Yu.V. Tchesskii, T.Yu. Tchesskaya

A COMBINED TRANSDUCER OF ULTRASONIC OSCILLATIONS

Stomatological Clinic "VISTOM"
18/1, Topoleva str., Odessa, 65114, Ukraine

Odessa State Environment University
15, Lvovskaya str., Odessa, 65016, Ukraine
E-mail: tatyana@odessa.zzn.com

A *combined transducer's construction of ultrasonic oscillations was considered. In this work the theory and calculations for a radiator looks like needle vibrator and combined with a waveguide are presented. The expressions for a receiver and its static sensitivity were found. A receiver was carried out as a piezoelectric cylinder with internal filling.*

Under researches realization in the small volumes it is often required to attach too much powerful ultrasonic vibrations and to measure its values synchronously, also surroundings response under effect by these vibrations. Above-said requirements are realized by using of a combined transducer that consists of a mechanical oscillation generator and a receiver of them space. The letter are separated in space and integrated to united construction (Fig.1).

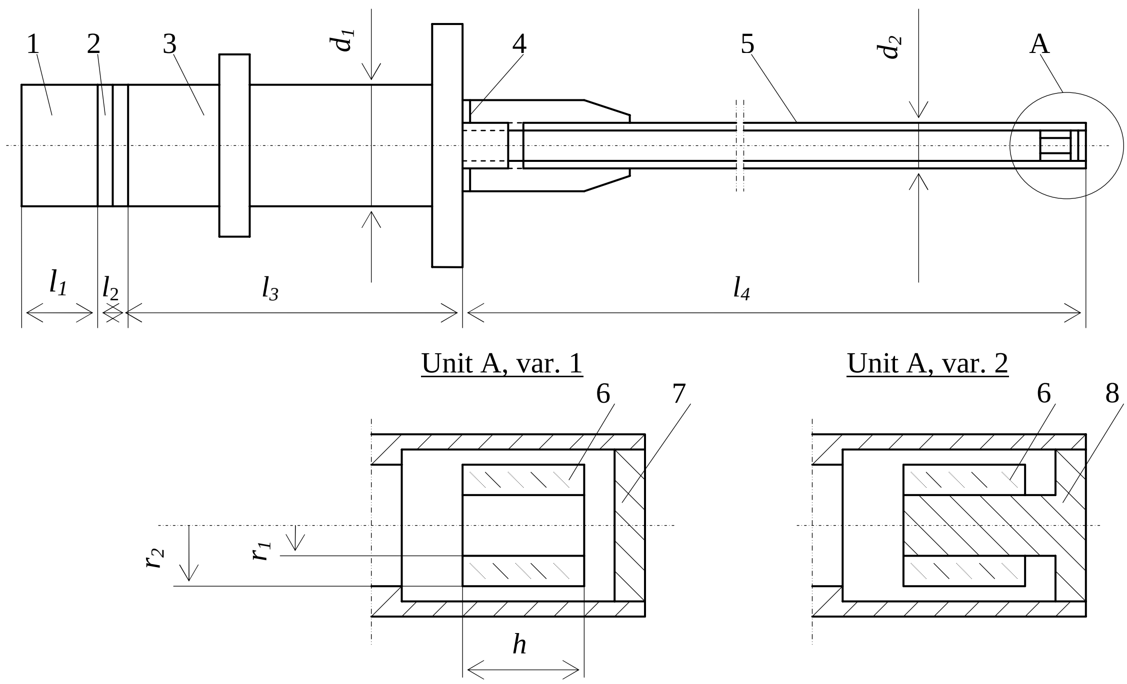

Fig.1. A combined transducer's construction: 1 –a tail nozzle; 2 – piezoceramics; 3 –a head nozzle; 4 – a washer; 5 – a waveguide; 6 – piezoceramics cylinder; 7 – a cap; 8 – a cap-waveguide; d_1 and l_1, l_2, l_3 - an external diameter and suitable length of nozzles and piezoceramics d_2 and l_4 - an external diameter and a length of a waveguide; r_1, r_2, and h - internal, external radiuses and a height of a piezoceramics cylinder.

