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EXPERIMENTAL IDENTIFICATION OF PIEZO ACTUATOR CHARACTERISTIC

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This paper deals with piezoelectric material, which can be used as actuator for conversion of electrical energy to mechanical work. Test equipment has been developed for experimental testing of the piezoactuators. Piezoactivity of this actuator has non-linear characteristic. This type of actuator is used for in-pipe mechanism design.

Key words: piezoelectric, actuator, step response, measurement

INTRODUCTION

The first demonstration of the direct piezoelectric effect was in 1880 by the brothers Pierre Curie and Jacques Curie. They combined their knowledge of pyroelectricity with their understanding of the underlying crystal structures that gave rise to pyroelectricity to predict crystal behavior, and demonstrated the effect using crystals of tourmaline, quartz, topaz, cane sugar, and Rochelle salt (sodium potassium tartrate tetrahydrate). Quartz and Rochelle salt exhibited the most piezoelectricity.

The Curies, however, did not predict the converse piezoelectric effect. The converse effect was mathematically deduced from fundamental thermodynamic principles by Gabriel Lippmann in 1881. The Curies immediately confirmed the existence of the converse effect, and went on to obtain quantitative proof of the complete reversibility of electro-elasto-mechanical deformations in piezoelectric crystals.

The piezoelectric effect is understood as the linear electromechanical interaction between the mechanical and the electrical state in crystalline materials with no inversion symmetry. The piezoelectric effect is a reversible process in that materials exhibiting the direct piezoelectric effect (the internal generation of electrical charge resulting from an applied mechanical force) also exhibit the reverse piezoelectric effect (the internal generation of a mechanical strain resulting from an applied electrical field) (Figure 1). For example, lead zirconate titanate crystals will generate measurable piezoelectricity when their static structure is deformed by about 0,1 % of the original dimension. Conversely, the same crystals will change about 0,1 % of their static dimension when an external electric field is applied to the material.

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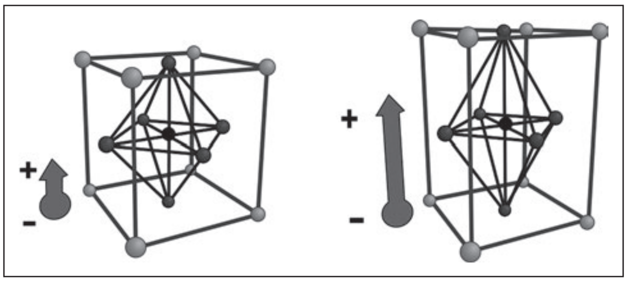

Figure 1 Working principle of piezoelectric actuator

The inverse piezoelectric effect is used in production of ultrasonic sound waves or it can be used as piezoactuator. The most commonly used piezoelectric ceramic is lead zirconate titanate ($PbZrO_3$-$PbTiO_3$ or PZT) but also other ceramic materials, such as barium titanate, exhibit the effect.

Piezoelectricity is found in useful applications such as the production and detection of sound, generation of high voltages, electronic frequency generation, microbalances, and ultrafine focusing of optical assemblies. It is also the basis of a number of scientific instrumental techniques with atomic resolution, the scanning probe microscopies such as STM, AFM, MTA, SNOM, etc., and everyday uses such as acting as the ignition source for cigarette lighters and push-start propane barbecues [1-5].

MATERIALS WITH PIEZOACTIVITY

Many materials, both natural (quartz, berlinite ($AlPO_4$), Sucrose, Rochelle salt, Topaz, Tourmaline-group minerals) and synthetic (Barium titanate ($BaTiO_3$), Lead titanate (PbTiO3), Lead zirconate titanate ($PbZrTiO_3$) more commonly known as PZT), exhibit piezoelectricity.

More recently, there is growing concern regarding the toxicity in lead-containing devices driven by the result of restriction of hazardous substances directive regulations. To address this concern, there has been a resurgence in the compositional development of lead-free piezoelectric materials (Sodium potassium niobate ($(K,Na)NbO_3$) also known as NKN, Bismuth ferrite ($BiFeO_3$), Sodium niobate $NaNbO_3$) etc.

