Experimental investigation of dynamics of linear piezoelectric actuator

R. Bansevičius, A. Bubulis, V. Jurėnas, K. Juzėnas

Kaunas University of Technology

Kęstučio 27, 44025, Kaunas, Lithuania, Phone: +370 37 300417, Fax: +370 37 323769, E-mail: kat0708@ktu.lt

Abstract

This paper deals with a linear ultrasonic motor characterized by a large displacement. Characteristics of this piezoelectric actuator were investigated experimentally. An experimental setup and conditions of experiments are presented. It was determined that reversion of such actuator may cause deviations in positioning of actuator's slider.

Key words: piezoelectric actuator, mechatronic system, dynamics

Introduction

Piezoelectric actuators of very simple design, such as ultrasonic motors, can generate a large output power. A direct drive and holding forces allows designing of smart systems that have no reducers and no brake mechanisms.

Recently piezoactuators are widely used in precise mechatronic devices, especially in cases when high resolution devices are designed. Applications of various designs of piezoactuators (linear drives, rotary drives, complex motion actuators) cover precision mechanisms and other specific applications [1, 2]. Motion generation is based on principles of oblique impact, propagating waves, friction anisotropy and other.

Naturally, piezoelectric actuators also have some limitations. Solid state constructions of such devices have many advantages comparing with conventional electromagnetic motors, but are sensitive to heat, have a relatively low efficiency, discontinuous motion, short operating life, instability of mechanical contact and suffer from fragility of piezoelectric ceramics.

Design of piezoactuators

Generally, there are three approaches to design a linear ultrasonic motor. In the first one, travelling wave mode motors use two power inputs with $\pi/2$ phase difference. This approach has been extensively exploited in rotary ultrasonic motors, but the travelling wave method has been rarely used in design of linear ultrasonic motors because of a complicated mechanical design and low efficiency. Standing wave motors generate a driving force from the elliptic vibration of surface points and a normal force component. They usually generate a large thrust force and their electrical excitation systems may be very simple, however the mechanical structure might be complex with a bi-directional motion. The third approach uses combination of vibration modes (such as longitudinal and bending vibrations) to produce an elliptical motion. Usually, in such designs, a rectangular plate vibrator of a sophisticated design is used to superimpose two resonant vibrations to produce the elliptical motion. Still, all actuators, the design of which is based on those three methods, have some disadvantages.

Recently new piezoelectric actuators of non-harmonic periodic vibrations are presented [3]. They can be designed

very small, have high resolution and simple control systems.

Although piezoactuators are widely used for various applications for a quite long time, development of new actuators still is a complicated scientific problem and needs analytical and experimental investigations.

Setup of experiments

We shall analyse a piezoelectric actuator of linear motion, designed for positioning of optical elements. It consists of a piezoceramic plate housed in special frame and a slider. Optical elements of a laser measurement or other precise systems like mirrors, lenses, etc., can be mounted on the slider. A rectangular piezoceramic plate is used. In our case electrodes of the piezoceramic element are divided into two sectors. It has two elastic supports and is mounted into a frame by contact areas (Fig. 1).

An experimental setup was composed of a personal computer, data acquisition device and inductive displacement sensor (Fig. 1).
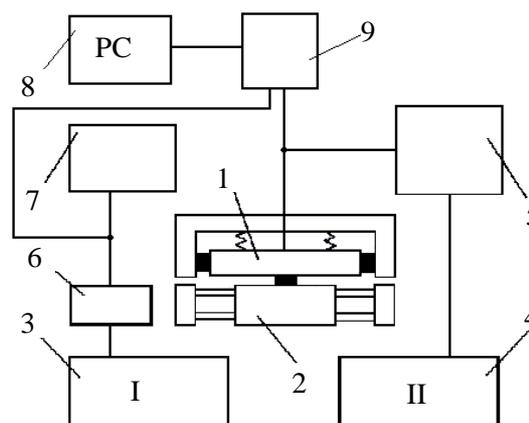

Fig.1. **Experimental setup 1 – piezoelement, 2 – slider, 3 – power supply I, 4 – power supply II, 5 – high frequency generator, 6 – inductive displacement sensor, 7 – multimeter, 8 – computer, 9 – oscilloscope**

The piezoelement is oscillating and pushes the slider of the actuator according to a certain law of motion at a certain distance. The size of this one motion step depends on several parameters:

1. Duration of the excitation impulse. Changes of the duration of the excitation signal are followed by changes of the piezoactuator motion.