Consisting of a tail nozzle 1, two piezoceramics caps 2 and a head nozzle 3 a combined transducer is joined to a hollow waveguide 5. Inside this waveguide, fig. 1 (Unit A, var. 1), a receiver 6 disposed, its end is closed by a cap 7. A waveguide is filled with organic-silicon liquid, and seal is provided for a washer.

A resonance frequency for a part of a combined transducer last one jointly to a waveguide presents a rod transducer is defined by a formula [1]:

$$\left(\frac{b_1}{b_3}t_1+\frac{b_2}{b_3}t_2\right)\left(\frac{b_4}{b_3}t_3t_4-1\right)+\left(\frac{b_1}{b_2}t_1t_2-1\right)\left(\frac{b_4}{b_3}t_4+t_3\right)=0\,, \qquad (1)$$

where $t_1=tg\alpha_1$, $t_2=tg\alpha_2$, $t_3=tg\alpha_3$, $t_4=tg\alpha_4$, $\alpha_1=p_1l_1$, $p_1=\omega(\rho_1/E_{Y,1})^{1/2}$, $b_1=p_1S_1E_{Y,1}$, $\alpha_2=p_2l_2$, $p_2=\omega(\rho_2 s_{33}^D)^{1/2}$, $s_{33}^D=s_{33}^E(1-k_{33}^2)$, $s_{33}^E=d_{33}^2/(\varepsilon_{33}^T k_{33}^2)$, $b_2=\dfrac{p_2S_2}{s_{33}^D}$, $\alpha_3=p_3l_3$, $p_3=\omega(\rho_3/E_{Y,3})^{1/2}$, $b_3=p_3S_3E_{Y3}$, $\alpha_4=p_3l_4$, $p_3=\omega(\rho_4/E_{Y,4})^{1/2}$, $b_4=p_3S_4E_{Y,4}$, $\omega=2\pi f$, ρ_i, $E_{Y,i}$ and S_i - a density, an elasticity module and a cross-section area of a transducer *i*-th part, *i* = 1, 2, 3, 4; s_{33}^E and k_{33} - an elastic flexibility and an electromechanical coupling coefficient of piezoelectric ceramics; *f* – frequency.

Shown in the picture 1 (Unit A, var. 1) choice of a receiver design was carted out on the basis of static sensitivity of a piezoceramics cylinder on the ground that sound pressure acts on only a cylinder's exterior surface. A static sensitivity expression under radial polarization of a piezoceramics cylinder in compliance with results of the work [2] looks like as:

$$\nu=\frac{U}{P}=\frac{r_2(1-\rho)}{1-\rho D}\left(g_{33}\frac{1-dD}{1+dD}+g_{31}\right), \qquad (2)$$

where $\rho=\dfrac{r_1}{r_2}$, $D=\left[1-\dfrac{(1-\mu_k)E_c}{(1-\mu_c)E_k}\right]\left[1+\dfrac{(1+\mu_k)E_c}{(1-\mu_c)E_k}\right]^{-1}$; E_k, E_c and μ_k, μ_c - Young modulus and Poisson's ratio for piezoceramics and filler respectively; g_{33} and g_{31} - piezoelectric constant.

