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THE INCREASE OF SOUND PRESSURE LEVEL OF MONOMORPH TRANSDUCERS WITH THE USE OF SPATIAL ENERGY FORCE STRUCTURE OF A PIEZOELEMENT

The work is devoted to the perfection of piezoelectric transducers based on disk monomorph piezoelectric elements. The purpose of this work is to increase sound pressure level of disk monomorph transducers and to develop a physical model of disk piezoelectric transducers with spatial energy force structure of piezoelectric element. The paper shows that amplitude-frequency characteristic of monomorph piezoelectric element at low-frequency area has resonant character. A method for increasing the level of low-frequency vibrations is proposed. A physical model of piezoelectric transducer with spatial energy force structure is offered. The electrodes on piezoelectric element must be placed in a way to make an angle between electric field vector of exciting voltage and polarization vector. Driving method of low-frequency vibrations in disk monomorph piezoelectric elements is discussed. Oscillating circuit at the input made by additional inductance and interelectrode capacitance of the piezoelement is created for further increassng of piezoelement sound pressure.

Keywords: *monomorph piezoelements, low-frequency vibrations, amplitude-frequency characteristic, sound pressure.*

Piezoelectric transducers are widely used in electroacoustics, hydroacoustics, measuring technology, nondestructive control, piezomotors, scanners of nanomicroscopes, other fields of science and technique [1, 7–9, 11].

It is considered that low-frequency vibrations do not occur in monomorph piezoelectric elements in the form of plates, bars, disks, etc. [1, 2].

Meanwhile, the appearance of low frequency oscillations is detected in monomorph piezoelectric elements, but sound pressure level, generated by piezoelectric monomorph transducers, is low [3, 4].

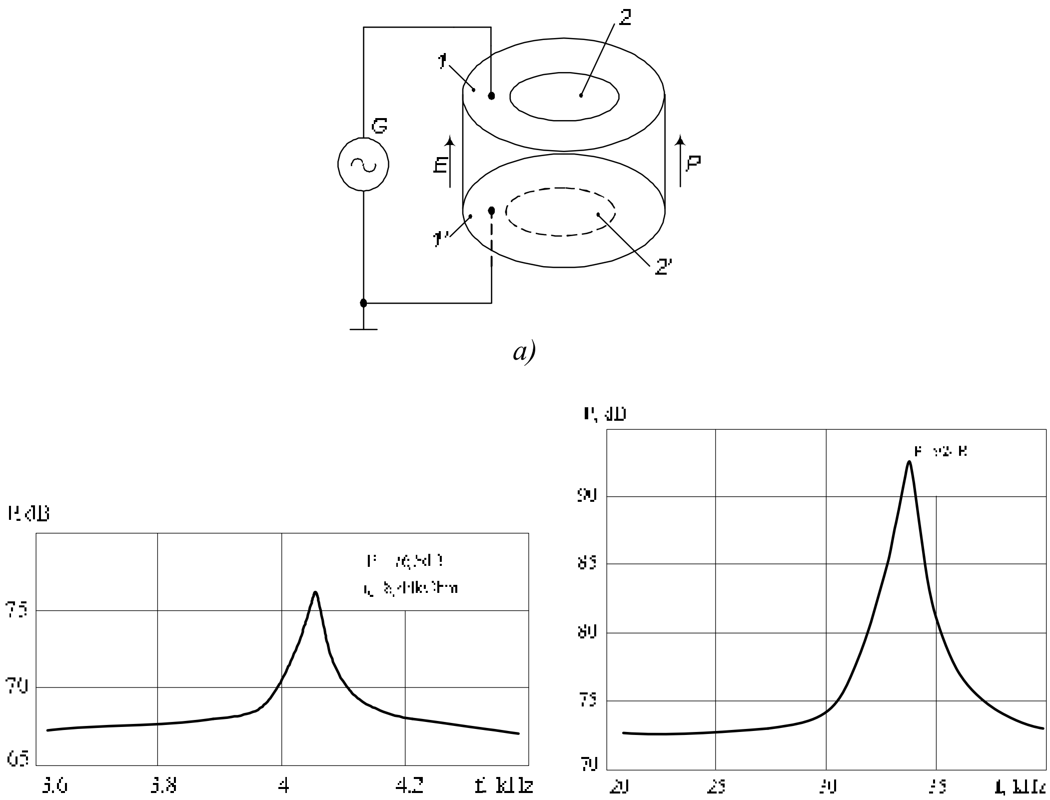
The purpose of this work is to increase sound pressure level of disk monomorph transducers and to develop a physical model of disk piezoelectric transducers with spatial energy force structure of piezoelectric element.

