piezocomposite the element thickness may be visibly reduced and by that f_r may be increased. High piezoelectric and physico-mechanical properties of composites allow to obtain on their base piezoelements of various configuration and resonance frequency. On principle, such task is solved even in the case of the piezoceramic elements application. However, the fragility and high internal mechanic voltage in piezoceramics do not allow to visibly reduce the piezoelement thickness. Besides, piezocomposite element may have because of the high possibility of the thickness reduction resonance at relatively high frequencies in comparison with the piezoceramic material. In the given paper possibilities of piezocomposite materials application as a piezoelectric resonator for aerosoltherapy devices are investigated. Composites are obtained on the base of the hot pressing. The piezoelement thickness is variated from 250 to 1500μm.

Piezoelements are obtained on the base of polyvinylidene-fluoride and polypropylene (table 1) of lead-zirconate-titonate family of various structures. Piezoelements are polarized at voltages of the polarization electric field from 1,0 to 16 mV/m and temperature from 373 to 450 K. The cubic content of the piezophase in composites is changed in limits from 10 to 70%. The dependence of piezoelectric characteristics of composites on conditions are presented on fig.1 and 2. It is seen, that composites have high piezosensitivity g_i and piezomodulus d_i. The piezomodulus dependence on the temperature (T_p) and the voltage of the polarization electric field (E_p) has extreme nature, at first by the growth of E_p and T_p the value d_{33} increases and achieve maximum, and then reduces. The value d_{33} from the cubic content of piezophase (F) grows quicker, than by the linear law. And g_{33} from F grows at first and 40% achieve the maximal value. Main parameters of piezoceramics –PCR-3M and PCR-7M, and also composites on their base and polymers PVDF, PP are presented in tables 1 and 2.

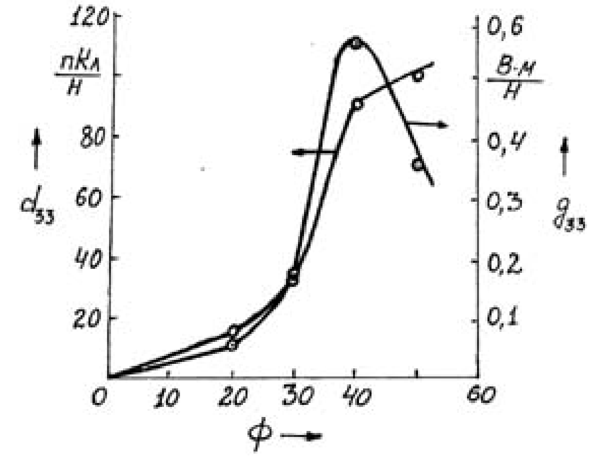

Fig.1 The dependence of d_{33} and g_{33} on F of the composition PP+PCR-3M T_p=393K, E_p =3mV/m.

Table 1.

The polymer Name	Polypropylene	Polyvinylidenefluoride
Thechemical composition Of links	$-CH_2 - CH_2 - CH_3$	$-CH_2 - CF_2$
The polymer code	PP	PVDF (F_2)
$\rho_{v\ (ohm.\ cm)}$	10^{14}-10^{15}	2.10^{14}
ε	2.3	13
D_{33}, (pC/N)	-	6.3
tanδ	4.10^{-4}	0,017
T_g, к	203	233
T_{pr}, к	463	473
ρ, (g/sm)	0,92-0,93	1,76
D_{31}, pC/N	-	15
E_{31}, V.m/N	-	0,11

