Excitation of Elliptical Trajectories in a Langevin Bending Type Transducer

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Abstract

Possibilities to employ bending type oscillations of the Langevin type piezoelectric transducer to drive slider are analyzed in the paper. Special aluminium plate with a drive tip is added in the middle of a typical half wavelength Langevin transducer. Piezoceramic rings with two directional polarization are used. Elliptical trajectory of the driving tip is excited when electric signal with shifted phase by π/2 is applied on different piezoceramic rings. Numerical and experimental investigation of the actuator was carried out to analyze natural shapes and harmonic response to the different excitation sets. Optimization of the aluminium plate design was carried out to maximize parameters of the elliptical motion of drive tip. The results of numerical and experimental study are discussed.

Key words: Langevin transducer, bending type piezoelectric actuator.

1. Introduction

Langevin type piezoelectric transducers are widely used for different applications such as precision positioning devices, micromanipulation systems, robotic systems and etc [1, 2]. Langevin transducers have several attractive features such as high mechanical quality factor, low impedance, good clamping possibilities [3, 4]. A typical design of the piezoelectric Langevin transducer consists of a piezoceramic stack and two metal blocks that are clamped by means of a pre-stressed bolt [5]. Usually Langevin transducer operates in longitudinal vibration mode and transfer vibration energy to some mechanical structure. Large vibration amplitudes and high output power can be achieved when transducer operates in longitudinal mode [6]. The goal of this paper is to investigate bending type oscillations of the half wavelength Langevin transducer and to employ them for elliptical trajectories formation of the driving tip. Design of typical Langevin transducer was modified for this purpose. Numerical modeling and experimental study were carried out to validate a new design concept and operating principle of the actuator. Finally, the results of numerical simulation and experimental study are analyzed and discussed.

2. Design concept

Design of a bending type transducer was started from typical half wavelength Langevin transducer that consists of the two steel cylinders, piezoceramic rings and bolt [7]. Special intermediate aluminium plate with a driving tip was added in the middle of the transducer between piezoceramic rings. Schematic Langevin transducer is shown in Fig. 1. Eight piezoceramic rings with two directional polarizations are used to excite bending type oscillations. Polarization of piezoceramic is oriented along thickness of the rings and has opposite directions on different sectors. Electrodes of the piezoceramic rings are divided into two equal sectors and correspond to the different polarization areas. Electric signal with shifted phase by π/2 is applied on different piezoceramic rings (Fig. 1). Elliptical trajectory of the drive tip motion is achieved by combining oscillations of the first bending mode of Langevin transducer and first bending mode of aluminum plate. Direct and reverse elliptical motion of the drive tip movement is controlled by changing phases of electric signal on the different ring sets.

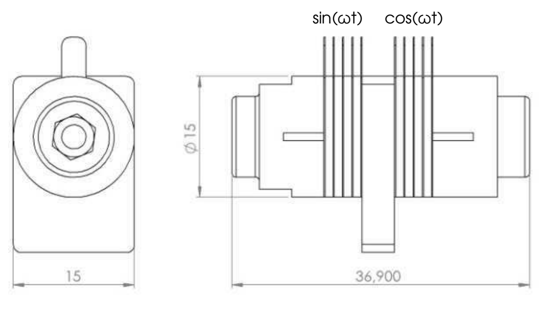


Fig. 1: Principle scheme of bending type Langevin transducer

3. Numerical Modeling and Results

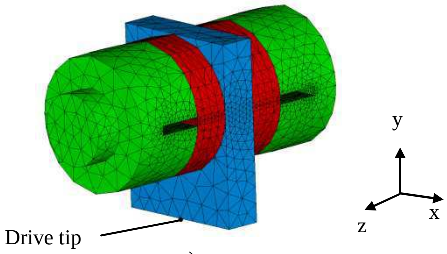
Finite element modeling was used to perform modal frequency and harmonic response analysis to calculate trajectories of the drive tip and to find optimal length of the aluminium plate. Basic dynamic equation of the piezoelectric actuator are derived from the principle of minimum potential energy by means of variational functionals and can be written as follows [8]:

$$\left.\begin{aligned}\mathbf{M}\ddot{\mathbf{u}}+\mathbf{C}\dot{\mathbf{u}}+\mathbf{K}\mathbf{u}+\mathbf{T}\boldsymbol{\varphi}=\mathbf{F}\\ \mathbf{T}^{\mathbf{T}}\mathbf{u}-\mathbf{S}\boldsymbol{\varphi}=\mathbf{Q}\end{aligned}\right\} \quad (1)$$

where M, K, T, S, C are matrices of mass, stiffness, electroelasticity, capacity and damping respectively; u, φ,

DOI: http://dx.doi.org/10.2314/IWPMA_57

F, Q are respectively vectors of nodes displacements, potentials, external mechanical forces and charges coupled on the electrodes. Displacements of the contact point can be found by solving eq.(1) when different excitation voltage is applied. Numerical simulation of the actuator piezoelectric motor was carried out by employing FEM software Ansys. Finite element model of the actuator was built (Fig. 2a). It contains all assembling parts mentioned in previous section. PZT-8 piezoceramic was used for modeling rings and steel X20Cr13 was used for modeling cylinders and bolt. Height of the aluminium plate initially was set to 20.0 mm. No mechanical boundary conditions were applied in the model. Modal shape with dominated first bending mode of the transducer was determined at 39.25 kHz (Fig. 2b).



a)

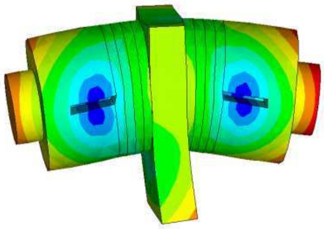

b)

Fig. 2: FEM model (a) and modal shape (b) of the bending type Langevin transducer at 39.25 kHz.

Harmonic response analysis was performed with the aims to find resonance frequency and to calculate trajectories of drive tip movement. 100V AC signal was applied on electrodes as shown in Fig.1. A frequency range from 35 kHz to 41 kHz with a solution at 0.5 kHz intervals was chosen to give an adequate response curve of contacting point. Suitable resonance frequency was found at 36.0 kHz and trajectory of drive tip was calculated (Fig. 3). Height optimization of aluminum plate has been performed to increase amplitude of contact point vibrations. Optimization problem can be written as follows:

$$\begin{cases} U_{cont}(h_{plate}) \Rightarrow \max \\ h_{\min} < h_{plate} < h_{\max} \\ \omega_{\min} < \omega < \omega_{\max} \end{cases} \quad (2)$$

where U_{cont} is drive tip oscillation amplitude, h_{plate} is height of the aluminium plate, l_{min}, l_{max} is lower and upper limits of the cylinder length, ω is operating frequency of the transducer, ω_{min} and ω_{max} is lower and upper limits of the frequency. Close to the optimal length of the plate can be calculated by equating formulas of resonance frequencies of the plate and Langevin transducer, but in this case we meet with the problem of evaluating irregular design of the transducer. Therefore parametric sweep harmonic response analysis was performed to solve optimization problem. The same frequency range 35-41 kHz was chosen for investigation. Height of the aluminium plate varied from 18.0 mm till 23.0 mm. Optimal height was found and at 21.85 mm while resonant frequency was 37.91 kHz. Elliptical trajectories of drive tip are presented in Fig.3, when initial and optimized heights are used. It can be noticed that major axis of elliptical trajectory has been increased 4.76 times i.e. from 1.09 µm till 5.19 µm.