In Fig. 1 the connection scheme (Fig. 1, *a*) and sound pressure amplitude-frequency characteristic (AFC) (Fig. 1, *b*, *c*) of monomorph piezoelectric element Ø66x3 mm, made of piezoceramics ЦТС-19, is shown.

As can be seen from Fig. 1, amplitude-frequency characteristic of monomorph piezoelectric element at low-frequency area has resonant character.

To clarify the type of oscillations for this piezoelectric element Chladni figures [10] were received (Fig. 2). As can be seen from Fig. 2, *a*, Chladni figure for the frequency of 4,05 kHz corresponds to bending vibrations of the piezoelement, and for the frequency of about 34 kHz – the main resonant frequency of radial oscillations (Fig. 2, *b*).

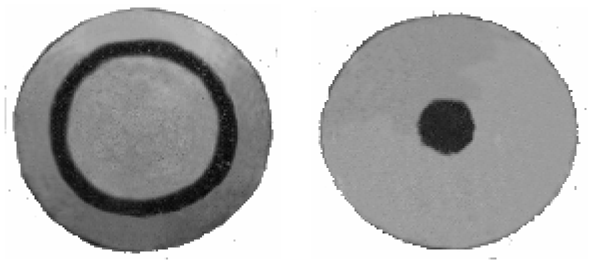
To increase the level of low-frequency vibrations it is proposed to create electric field in the piezoelement which stimulates these oscillations. The electrodes on the piezoelement must be placed in a way to make the angle α between electric field vector **E** of exciting voltage and polarization vector **P**, where $0 < \alpha \leq 90°$ (Fig. 3, *a*, *b*).



a)

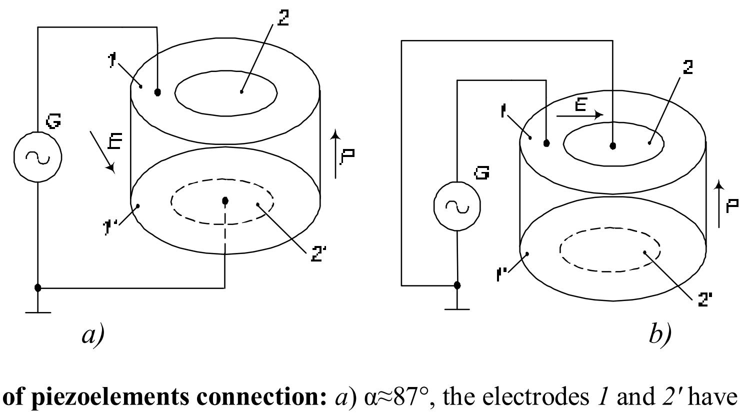
b) c)

Fig. 1. Connection scheme (*a*), sound pressure amplitude-frequency characteristic at low-frequency (*b*) and high frequency (*c*) areas of monomorph piezoelectric element Ø 66x3 mm



a) b)

Fig. 2. Chladni figures for bending (*a*) and radial (*b*) oscillations of monomorph disk piezoelement



a) b)