2. Voltage of excitation. The higher voltage gives a higher amplitude of the impulse that is followed by a larger elongation of the excited piezoelement. That means that discretion of the actuator rises.

3. Resonance frequency of the piezoelement. The range of resonant frequencies is very narrow and demands fine tuning of hardware settings. In the presented case, the resonant frequency is 130 kHz.
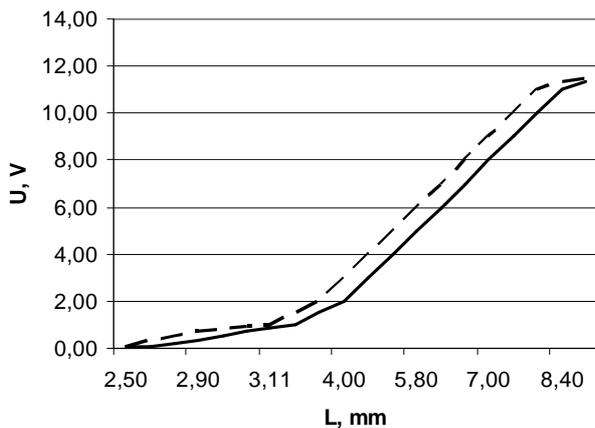

Fig.2. **Displacement of actuator. Here the solid line shows the data obtained with the load of 1 kg and the dashed line shows data obtained with the load of 2 kg**

Festo Didactic E102 inductive displacement sensor and etalon measurement plates were used to determine the exact distance between the sensor and the slider of the piezoelectric actuator and for measurement of displacements. Motion of the actuator without a load mass was analysed in the first stage of experiments. Motion of the actuator, loaded with 0.1 and 1 kg mass was analysed later. Values of the monitored parameters remained almost unchanged for those loads. The results of those measurements are presented in Fig. 2.
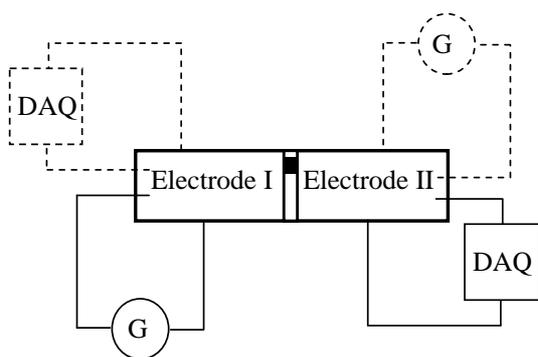

Fig.3. **Measurement of characteristics of piezoceramic element. Here G – high frequency generator, DAQ – data acquisition device**

The inductive sensor, used in our experiments, is not very sensitive, therefore a longer piezoelement excitation signal was chosen. Such a duration of excitation gave a displacement of the slider $\Delta l = 1$ mm.

The same experiments were repeated with loading masses equal to 2 kg (dashed line in Fig. 2) and 5 kg. In case of the 5 kg static load, operation of the actuator

became very unstable, slipping of the piezoelement contact pair started and the actuator could not perform well.

It was determined experimentally that the actuator can perform well while a static load is lower than 1 kg (that satisfies requirements for this actuator because most of optical elements have a relatively small mass). An acceptable precision of motion and positioning can be achieved for such loads. Increase of a static load is followed by increase of positioning errors caused by rise of friction forces in the slider's mechanism.

