

Researching to Determine the Characteristic Parameters of the Power Ultrasonic Transducer by Finite Element Method and COMSOL-MULTIPHYSICS Program

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Abstract— The power ultrasonic transducer operates in range of frequencies from 18 KHz to 45 kHz [9]. Depending on the material, the transducer structure has the characteristic parameters that suitable for each application. The research results in this paper: building the power ultrasonic transducer model from the PZT hard piezoelectric materials and using finite element method (FEM - Finite Element Method) and COMSOL- Multiphysics (CM) program determine characteristic parameters. The research result has identified resonant oscillation frequency, the transducer displacement and the characteristics of the sound pressure emanating from the ultrasonic transducer. These results are fundamental for the designing and applying in the high power ultrasound techniques..

Keywords—Langevin transducer; PZT hard piezoelectric ceramic ; sound pressure field; FEM; COMSOL-Multiphysics

I. INTRODUCTION

The Langevin ultrasound transducer is a key element using to make high power ultrasonic devices. Depending on the material and the design model, the ultrasonic transducer has different characteristic parameters. In order to achieve the specific application purpose, it is necessary to determine the ultrasonic transducer characteristic parameters. By constructing PZT doped hard piezoelectric ceramic models and Langevin transducer, using finite element method in the PZT hard piezoelectric material environment, COMSOL-Multiphysics program survey the dependence of characteristic parameters according to frequency. In this paper, we simulated to determine the oscillation characteristic, the resonance frequency of the PZT hard piezoelectric ceramic, the Langevin transducer displacement and the sound pressure field to emanate from the front of the Langevin transducer. Research results are the basis for selecting materials, designing plans and applications.

II. FINITE ELEMENT METHOD IN PIEZOELECTRIC ENVIRONMENT [4], [6], [9]

Finite element method is applied to analyse the characteristic piezoelectric transducer parameters with different design models. In order to achieve accurate analytical results, it is necessary to set up mathematical and physical equations and impose boundary condition on each case.

A. Continuous equations in piezoelectric environment

$$\{T\} = [c^E]\{S\} - [e]\{E\} \quad (1)$$

$$\{D\} = [e]^\dagger\{S\} + [\varepsilon^S]\{E\} \quad (2)$$

In which, $\{T\}$, $\{D\}$, $\{E\}$ are the stress vector, the electric displacement vector and the electric field intensity vector respectively. $[e]$, $[\varepsilon^S]$, $[c^E]$ are the piezoelectric coefficient matrix, the dielectric constant matrix and the stiffness matrix respectively. Index \dagger symbolizes for matrix or shift vector. Index "†" symbolizes for matrix or shift vector. The mechanical terms in equation (1) follow 2 Newton's law, according to (3).

$$\frac{\rho \partial^2 \{\mathbf{R}\}}{\partial t^2} = -\{T\} \quad (3)$$

With $\mathbf{R} = \{u \ v \ w\}^\dagger$ is mechanical displacement vector along axes x , y and z . The $\{S\}$ strain vector relates the $\{R\}$ the displacement vector according to the expression according to the expression:

$$\{S\} = [\mathbf{B}_R]\{\mathbf{R}\} \quad (4)$$

In which:

$$[\mathbf{B}_R] = \begin{bmatrix} \frac{\partial}{\partial x} & 0 & 0 & 0 & \frac{\partial}{\partial z} & \frac{\partial}{\partial y} \\ 0 & \frac{\partial}{\partial y} & 0 & \frac{\partial}{\partial z} & 0 & \frac{\partial}{\partial x} \\ 0 & 0 & \frac{\partial}{\partial z} & \frac{\partial}{\partial y} & \frac{\partial}{\partial x} & 0 \end{bmatrix} \quad (5)$$

The electric terms in (1) follow Gauss's law, with the assumption that piezoelectric materials are insulating materials, no charge current running in the transducer.

$$\nabla \cdot \{D\} = 0 \quad (6)$$

The E electric field is related to the Θ voltage by

$$\{E\} = -\{B\}\Theta \quad (7)$$

$$\text{with, } \{B_\Theta\} = \left\{ \frac{\partial}{\partial x} \ \frac{\partial}{\partial y} \ \frac{\partial}{\partial z} \right\}^\dagger \quad (8)$$