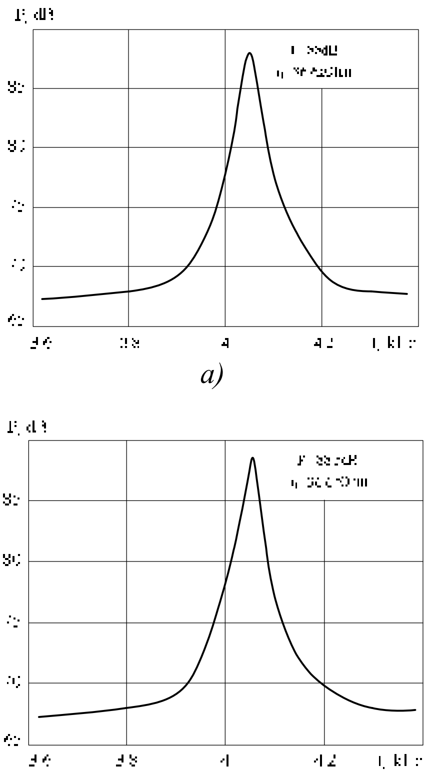
Fig. 3. Schemes of piezoelements connection: *a*) α≈87°, the electrodes *1* and *2′* have coplanar location; *b*) α=90°, the electrodes *1* and *2* have planar location

It should be noted that such arrangement of electrodes on the piezoelements is widely used in the so-called domain-dissipative piezoelements, in which the angle α is created by polarization vector and electric field vector of output voltage of piezoelectric sensor [2, 3].

When we use such scheme in piezoelectric transducers two competing processes are possible – increasing of low-frequency vibrations due to the location of exciting field vector and at the same time reducing of these oscillations by increasing own resistance of piezoelement [5]. The proposed idea has been experimentally verified.

The piezoelement Ø 66 and 3 mm thick made of piezoceramics ЦТС-19 was used for the experiments.

Sound pressure amplitude-frequency characteristics (AFC) were measured by sound level meter RFT for connection schemes shown in Fig. 3. Simultaneously, internal friction in piezoelectric element was measured on resonant frequency. These results are shown in Fig. 4.



a)

b)

Fig. 4. AFC of piezoelectric transducers shown in the scheme: *a)* Fig. 3, *a*; *b)* Fig. 3, *b*

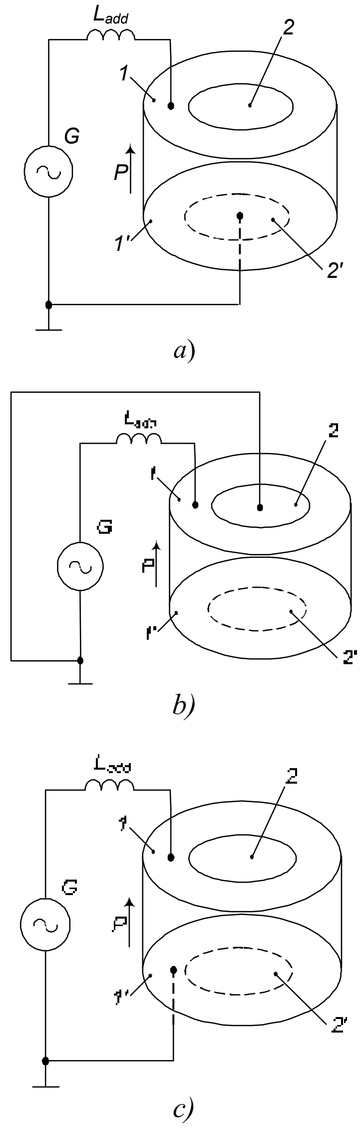
Fig. 4 shows that for schemes with α≈90° sound pressure level has increased by about 12 dB, resonant frequency has not changed, and r_0 has increased approximately four times compared with the transducer with α=0° (Fig. 1, *a*).