If a very precise motion (steps with precision of nanometres) should be achieved, a very precise power supply and other devices are needed. Quality of a piezoelectric material as well as precision and other parameters of a mechanical subsystem of the actuator are important limiting factors too. Therefore oscillations of the piezoceramic element and excitation signals were analysed in the second stage of the experiment. The basic scheme of those experiments is presented in Fig. 3.

Excitation signals were measured connecting an oscilloscope to the excitation circuit of the actuator's piezoelement. Oscillations of the piezoceramic plate caused by the exited part of the element were measured connecting the oscilloscope to the electrodes of not powered part of the piezoceramic element. The experiments were repeated for the first and the second sides of the piezoceramic element.

The shortest excitation signal is presented in Fig. 4. The period of this signal $T = 8.5$ µs and the duration of whole package is 125 µs. It was the shortest signal which could be generated by the high frequency generator used in the experiments.

Oscillations of not powered side of the element, while the first side was excited by the shortest signal of excitation, are presented in Fig. 5.

The same measurements were repeated exciting the piezoceramic element by signals of different length. Results of such measurements for the signal of duration equal to 2.7 ms are presented in Figs. 6 and 7.

Analysing the results of measurements it can be noted, that there are differences between the signal read from the powered and not powered part of the piezoceramic element (for all durations of excitation signals). That indicates some differences of properties of those parts. In applications, when very precise reversing of actuator's motion is needed, that can cause some deviations of sliders positioning and should be taken into account.

There are several possible characteristics that may differ for different parts of the same piezoelement. First of all, the electrodes of the element were divided into not equal parts. Usual precision of such dividing is acceptable for many applications, but it is evident that it should be improved when piezoceramic elements are manufactured for very precise mechanisms like in this case. Also there can be some defects in an internal structure of the ceramic element That is why responses of different parts of the same element differ.

