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CONSIDERATIONS REGARDING FINITE ELEMENT MODELLING OF A PIEZOCERAMIC TRANSDUCER – PART I –

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Summary: The paper describes general notions regarding the ultrasonic system representing a component part of an ultrasound processing plant, as well as the general notions concerning the active element, namely the ultrasonic transducer.

1. GENERAL NOTIONS REGARDING THE ULTRASONIC SYSTEM

The ultrasonic system represents the most important subassembly unit of an ultrasound processing plant as it achieves the acoustic parameters (acoustic power, sound energy density, oscillation amplitude, the sound wave type, oscillations' frequency) and mechanical parameters (static pressure and pressure force).

The principle general scheme of an ultrasonic system defined in this way is displayed in figure 1.

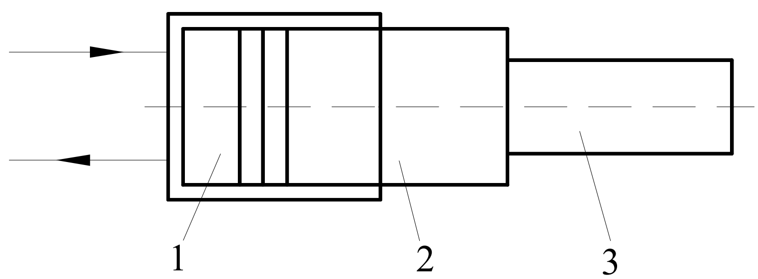

Fig. 1 The main component parts of the ultrasonic system:
1 – electro-mechanic transducer; 2 – acoustic concentrator; 3 – cutting tool

The active element of the ultrasonic system is represented by the electro-mechanic transducer (mechano-electric) which on the basis of a specific effect (electromagnetic, electrodynamic, magnetostrictive, piezoelectric, etc) converts the electric oscillations applied by the electronic generator into elastic oscillations. These oscillations are delivered, concentrated and focused by means of the acoustic transformer 2 and the cutting tool 3 within the processing environment. The ultrasonic system could also perform a reverse running - it accepts the elastic oscillations of the medium, conveys them and transforms them into electric oscillations at the transducer outlet.

The conditions which are imposed to ultrasonic systems largely depend on the specific applications for which they have been initially designed, being, for this reason, very diversified, taking into account the great variety of their usage.

There are, however, a series of common requirements, technological and acoustic that any acoustic system has to comply with. The technological requests should be observed by the final part of the system – the acoustic transformers; they are linked to calculation and making accuracy, wear resistance and fatigue, the system's hardness, operation stability, the quality of junction with the transducer, etc. The acoustic requirements are determined by the need to create within the entire oscillator system of an oscillation regime that would allow the efficient conveyance of the ultrasonic energy from transducer to medium. They could be formulated as follows:

- minimum energy losses in transducer and transformer;
- the maximum concentration of the ultrasonic energy;
- the stability of the resonance regime for the oscillator system;
- the optimum adaptation of the system to the electric oscillations generator;
- uniformity of acoustic energy radiation throughout all the utility domain;
- maximum efficiency;
- maximum acoustic responsiveness;
- maximum directivity;
- steady-state conditions for the oscillator system functioning within a certain time-limit;
- the possibility to control the main operational parameters at any time during the operation;
- technological and constructive simplicity of the component parts and of the entire oscillator system as a whole;
- increased reliability.

2. GENERAL NOTIONS REGARDING PIEZOCERAMIC TRANSDUCERS

The transducer provided with a piezoceramic disk represents a resonator system of active elements (piezoceramic) and passive elements (non-piezoceramic) which transforms with maximum efficiency a variable electric or mechanical signal into the complementary variable, being designed in such a way as to ensure frequency, vibration amplitude, directivity and the capacity corresponding to the intended target.

The piezoceramic transducer operates on the basis of piezoelectric effect which consists in the emergence of some electric loads induced on a body subject to mechanical pressures. The intensity of electric load is proportionate to applied mechanic strength and the sign modifies depending on distortion (if this is distortion during expansion or shrinkage distortion). The phenomenon could occur inversely: if an electrical field might be applied on the object having piezoelectric characteristics, the latter endures a mechanic distortion proportionate to the applied electrical field. There might be a distortion during expansion or a shrinkage distortion depending on the sign of the electrical field.

Figure no. 2 represents a composed piezoceramic transducer formed by three mediums, the ceramic medium being disposed in the middle.