Oscillating circuit at the input made by additional inductance L_{ad} and interelectrode capacitance of piezoelement C_{el} was created for further increassng of piezoelement sound pressure. The inductance is determined from the expression [6]:

$$L_{add} = \frac{1}{4\pi^2 f_r^2 C_{el}},$$

where f_r –resonant frequency of piezoelectric element; C_{el} – the capacitance between the electrodes 1–2', 1–2 and 1–1', respectively.

Connection schemes of piezoelectric element with additional inductance are shown in Fig. 5.



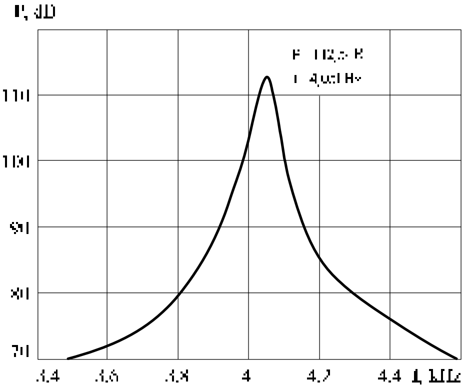
a)

b)

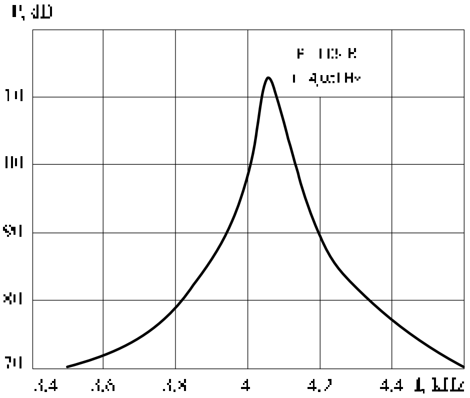
c)

Fig. 5. Schemes of piezoelement connection with additional inductance:
a) $C_{1-2'}$=1,2 nF, L_{ad}=1,25 H; *b)* C_{1-2}=1,13 nF, L_{ad} =1,3 H; *c)* $C_{1-1'}$=8,1 nF, L_{ad} =0,185 H

The measurement results of AFC are shown in Fig. 6.



a)



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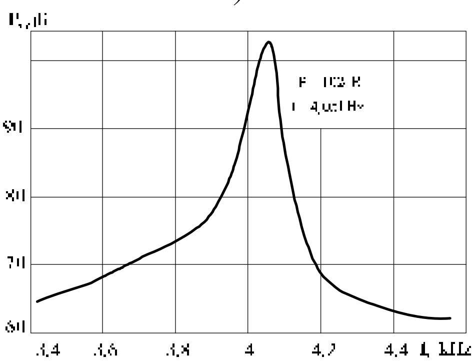

c)

Fig. 6. AFC of piezoelectric transducers with additional inductance:
a) Fig. 5, *a*; *b)* Fig. 5, b; *в)* Fig. 5, *c*

Fig. 6 shows that sound pressure level on the frequency of 4.05 kHz for transducers with additional inductance (Fig. 5) has increased by about 24 dB in comparison with the transducers without inductance (Fig. 4) and by about 36 dB in comparison with the known connection scheme (Fig. 1) on the same frequency. For schemes with α≈90° (Fig. 5, *a, b*) sound pressure level has increased by about 10 dB in comparison with the transducer with α=0° (Fig. 5, *c*).

Conclusions

1. A method for increasing the level of low-frequency vibrations is proposed.
2. A physical model of piezoelectric transducer with spatial energy force structure is offered. It is advised to create electric field in piezoelectric element which stimulates low-frequency oscillations. The electrodes on piezoelectric element must be placed in a way to make the angle between electric field vector of exciting voltage and polarization vector.
3. Driving method of low-frequency vibrations in disk monomorph piezoelectric elements is discussed. Physical model of piezoelectric transducer with additional inductance and interelectrode capacitance of the piezoelement is created for further increassng of sound pressure.
4. New offered physical models of monomorph piezoelectric elements allow to increase sound pressure level by 24-36 dB.
5. The results can be used for electroacoustic transducers designing.

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