БЪЛГАРСКА АКАДЕМИЯ НА НАУКИТЕ . BULGARIAN ACADEMY OF SCIENCES

ПРОБЛЕМИ НА ТЕХНИЧЕСКАТА КИБЕРНЕТИКА И РОБОТИКАТА, 46
PROBLEMS OF ENGINEERING CYBERNETICS AND ROBOTICS, 46

София . 1997 . Sofia

Analysis of High Density Sensor for Specialized Electronic Equipment

Tihomir Trifonov, Mitko Gospodinov***

**Department of Radio-electronics, Vassil Levsky Military Academy, 5000 Veliko Tirnovo*
***Central Laboratory of Mechanics and Instrumentation, BAS, 5000 Veliko Tirnovo*

1. Introduction

Many constructions of the piezoceramic microphones, hydrophones, geophones, accelerometers, etc. are based on an active element, named bimorph. It is composed of two piezoceramic plates (generally disks), pasted each other with conductive glue. Depending on the direction of the polarization vector on disks, two variants of electrical connection between them are possible. For mechanical strength one of them can be constituted for passive - from alloyed steel, titanium and others.

The “sound cell” is composed of one or two bimorph elements. The symmetric construction, shown schematically in Fig.1, is a typical one.

Fig. 1. Shema of symetric construction: 1 – support; 2 – bimorph; *p* – sound pressure; P_0 – polarization vector

Because the velocities of vibration of the opposite active surfaces are equal in value and opposite in sign, the transducer is classified like a pulsing one. This fact allows the problem of obtaining the acoustic field to be substituted for the equivalent problem of obtaining the field of the same transducer, installed in absolutely rigid acoustic baffle.

Except this, it is clear that the sensor is an electromechanical system with distributed parameters. Because of the anisotropic characteristics of the piezocristals their analysis of this type is very complicated [1, 2]. For this reason the electromechanical circuit model with concentrated parameters is very useful.

2. Circuit model of the sensor

To transform the distributed parameters to concentrated ones, at first the point of reduction is selected. For convenience sake the point is determined in the centre of symmetry of the disk surface (point A in Fig. 1). It must be taken into consideration, that for simplicity sake of the formulae, linear dimensions of the bimorph have to satisfy the condition:

(1) $$h \leq 0.1a.$$

The greater thickness must be taken into account when the equivalent parameters are derived. After this, for obtaining the values of the basic equivalent parameters, mass m_e and elasticity s_e, reduced to the point A, the method of the energy equivalents is applied [3, 4]. Its essence is the description of the expressions of the kinetic and potential energy of the equivalent harmonic oscillator using the dynamic deformation of the active surfaces, obtained by other methods. By this method the equivalent force in the point of reduction F_e and the area of the equivalent piston S_e can be received as well. It is evident that depending on the conditions of fixing of the bimorph perimeter, the equivalent parameters are different. As it is known [1, 2], each electromechanical transducer can be presented like a quadripole with two electrical and two mechanical parameters (current I, voltage U, mechanical force F and velocity of vibration v). If it is assumed that the quadripole is linear, passive and reversible, the two-directional electromechanical transformation is written down by equations as follows:

(2) $$F = ZI + k_1 v, \qquad F = zv + k_2 I,$$

where $Z=U/I|v=0$ is input electrical impedance in fixed mechanical system, that is set; $Z=F/v|I=0$, $z_l=0$ is mechanical impedance of unloaded mechanical system; k_1 and k_2 are electromechanical coupling coefficients.

The coefficient of electromechanical transformation n is determined from (2) and is described with relations:

(3) $$n= I / v\,|U=0;\; n= F / U\,|v=0.$$

In this way the mechanical and electrical parts of the transducer can be connected by virtual ideal transformer with a coefficient n (Fig. 2).

Using the circuit, shown in Fig. 2, the reduced equivalent parameters and the balance of the powers of the system, the final equivalent electromechanical circuit with concentrated parameters is obtained. For free fixed (hinged) bimorph element (Fig. 1), it is composed in Fig. 3.

The circuit elements are calculated by expressions:

(4) $$m_e = 0.3\, m,$$

m – bimorph mass,

(5) $$c_e = \frac{3a^2(1-v^2)}{4\pi E_y h^3},$$

where V is Poisson's coefficient; E_y – Young's module; a – piezoceramic disk radius; h – thickness of the disk (Fig. 1).

The radiation impedance z_r is equal to

(6) $$z_r = r_r + j\, x_r,$$

where

(7) $$r_r = \rho_m\, c_m S_e + r_r,$$

(8) $$r_{r_1} = \left[1 - \frac{J_1(2ka_e)}{ka_e}\right],$$

(9) $$x_r = \rho_m\, c_m S_e\, x_r,$$

(10) $$r_{r_1} = \left[\frac{H_1(2ka_e)}{ka_e}\right],$$

where a_e is radius of the equivalent piston; $\rho_m c_m$ – characteristic impedance of the working medium; $k = 2\pi/\lambda$ – wave number; $J_1(.)$ – Bessel's function; $H_1(.)$ – Struve function; S_e – area of the equivalent piston and

(11) $$n = 6.78\, d_{31} E_y h,$$

where d_{31} is a piezoelectric constant.