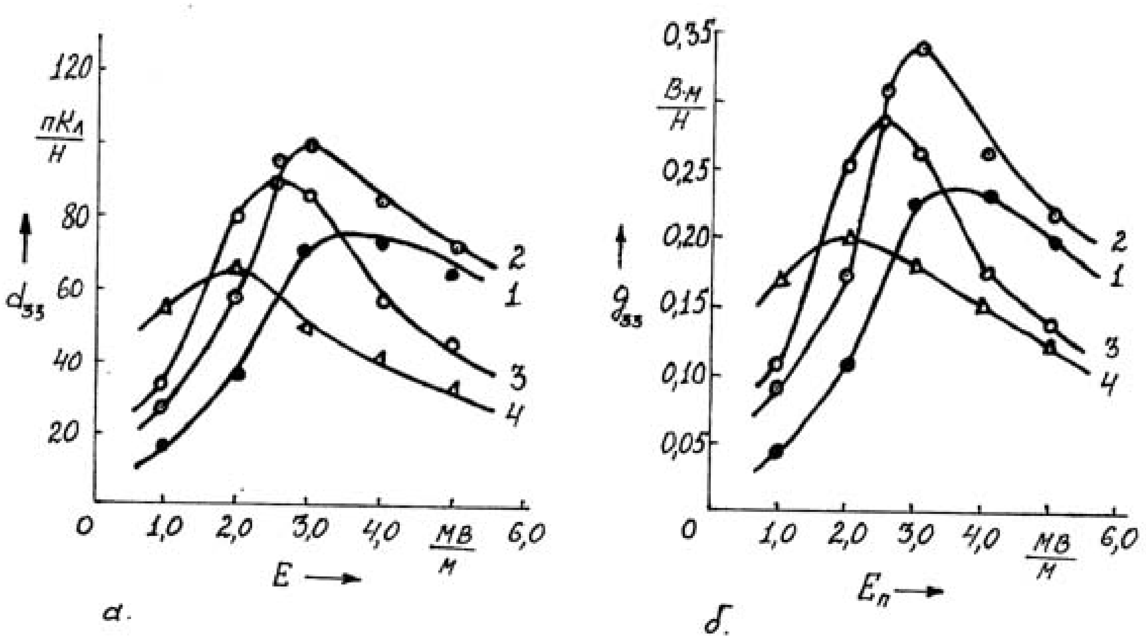

Fig.2 a. The dependence of d_{33} on E_p of the composition PP+PCR-3M: T_P=373 K, 2- T_P =393 K, 3- T_P=413 K, 4 – T_P=433 K.
b. The dependence of g_{33} on E_p of the composition PP+PCR=3M: T_P=373 K, 2- T_P =393 K, 3- T_P=413 K, 4 – T_P=433 K

Piezocomposites, in their turn, have in comparison with piezoceramics defects (faults), connected with the low radiation power and capacity. Therefore, it is necessary to work out piezocomposites with radiation power no lesser (0,15÷5) Pa/V. If in the regime of the acoustic wave receipt the piezocomposites in comparison with the piezoceramics are more sensitive, at least to an order (table 2 and 3), then in the radiation regime they yield to the piezoceramics (table 3). Therefore it is better to variate physico-mechanical properties of piezocomposites. So, that in the radiation regime their efficiency is to be equal and close to the piezoceramics efficiency. One of the factor of the piezoelectric materials efficiency is the coefficient of the electromechanical coupling. If the sample has the shape of the plate with cross sizes, which is far more than the thickness, and vectors of the polarization and the voltage of the electric field are directed perpendicularly to electrodes, then all values, included in the equation of the direct and inverse piezoeffects, have only one component and the coefficient of the electromechanical coupling is determined by the expression:

$$\beta^2 = \frac{d^2}{\varepsilon^\sigma S^E} = \frac{h^2 \varepsilon^u}{C^D} = \frac{g^2 \varepsilon^u}{S^D}$$

where *d*-is the piezomodulus, ε^σ, ε^u are dielectric constant at $\sigma = 0$ and $u = 0$, respectively, S^E - is the pliability, *h*-is the piezocoefficient, *g*-is the piezosensitivity, C^D -is the elasticity coefficient at *D*=0.

Table 2.

Characteristics of compositions and pizoceramics	Composites and conditions of their polarization	d_{33}^k pC/N	g_{33} V.m/N	ε_{ik}	d_{33}^k pC/N	d_{33}^k/ε_k V.m/N
PP+50% com PCR-7M T_p=393 K	E_p=3 MV/м E_p=6 MV/м E_p=12 MV/м E_p=9 MV/м	16,5 23 40 45	0,072 0,135 0,157 0,212	5000 - - -	760 - - -	0,0108 - - -
PP+50% com. PCR-3M T_p=393 K	E_p=1 MV/м E_p=2 MV/м E_p=3 MV/м E_p=5 MV/м	28 59 120 74	0,086 0,17 0,339 0,213	400 - - -	99 - - -	0,028 - - -
PVDF+50% com. PCR-3M T_p=413 K	E_p=4,5 MV/м	160	0,290	400	99	0,028

The square of the electromechanical coupling coefficient β^2 is determined by the piezoconverters sensitivity at the emission (radiation) and the receipt of sound waves. We compare the value β^2 of the piezoceramics and piezocomposites with the aim to determine the application possibilities of polymer-piezoceramics composites for the creation of medical devices radiators. Parameters, included in the formula β^2

and values β^2 for various piezoceramics and PVDF+PCR-3M composite, are presented in the table 3.