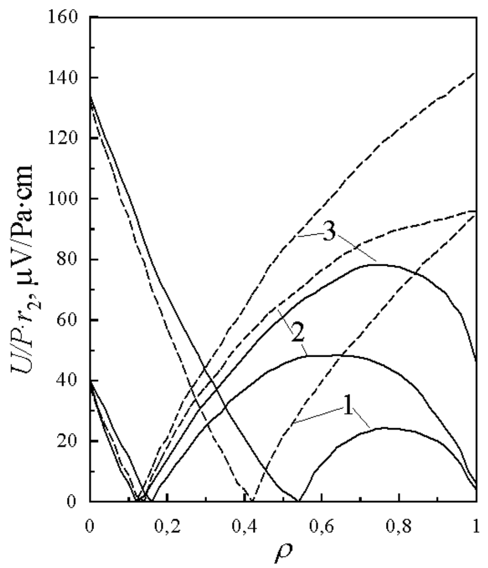

Fig. 2. Static sensitivity of a cylindrical piezoceramics receiver getting signals by external depends upon a relative radius

Computing results by formula (2) for a cylinder receiver of ZTP-19 [3, 4] are shown in the picture 2 by way of diagram for ν/r_2, in other words all calculation results by formula (2) are divided by r_2 parameter**.** Indicated computing were carried out for piezoceramics cylinder with dimensions: radius r_2 = 0,625 mm, height h = 1,5 mm and relative radius ρ = variant. In this picture numerical calculations are given for three variants of the end design for a piezoceramics cylinder that are demonstrated by suitable line: 1 - protected; 2 – opened; 3 – covered by a cap. Moreover theoretical investigations were performed for two filling variants of a piezoceramics cylinder inside space. It is imaged by lines as: (– – –) for air and (———) for epoxy resin.

Carried out analysis are permitted to offer using of piezoceramics cylinders with opened or covered by a caps ends for given variant of design. In this case an optimal relative radius ρ of piezoceramics cylinders lies within the limits of 0,5 to 0.8.

A combined transducer's design with receiver, presented in the picture 1 (Unit A, var.2) was made with filled by air a waveguide. Here ultrasonic oscillations act on inside surface a piezoceramics cylinder since the last one rigidly is joined by a cap-waveguide.

With the assumption that sound pressure P acts on inside surface, strain state of a piezoceramics cylinder containing a metal waveguide one can determine by an expression [5]:

$$T_r = A - \frac{B}{r^2}, \tag{3}$$

$$T_t = A + \frac{B}{r^2}, \tag{4}$$

$$T_z = 0, \tag{5}$$

$$u = \left(T_t - \mu_k T_r\right)\frac{r}{E_k}, \tag{6}$$

where T_r, T_t, and T_z - radial, tangential and axial mechanical stresses; r - instant radius; A and B - arbitrary constants, that determined by boundary conditions; u – a radial displacement.

For a waveguide situated within r length of a centre on the assumption of its immobility $T_{r8}(r) = T_{t8} = C$ and a radial displacement are expressed in the form of

$$u_8 = (1 - \mu_8)C\frac{r}{E_8}, \tag{7}$$

where E_8 and μ_8 - Young modulus and Poisson's ratio of a waveguide.

Boundary conditions for given problem on internal r_1 and external r_2 radiuses of a piezoceramics cylinder look as:

$$T_{rk} = T_{r8} + P, \quad \text{under } r = r_1, \tag{8}$$

$$u = u_8, \quad \text{under } r = r_1, \tag{9}$$

$$T_{rk} = 0, \quad \text{under } r = r_2. \tag{10}$$

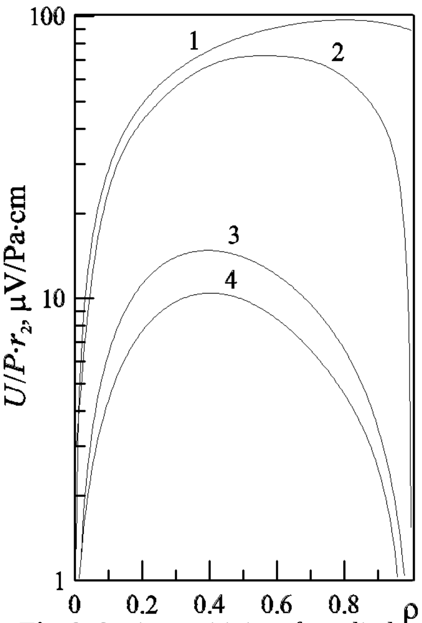

Fig. 3. Static sensitivity of a cylindrical piezoceramics receiver getting signals by interior surface depends upon a relative radius