Polyvinylidene fluoride (PVDF): PVDF exhibits piezoelectricity several times greater than quartz. Unlike ceramics, where the crystal structure of the material creates the piezoelectric effect, in polymers the intertwined long-chain molecules attract and repel each other when an electric field is applied [3, 6].

PIEZOELECTRIC ACTUATORS

The most commonly used piezoelectric actuators are in two possible types as “stack” also known as “piezostacks” or “bender” also known as “piezobender”.

The piezoactivity can be described in simplified form as:

$$\Delta l = d_{33} \cdot U \tag{1}$$

where Δl is deformation (or actuator stroke); d_{33} is piezoelectric strain constant and U is applied electric voltage. Consequently, the deformation does not depend on dimension of piezomaterial.

The piezoelectric strain is generally very small (approx. 10^{-9} m/V). This significant problem can be solved via using of piezostack. The piezostack is composed of many thin piezo layers, which together produce a higher stroke [7, 8].

Overal stroke of piezostack can be expressed as:

$$\Delta l = n \cdot d_{33} \cdot U \tag{2}$$

where n is number of piezoelectric layers in piezostack.

Blocked force can be derived in form:

$$F = \frac{\Delta l \cdot A}{n \cdot t \cdot S_{33}^{E}} \tag{3}$$

where Δl is deformation (or actuator stroke); S_{33}^{E} is elastic constant (m^2/N), t is thickness of layers, n is number of piezo layers and F is blocked force (N).

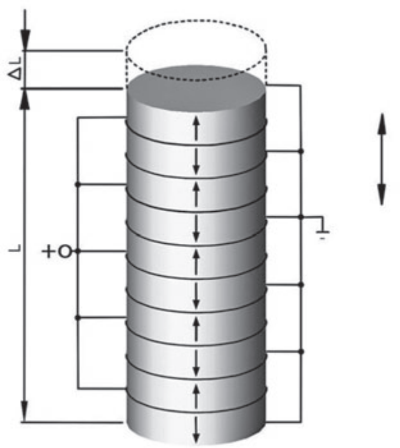

Figure 2 Piezostack structure [8]

TEST EQUIPMENT FOR PIEZO ACTUATORS

The piezostack actuator has been tested in this work. Test equipment for this testing has been developed (Figure 3). The piezostack acts mainly like an expanding element “pusher” generating a compressive force. Loading of the piezostack has been through the set of etalon weights. Loading frame has been used for this purpose. Piezoactivity has been measured through the dial indicator.

Excitation of the piezostack has been realized via using of microcontroller and the overall activation and deactivation process was automatic for obtaining of the stabile measurement conditions.

Measured characteristic (Figure 4) shows nearly linear characteristic as it is defined in math model, but polynomial function is a better model. Also hysteresis for this characteristic is the typical property of this material.

Measured piezostack characteristic projected in 3D graph (Figure 5) shows that maximum stroke of actuator was 19,5 μm. Maximum blocked force was 150 N, but maximum testing load was only 60 N, which causes decrease of stroke to value of 5 μm.

The tested piezostack is able to operate in non-resonant cycling (< 1 kHz) with maximum strain and non-resonant cycling (< 10 kHz) with reduced strain.