In which, $\{\sigma_G\} = \{T \ D\}^\dagger$, $\{\varepsilon_G\} = \{S \ E\}^\dagger$ are the stress vector and the general deformation vector respectively. The $[c]$ general elastic matrix form:

$$[c] = \begin{bmatrix} c^E & e \\ e^T & -\epsilon^S \end{bmatrix} \quad (9)$$

The stress and strain relationships are represented by the equation:

$$\{\epsilon_G\} = [B_G]\{\mathcal{R}_G\} \quad (10)$$

In which, $\{\mathcal{R}_G\} = \{\mathcal{R}\Theta\}^\dagger = \{u \ v \ w \ \Theta\}^\dagger$ is the general displacement vector and the general matrix with form:

$$[B_G] = \begin{bmatrix} B_R & 0 \\ 0 & B_\Theta \end{bmatrix} \quad (11)$$

B. Dynamic equations in piezoelectric environment

With piezoelectric materials that have satisfied the continuous equations, the \mathcal{R}_G general displacement of any approximated point by $[N]$ displacement function and the $\{\mathcal{R}\}$ vector containing the finite displacement nodes.

$$\{\mathcal{R}_G\} = [N]\{\mathcal{R}\} \quad (12)$$

Đối với bài toán này, tại nút thứ h có 4 bậc tự do. Trong hệ tọa độ Descartes 3 chiều vector của nút thứ h có dạng.

For this problem, at the h node has the 4 freedom degrees. In the 3-dimensional Descartes coordinate system, the $\{\mathcal{R}_h\}$ vector of the hth node is the form:

$$\{\mathcal{R}_h\} = \{\mathcal{R}_h \ \Theta_h\}^\dagger = \{u_h \ v_h \ w_h\}^\dagger \quad (13)$$

Mathematical, physical basis for determining piezoelectric material parameters are described by general equations (1)-(13).

An arbitrary problem is solved by imposing boundary conditions, algorithm of finite element analysis based on input data as matrix of material coefficients: elasticity coefficient, piezoelectric coefficient and dielectric constant. The resonant oscillation frequency and characteristics are obtained by combining individual solutions.

C. Building the Langevin transducer model [2], [3], [5], [8]

Figure 1, describing the Langevin transducer structure consists of two PZT hard piezoelectric ceramic plates. The front is an aluminum metal block. The back is a metal block of steel. The whole transducer is linked by steel bolt.

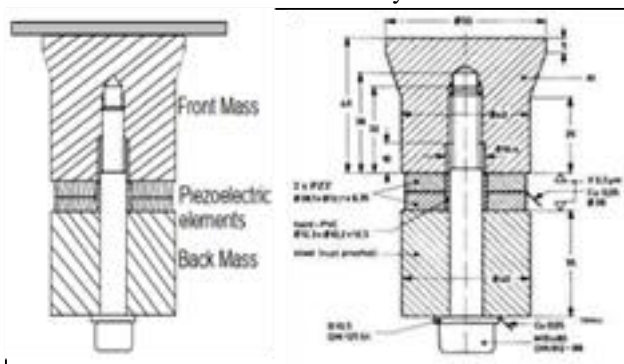


Fig. 1. The Langevin transducer structure [3]

III. SURVEYING THE LANGEVIN TRANSDUCER CHARACTERISTIC PARAMETERS BY COMSOL - MUTIPHYSICS PROGRAM

A. Setting the piezoelectric ceramic plate model and sound pressure field

Figure 2 is the oscillation survey model according to the different frequencies of the PZT piezoelectric hard ceramic to be built from the COMSOL - Multiphysics program, the meshes and nodes distribution with FEM. Sizes: the 40mm outer diameter, the 16mm internal diameter and the 5mm thickness that are also the actual sizes to manufacture the Langevin transducer.

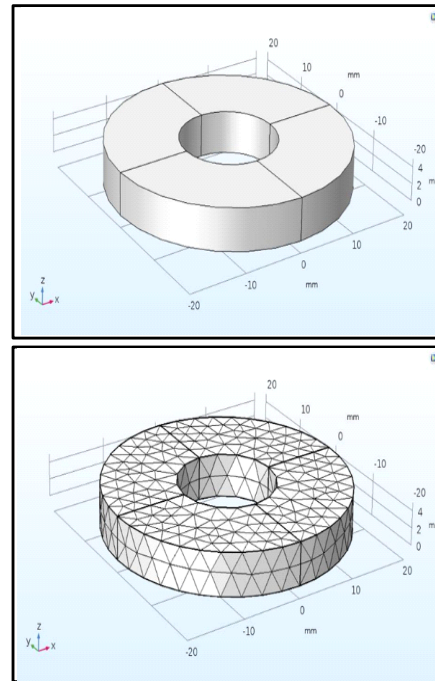


Fig. 2. The PZT piezoelectric ceramic plate model distributing the meshes and buttons with FEM

The model surveys the displacement and the emitted sound pressure field from the front of the Langevin transducer according to different frequencies, in Figure 3.