Expressions (3-7) substitute for boundary conditions (8-10). Obtained combined equations permit to define radial T_{rk} and tangential T_{tk} components for mechanical stress of a piezoceramics cylinder as:

$$T_{rk} = \frac{\rho^2 DP}{d_1\left(1 - \rho^2 D\right)}\left(1 - \frac{r_2^2}{r^2}\right), \tag{11}$$

$$T_{tk} = -\frac{\rho^2 DP}{d_1\left(1 - \rho^2 D\right)}\left(1 + \frac{r_2^2}{r^2}\right), \tag{12}$$

where $d_1 = 1 - \frac{(1+\mu_k)E_8}{(1-\mu_8)E_k}$, $D = d_1\left[1 - \frac{(1+\mu_k)E_8}{(1-\mu_8)E_k}\right]^{-1}$.

Statically sensitivity of radial polarized a piezoceramics cylinder is determined on the base of expression [2]:

$$V = \int_{r_1}^{r_2}\left[g_{33}T_{rk} + g_{31}\left(T_{tk} + T_{zk}\right)\right]dr. \tag{13}$$

Substituted for formula (13) expressions (5), (11), (12) and after subsequent integration an expression for statically sensitivity of waveguide's receiver one may get as:

$$\nu = \frac{V}{P} = -\frac{r_2 \rho^2 (1-\rho) D}{d_1 (1-\rho^2 D)} \left[(g_{33} + g_{31}) - \frac{1}{\rho} (g_{33} - g_{31}) \right]. \tag{14}$$

Computations for a waveguide cylinder receiver of ZTP-19 piezoceramics are resulted by a formula (14). Data (fig.3) as dependence of a receiver's static sensitivity ν/r_2 upon a relative radius ρ were gotten for waveguides: 1 – water; 2 – acrylic resin; 3 – copper; 4 - stainless steel (1Cr18Ni10Ti). All calculation results by formula (14) are divided by r_2 parameter.

Under consideration receivers were accounted for waveguides with impedances at rod's oscillation mode $Mkg/m^2 \cdot s$: stainless steel (1Cr18Ni10Ti) – 40,3; copper – 33; acrylic resin – 3,13. Basic data for impedances calculation were taken from reference book [4, 6]. Based on accounts one can see with waveguide's impedance reduction detecting device sensitivity is increased.

In respect to design's mechanical properties using of waveguides from metal is optimum.

Executed investigations allow to offer use of piezoceramics cylinders with an optimal relative radius ρ in the range of 0,3 till 0,55 in given construction variant with waveguide's receiver.

REFERENCES

1. Tchesskii Yu.V. Pivot Transducer Jointed to Concentrated Waveguide of Ultrasonic Oscillations. // Transactions XIII session RAS: Ultrasound and ultrasonic technologies. M.: GEOS, 2003. V.2. P. 209-213. (in Russian)
2. Langevin R.A. The Electro–Acoustic Sensitivity of Cylindrical Ceramic Tubes // JASA, 1954, V.26, #3. P. 421-428.
3. Piezoceramics Transducers. Reference book / Edited by S.I. Pugachev. Leningrad: Sudostroenie, 1984. 256 p. (in Russian)
4. Underwater Electroacoustic Transducers. Reference book / Edited by V.V. Bogorodskii. Leningrad: Sudostroenie, 1983. 248 p. (in Russian)
5. Love A.E.H. A Treatise on the Mathematical Theory of Elasticity. Cambridge: At the University Press, 1927. 674 p.
6. Tables Physical Magnitudes. Reference book / Edited by I.K. Kikoin. Moskva: Atomizdat, 1976. 1006 p. (in Russian)