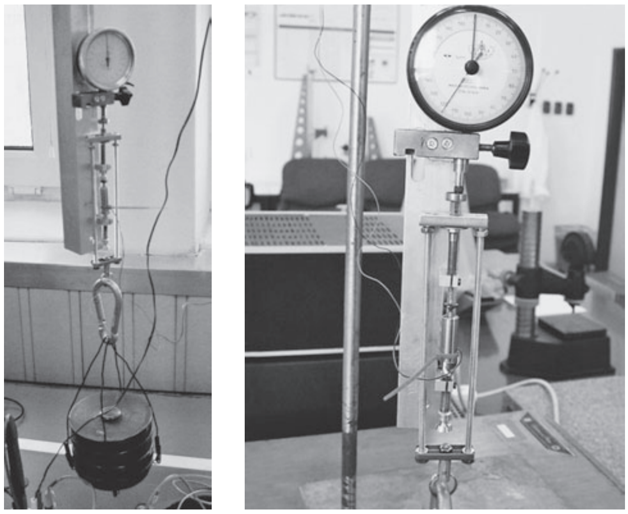

Figure 3 Test equipment for piezoelectric actuators

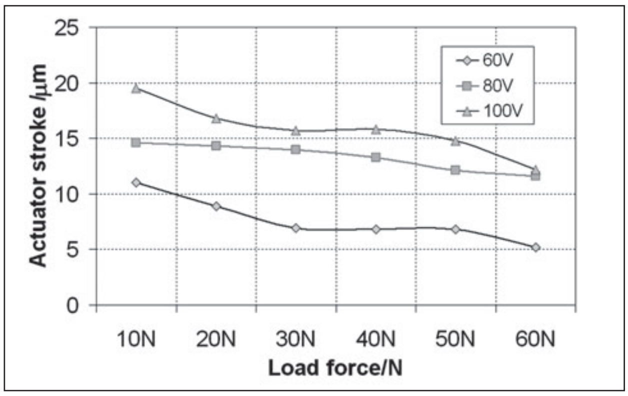

Figure 4 Measured characteristic of piezostack for different excitation voltages

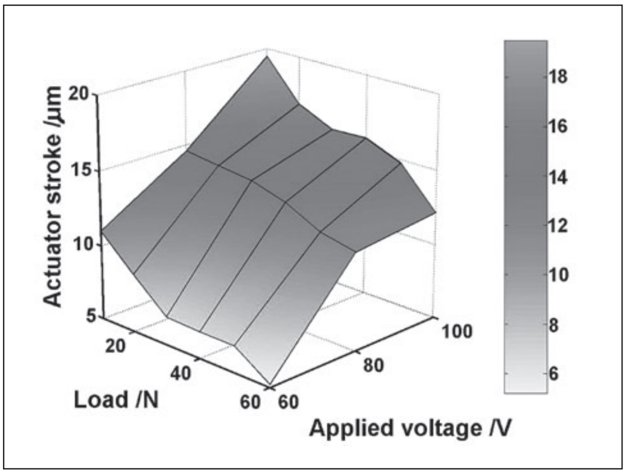

Figure 5 Measured characteristic of piezostack

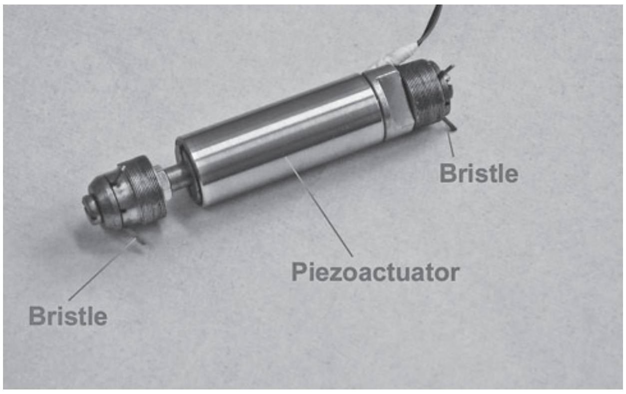

Figure 6 In-pipe robot with piezoactuator

In-pipe robot (Figure 6) with piezoactuator is one of our applications of this actuator. The in-pipe robot locomotes via using of periodical excitation of piezoactuator. It uses friction difference between the bristle tips and inner pipe wall. The in-pipe robot can operate inside the pipe with inner diameter 11 mm.

CONCLUSION

The displacement of piezoactuators is very low. For many applications it is necessary to increase it via using of mechanical amplifier as lever or arm. This amplified piezoactuators have a stroke approximately 10 times higher than basic piezostack structure. Also another composition is possible for many applications as Inchworm motor or ultrasonic motor for obtaining of high movement output. These structures can be used also for high precision nano positioning [7, 8].

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