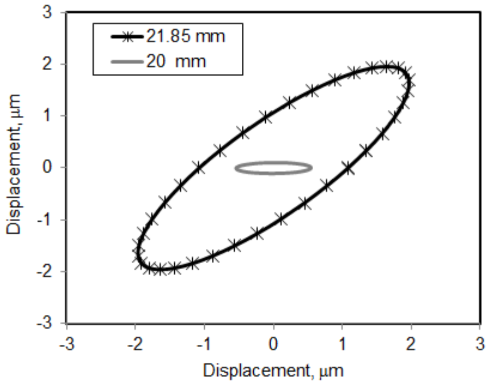


Fig. 3: Trajectories of drive tip movement in yz plane when different height of the plate is used

Based on results of simulation it can be concluded that excitation frequency at 37.91 kHz should be used as operating frequency of the Langevin transducer with plate length equal to 21.85 mm.

4. Experimental investigation

Prototype of the bending type Langevin transducer was made for experimental investigation (Fig. 4). The goal of experiment was to validate design and operating principle of the transducer and to verify results of numerical modelling.

Fig. 4: Prototype of the bending type Langevin transducer

Amplitude-frequency characteristic of the actuator were measured with the help of the impedance analyzer 4192A LF (Hewlett Packard). Results of the measurement are given in Fig. 5 when height of the aluminium plate is 21.85 mm. Two lines show impedance measurement results on two different electrode sets in Fig. 5. It can be indicated that resonance frequency is obtained at 36.1 kHz and difference between measured and calculated resonant frequency is 4.7%. Oscillation amplitudes of the drive tip were measured in *y* direction using POLYTEC vibrometer. Measurements were done using excitation scheme of electrodes as shown in Fig. 1. Results of measurements are given in Fig. 6. Difference between drive point oscillation amplitudes obtained in numerical modelling and measured during experiment is 5-8%.

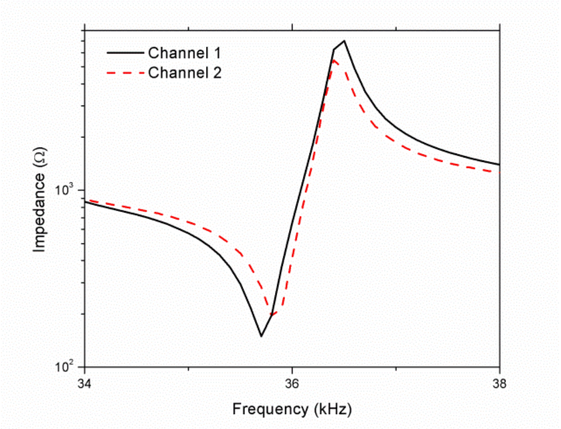


Fig. 5: Measured impedance of the transducer versus frequency

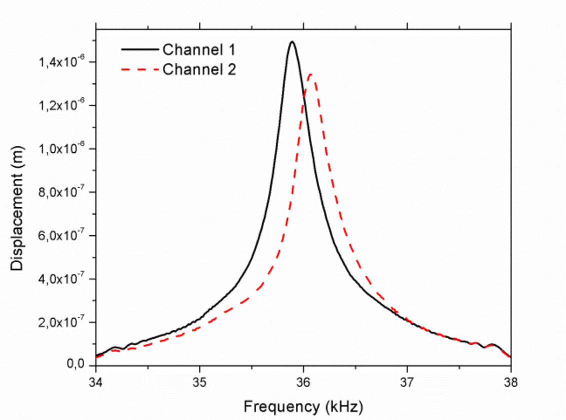


Fig. 6: Measured vibration amplitudes of the drive tip versus frequency

5. Conclusions

Bending type Langevin piezoelectric transducer was developed and investigated. Optimal length of the aluminium plate was found to achieve maximal oscillation amplitudes of the drive tip. The major axis of elliptical trajectory has been increased 4.76 times. Numerical and experimental study confirms that elliptical trajectories can be obtained using proposed design of bending type Langevin piezoelectric transducer.

Acknowledgement

This work was supported by the 111 project (Grant no. B12021), Research Council of Lithuania under projects No. MIP-12256 and European Social Fund under the project "Microsensors, microactuators and controllers for mechatronic systems (Go-Smart)", agreement No. VP1-3.1-ŠMM-08-K-01-015.

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