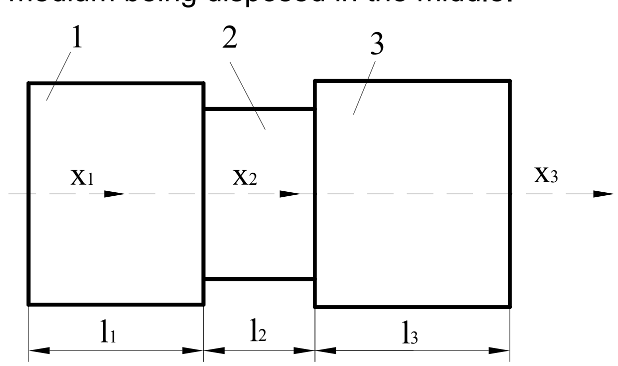

Fig.2 Composed piezoceramic transducer:
1 – refector; 2 – piezoelectric element; 3 – radiant

The three mediums are physically represented by their densities ρ_i, elastic longitudinal modules Y_i, lengths l_i and surfaces perpendicular on the vibration direction A_i (i = 1, 2, 3)

The equation of plane sound wave propagation within the composed vibrator is:

$$\frac{\partial^2 \xi_i(x_i,t)}{\partial x_i^2} = \frac{\rho_i}{Y_i} \cdot \frac{\partial^2 \xi_i(x_i,t)}{\partial t^2} \qquad (1)$$

For the mathematical treatment, the composed piezoceramic transducer is considered as being composed of:

- active element (the vibration source) which is generally a piezoceramic element;
- the reflector element which compose the backside of the transducer (generally metallic);
- radiant element which propagates the vibrations from the source to the electric load (generally metallic);

Denominations of "reflector" and "radiant" have adapted because, on a general basis, the composed transducers are destined to radiate unidirectionally.

The principle three-dimensional scheme of the acoustic transducer is displayed in figure 3.

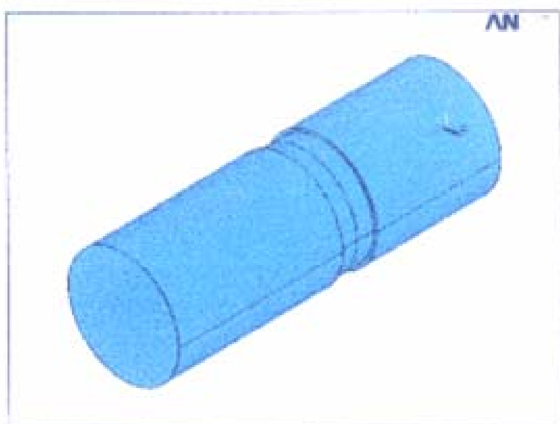

Fig. 3 The principle three-dimensional scheme of the acoustic transducer

Piezoceramic materials should fulfill the following conditions:

- to display satisfying piezoelectric characteristics for the necessary vibration modes;
- to be homogenous;
- to be able to be processed under the desired shape and size;
- their properties should have small temperature variations;
- to have internal friction as little as possible;
- to be physically and chemically stable;
- to maintain their piezoelectric properties within the entire temperature domain in which they would be used.

The advantages of using piezoceramic materials (especially those of PZT type) within the construction of transducers are given by big electro-mechanical coupling coefficients, chemical stability, the operational temperature which is relatively high, as well as the possibility to produce under various forms (by pressure) and to select any direction for the polarization axis.

The piezoceramic element, within a composed transducer, is placed in such a way as to limit the tensions' amplitude and to be phasing the vibrations of the entire assembly.

The active element vibrates by relatively small amplitude but it produces high tensions in passive elements with which it interacts.

The ceramic element is driven by an electronic oscillator to a frequency corresponding to the ensemble own frequency vibration, and the transducer as well as the contact media are considered as a system under forced oscillation regime. Such a system requires a very complicated mathematical treatment where the five distinct media representing the transducer and the contact media should be taken into account; ceramics should be considered piezoelectric medium, the treatment being made in terms of time dependent functions and by means of the three spatial coordinates.

The simplified mathematical model of the composed transducer is based on the following simplifier hypothesis:

- the longitudinal vibration alone is being considered;
- the influence of contact media is being neglected;
- the piezoelectric ceramics is considered passive, homogenous and isotropic medium;
- the reflector and radiant media are passive, homogenous and isotropic;
- the vibration axis coincides with the polarization axis, also being cylindrical symmetry axis.

There is a certain limit of the report between the active element length and that of the whole transducer. This could not exceed a certain value, determined by the emergence of inhomogeneities within the tensions' distribution into the active element, which could lead to a reduction in the effective electro-mechanic coupling coefficient of the transducer.

This depends on the electro-mechanic coupling coefficient of the piezoelectric ceramics and on the elastic energy within the transducer elastic elements. The precise calculation of this coefficient is difficult to make due to an undetermined distribution of tensions within the ensemble.