The internal impedance of the sensor is determined by capacitance C_0. In practice, for engineering applications, it can be accepted

(12) $$C_0 = \frac{\varepsilon^S_{33}}{2h} S,$$

where ε^S_{33} is dielectric permitivity of the piezoceramic when the deformation is zero; S – area of the disk electrode.

The resistance of the mechanical losses r_{mi} is taken into consideration introducing the acoustomechanical coefficient of performance, η=0.6–0.8 [1].

3. Open circuit sensitivity

Open circuit sensitivity Mo is given by [2, 5]:

(13) $$M_0 = \frac{U_{oc}}{p},$$

where U_{oc} is open circuit voltage; p – sound pressure.

Frequency response of M_0 can be obtained from the equivalent circuit (Fig. 3):

(14) $$|M_0| = \frac{n\, S_e}{wC_0 |Z|},$$

where

(15) $$|Z| = \left[\left(\frac{r_r}{\eta} \right)^2 + \left(wm_e + x_r - \frac{1}{wc_e} - \frac{n^2}{wC_0} \right)^2 \right]^{1/2},$$

$w = 2\pi f$ – angular frequency.

The frequency of the electromechanical resonance f_0 can be derived from (15):

(16) $$w_0 m_e + x_r - \frac{1}{w_0 c_e} - \frac{n^2}{wC_0} = 0.$$

The reactive part of the radiation impedance x_r (9) can be expressed with associated mass m_a as well.

(17) $$x_r = w\, m_a.$$

For a diskq substituted with its equivalent piston in an infinite absolutely rigid acoustic baffle, in low frequencies, m_a is given by Rayleight formula:

(18) $$m_a = \frac{8}{3} \rho_m a^3_e,$$

where ρ_m is the density of the medium (gas, air, water, etc.).

The typical form of the frequency response is shown in Fig. 4.

4. Experimental results

On the basis of the equivalent surface, shown in Fig. 3 and of the relations (4-15), a method was created for designing of sound cell transducers for passive underwater antennas. Some Bulgarian piezoceramic materials of the type of barium titanate – $BaTiO_3$, PZT – $PbSr(TiZr)O_3$, etc. were used. The sensitivity of the samples was measured by the substitution method and by the standard reciprocity method in the anechoic water tank [5,6].

An arrangement of the measurement hydrophones and electronic instruments produced in "Bruel & Kaer" – Germany, was used, [7]. The frequency response of the sensitivity to the resonance, which came out experimentally, coincided with the theoretical one [14]. The maximal deviation was not greater than ±1dB.

The most significant difference between theoretical and experimental results was obtained when the electromechanical frequency was determined (up to ±1kHz). As a rule the experimentally obtained resonance frequency was higher than the calculated by formula (16). The investigation showed that the reason for this fact is inaccurate fulfillment of the boundary condition – free fixing on the support of the bimorph elements.

5. Conclusion

The comparison between theoretical and experimental results shows that the equivalent circuit used is useful for engineering design of the sound sensor of bimorph type. The most important parameters can be calculated with satisfactory accuracy.

References

1. Belous, E. S., V. S. Gorbenko, V. P. Pougach. Underwater antenna and transducer design. Kiev, Polytechnic institute, 1975 (in Russian).
2. Physical Acoustics. Principles and Methods. W.P. Mason (editor). Volume 1, part A. Academic Press, 1964.
3. Sverdlin, G. M. Underwater Transducers and Antennas. Leningrad, Sudostroene, 1988 (in Russian).

4. Trifonov, T. St. Sensitivity of receiver sound cell. Reprints on Scent. Session of Vassil Levsky Military Academy, Veliko Turnovo, 15 June, 1995 (in Bulgarian).
5. IEC Publication 565. Calibration of Hydrophones. 1977.
6. ANSI S1.20-1972. Producers for Calibration of Underwater Electroacoustic Transducers. 1972.
7. Bruel & Kaer, Electronic Instruments, 1986.

Анализ высокочувствительного датчика для специализированного электронного оборудования

Тихомир Трифонов, Митко Господинов***

** Катедра Радиоэлектроники академии "Васил Левски", 5000 Велико Тырново*
*** Центральная лаборатория мехатроники и инструментации, БАН, 5000 Велико Тырново*

(Р е з ю м е)

В статье представлена модель пьезокерамического датчика акустических волн биморфного типа. На основе эквивалентных схем со сосредоточенными параметрами предложена методика вычисления основных ее параметров. Полученные экспериментальные результаты дают возможность сделать вывод, что методика дает удовлетворительную для практики точность. Результаты применимы при проектировании датчиков для систем контроля и автоматизации процессов.