Table 3.

Piezoelectric materials	Piezomodulus $d_{iж}$. 10^{12}, C/N	Elastic pliability $S_{ik}\cdot 10^{12}$, m^2/N	Relative dielectric constant ε_{33}	Piezosensitivity g_{ij}, Vm/N	β^2
PZT-19 ZTPNB –1 \ZTBP-3	250 400 300	14.9÷10.4 16.8÷14.7 12.2÷10.7	1725±326 2250±560 2350±500	0,013 0,02 0,016	2,6 3,6 3,0
Piezocomposite PVDF+PCR-3M	160÷200	160	100±10	0,25	1,6÷2,5

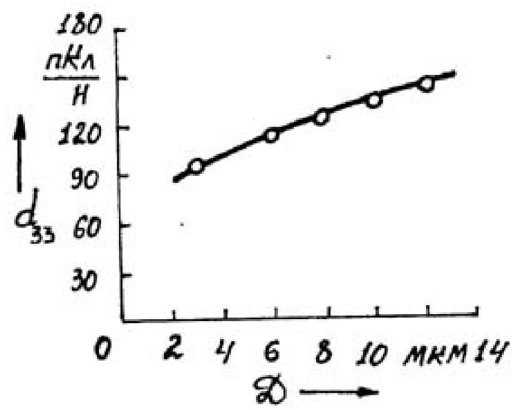

Fig. 3. The dependence of d_{33} of the composite PP+50 % PCR-5 on the grain diameter of the piezoparticle PCR-5

It is seen from the table 3, that values β^2 for high effective piezoceramics PZT-19, ZTBP and ZTPNB-I and the composite PVDF+PCR-3M, distinguish a little. So, for example, values ratio β^2 for ZTPNB-I and PVDF+PCR-3M is equal to ~1,5. Piezoceramics factors (indices) may be obtained in the radiation regime in composites by the small growth of the value d_{ij} and the reduction of s_{ic} by means of the variation of the cubic content and the grains size (*D*) (fig.3) of the piezofiller in the composite and the improvement of technical regimes of the composites receipt and also small increase of the excitation voltage. S_o, for example, the piezomodulus value (d_{33}) of the composite PP+50 % PCR-5 may be regulated by the variation of the size of the piezoparticles (piezophase) grain PCR-5. The grain diameter (*D*) is variated by the change of the pressure and sintering temperature of the piezoceramics PCR-5. It is seen, that d_{33} of the composite grows visibly by the increase of *D*. The simplicity of the receipt technology, high physico-mechanical and piezoelectric characteristics, and the possibility of the piezoelement receipt of the various configuration make the piezocomposite more effective piezomaterial for the creation of electroacoustic converters of the new generation, distinguished by high exploitational characteristics. We should note, that the research on the creation of medical devices, in particular, aerosoltherapy devices on the base of piezocomposites is in present time on the initial stage. It is necessary to work out the physical principles of the composite material creation for radiators and receivers, to calculate optimal constructions of separate converters, to determine configurations and geometric sizes of the piezocomposite element, and also optimal regimes of the polarization. It is necessary to especially note, that the amplitude-frequency characteristic (AFC) and the radiation power of piezocomposite converters essentially depend on the configuration of the piezocomposite element (table 4). Results are obtained at the application to the piezoelement of 10V voltage.

The possibility of the wide variation of the configuration, what is impossible to obtain in the case of the piezoceramics capacity and piezomodulus d_{ij}, and, respectively, g_{ij}. It gives the chance of the creation of high effective piezocomposite radiators of the medical purpose.