Another group of problematic points is elements of a mechanical subsystem. There can be some differences in properties of elastic supports, some differences in properties of contacts between the piezoceramic element and the frame of actuator and so on.
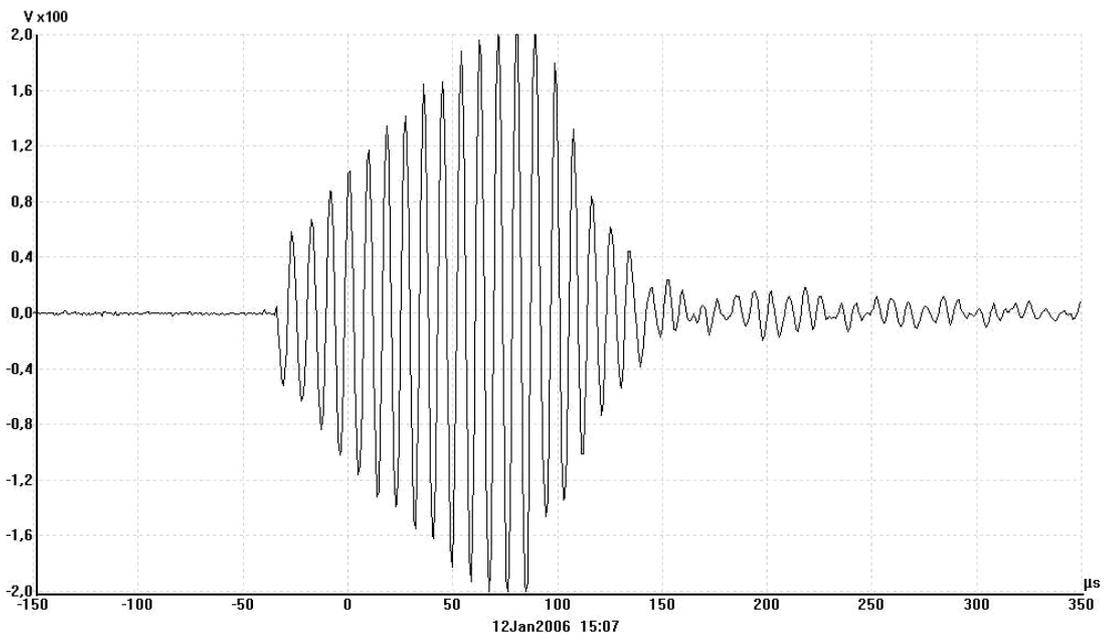
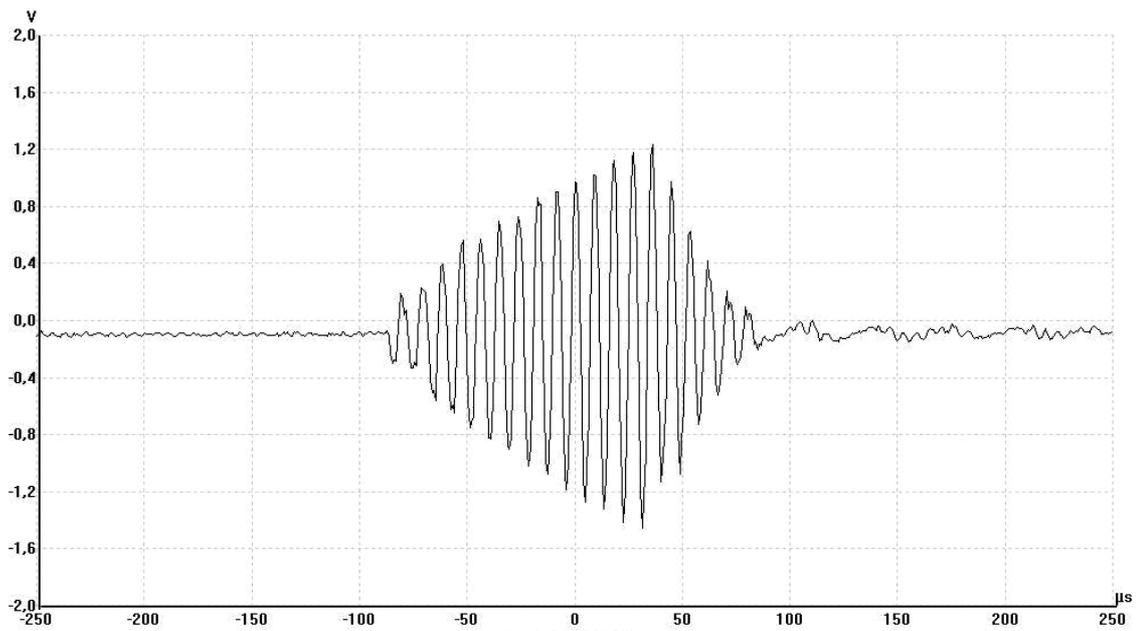Fig.4. **The shortest signal of excitation**