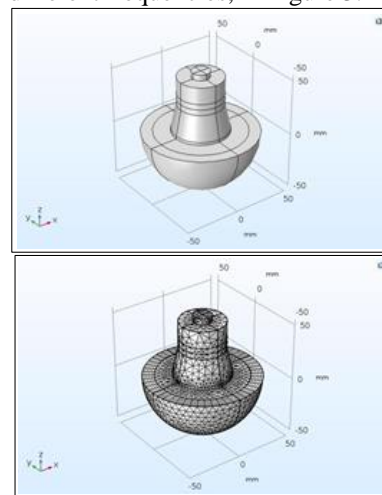


Fig. 3. The surveying model of the displacement and the sound pressure field

After the built model, we simulate the hard PZT piezoelectric ceramic operation and the Langevin transducer

according to frequency. The simulation process purpose is to determine the resonant frequency, the displacement dependence according to the resonant frequency, the emitted sound pressure field characteristic from the Langevin transducer front.

B. The simulation results to determine the PZT piezoelectric ceramic plate resonant frequency [7], [2]

Determining the resonance frequency, we surveyed the PZT hard piezoelectric ceramic plate oscillation state in the frequency range from 16.855 kHz to 44.334 kHz.

Figure 4 shows the resonant oscillation dependence of the PZT piezoelectric ceramic plate by frequency. The simulation result at the 40 kHz oscillation frequency of the ceramic plate according to the radius in the Figure 4.c is the best match. The ceramic plate oscillates according to the thickness from 16.855 kHz to 27.5 kHz frequencies (Figure 4.a, b) and to be twisted at the 44.334 kHz frequency.

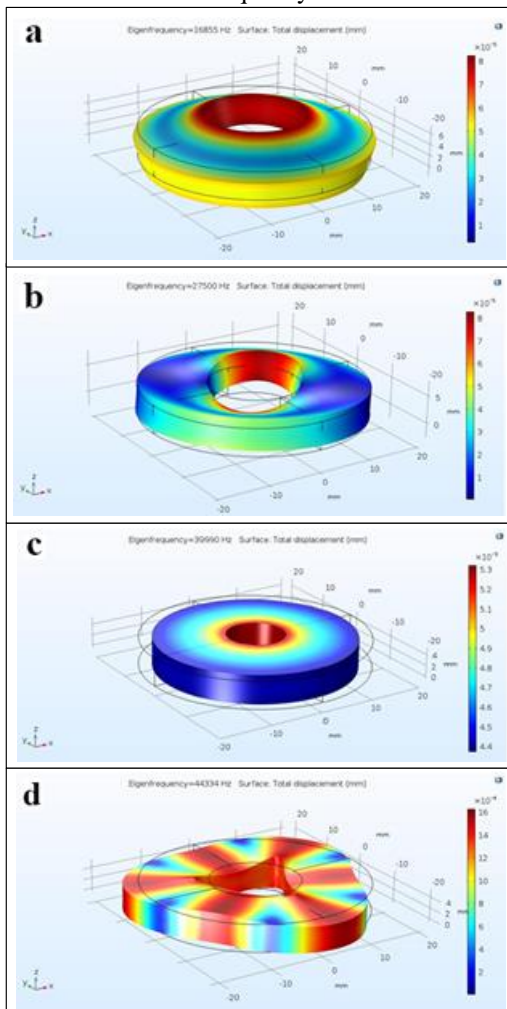


Fig. 4. The PZT piezoelectric ceramic plate resonance oscillation dependence according to frequency

The oscillation spectrum represents the PZT hard piezoelectric impedancedependence by frequency in the Figure 5. The result shows that the impedance reaches the minimum value (Z_{min}) at the 40 kHz frequency and the resonance phenomenon starts happening. This result is completely suitable for the PZT piezoelectric ceramic plate resonance oscillation at 40 kHz frequency (Figure 4.c).

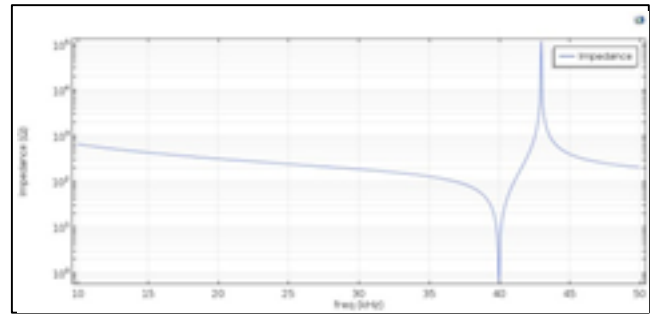


Fig. 5. The PZT piezoelectric ceramic plate impedance dependence by frequency

C. The simulation result to determine the displacement of the Langevin transducer [2], [1]

The results in Figure 6.c and Figure 7 show that the transducer displacement is maximum at 40 kHz frequency.