Table 4

f, Hz	*P*, *Pa*, the flat (plane) element	*P*, *Pa*, the domed (dome-shape) element $\tau_{cr} = 1mm$
1000	26,0	9,0
1200	6,25	16,0
1300	4,0	24,5
1400	3,0	45
1500	2,82	68
1800	4,0	11,0
2000	1,8	7,5
2500	1,9	2,25
3000	0,1	2,25
4000	0,17	2,4

Amplitude-frequency characteristics of piezoresonators from the composite PP+50 % PCR-3M (the curve 3) and the piezoceramics PZT-19 (curve 2) are compared on fig. 4.

It is seen that the value of the resonance frequency f_r of the inhaler piezoresonator of the TUMAN-1.1 type may be increased at the piezocomposite application as a piezoresonator. The growth of f_r, as it has been already noted, leads to the reduction of the diameter of the medicinal aerosol particles of the inhaler, and consequently, increases the efficiency of this device.

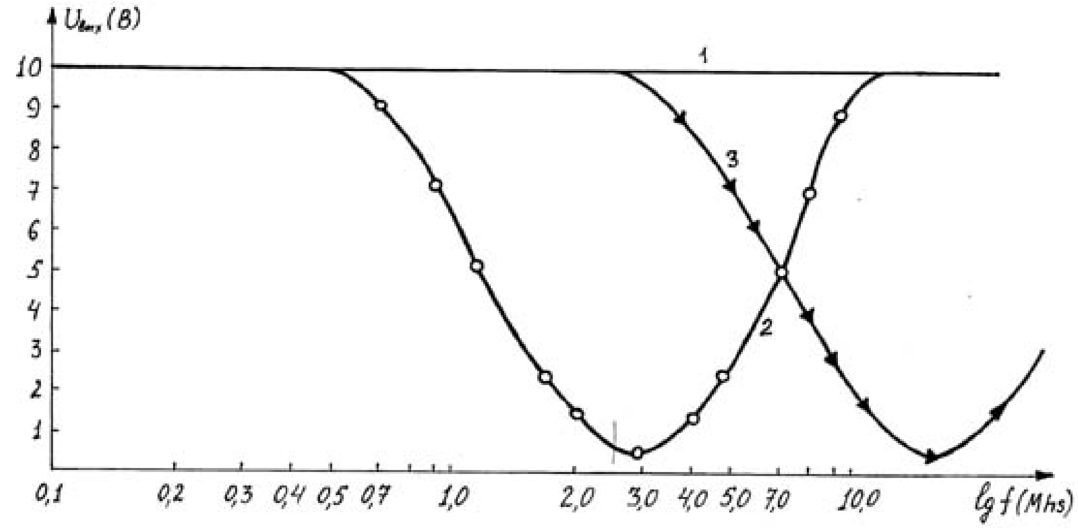

Fig. 4 The amplitude-frequency characteristics of the signal generator in the regime of the inverse piezoelectric effect

1. The regime of the idle run
2. The regime with the use of piezoceramics PZT-19
3. The regime with the use of piezocomposites PP+PCR-3M

The thickness of the piezoceramic element PZT-19 is 1,5 mm
The thickness of the piezocomposite element PP+PCR-3M is 0,5 mm.

Therefore, piezoelectric acoustic converters of the medical purpose may be created by the change of physico-technological regimes of the polarization condition, physico-mechanical characteristics, the configuration and geometric sizes of the piezocomposite elements receipt.

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TİBB MƏQSƏDLİ APARATLAR ÜÇÜN PYEZOKOMPOZİT ŞÜALANDIRICILARIN HAZIRLANMA İMKANLARI HAQQINDA

Təcrübi olaraq müəyyən edilmişdir ki, kizokompozit elementlərin polyarizasiya şərtlərini, fiziki-mexaniki xarakteristikalarını, konfiqurasiyasını və həndəsi ölçülərini dəyişməklə tibbi məqsədlər üçün elektroakustik çeviricilər hazırlamaq mümkündür.

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О ВОЗМОЖНОСТИ СОЗДАНИЯ ПЬЕЗОКОМПОЗИТНЫХ ИЗЛУЧАТЕЛЕЙ ДЛЯ АППАРАТОВ МЕДИЦИНСКОГО НАЗНАЧЕНИЯ

Экспериментально установлено, что изменяя условия поляризации, физико-механические характеристики, конфигурации и геометрические размеры пьезокомпозитных элементов, можно создать электроакустические преобразователи медицинского назначения.

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