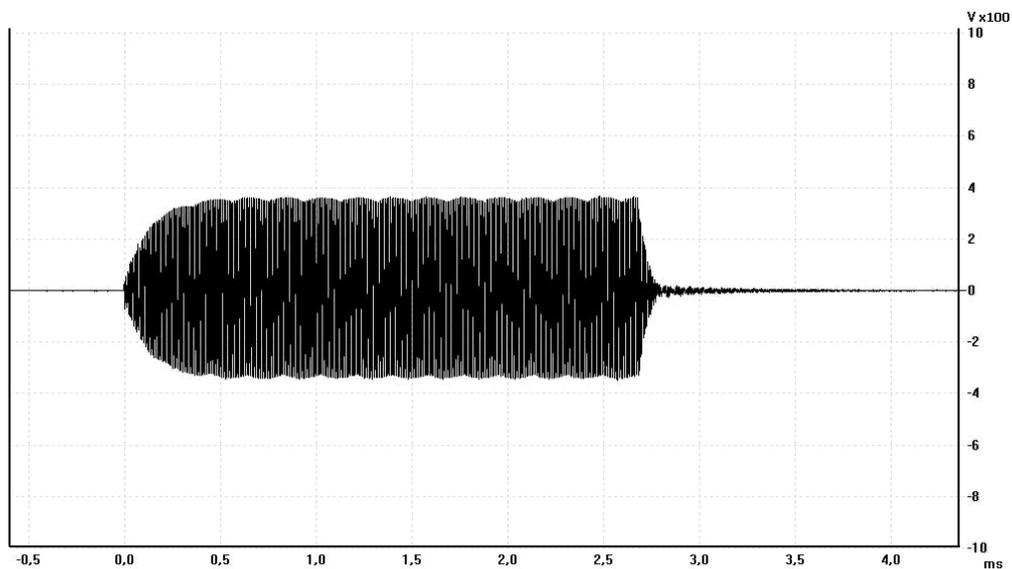Fig.5. **Oscillations of piezoceramic element excited by the shortest signal of excitation**
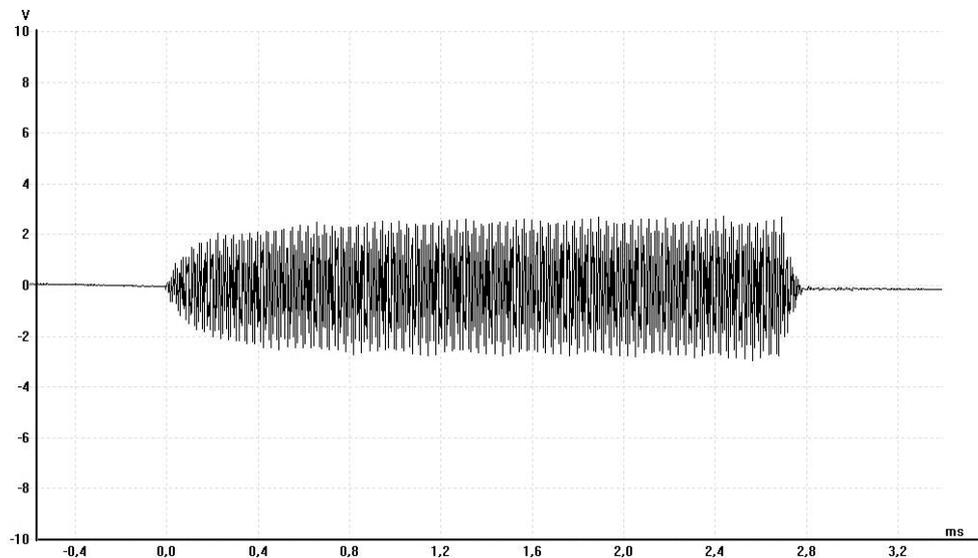
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Fig.6. **2.7 ms signal of excitation**

Fig.7. **Oscillations of piezoceramic element excited by 2.7 ms signal of excitation**

Conclusions

This investigation showed that design of reliable high precision ultrasonic actuators is followed by several problems. In some cases, achievement of a desirable precision of an actuator operation, especially when direction of the actuator's motion is reversed, can be complicated because of differences of active element's internal properties and lack of precision during actuator's manufacturing process.

It can be suggested that additional experiments should be performed for high precision actuators and the discovered problems should be eliminated by tuning actuator's excitation system or by mechanical maintenance.

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Linijinės pjezoelektrinės pavaros dinamikos eksperimentinis tyrimas

Reziumė

Aprašomas linijinis pjezoelektrinis didelės eigos variklis. Šios konstrukcijos charakteristikos buvo tiriamos eksperimentiškai. Yra aprašytas eksperimentinis stendas ir bandymų sąlygos. Nustatyta, kad reversuojant tokią pavarą gali būti gaunamas nepakankamas pozicionavimo tikslumas.