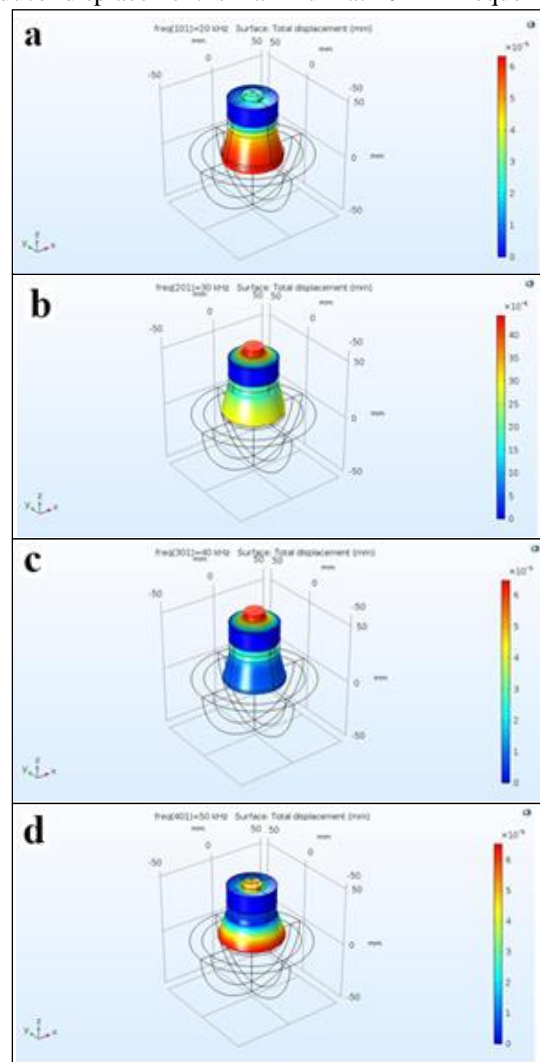


Fig. 6. The transducer displacement dependence by frequency

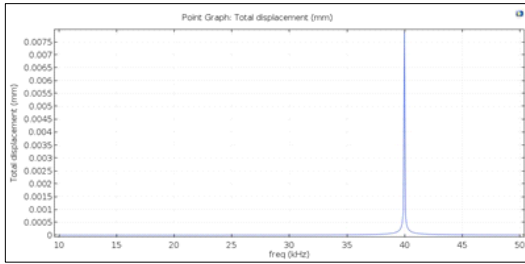


Fig. 7. The oscillation spectrum represents the transducer displacement by frequency

D. The survey result to determine the sound pressure field of the Langevin transducer front [1], [2]

Figure 8 is the simulation result of the emitted sound pressure field from the Langevin transducer front. The sound pressure field clearly shows the compression - expansion process, the spread of the ultrasonic wave to the frequency dependence environment. At the 40 kHz frequency, the sound pressure is maximum at the center and widened the boundary with the best orientation, Figure 8c.

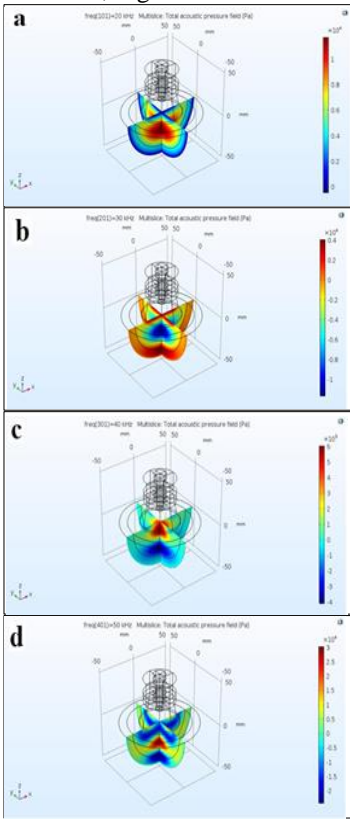


Fig. 8. The sound pressure field of the Langevin transducer front

CONCLUSION

By finite element method, we have established the continuous equations, kinetic equations, the elastic coefficient matrix, piezoelectric coefficient, dielectric constants of piezoelectric environment.

Using the COMSOL-Multiphysics program builds the model to survey the characteristic parameters of the PZT hard piezoelectric ceramic plate and the Langevin ultrasonic transducer.

The resonant frequency of the PZT hardened piezoelectric ceramic is determined at 40 kHz. At this frequency the displacement and the sound pressure field are maximum and the best orientability.

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