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Ultrasonic motors for mass-consumer products

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Abstract

Some new approaches and experiments on active kinematic pairs, transforming resonant non-harmonic periodical vibrations into a continuous directional motion are presented. Uniqueness of a piezoelectric motor utilizing these approaches is that it can be made limited arbitrary cross-section size. Some examples of this type of the piezomotor are presented, allowing miniature on plane positioning systems and angular scanning systems to be created. Examples of multi-degree-of-freedom piezomotors application in mass-consumer products are shown by "smart" toy prototypes made from standard LEGO™ construction blocks and minifigure.
Keywords: piezoelectric motor, ultrasonic motor, piezomotor, impact drive mechanism, slip-stick motor

Introduction

Rapid application of mechatronics in industrial, medical, electronics and consumer markets, creates greater demand for a new generation of compact, simple, low cost, less power consuming and smart actuators with a nanometer resolution. Piezomotors can meet all the demands, because of their high power to weight ratio, no reduction gears, no electromagnetic noise, no backlash, scalability, simplicity and sensing capabilities. Up to date their main applications are for adjustment of optics in laboratories, mass-consumer photo and video cameras, with latest application in mobile phones, though given characteristics make them attractive for almost any positioning task. Piezomotors could be especially attractive for small toys and robotic systems, where conventional actuators would be unacceptable.

Non-harmonic vibration piezomotors

Non-harmonic vibration (inertial) piezomotors are particularly capable of miniaturization and actuation in limited spaces, because of their simple design (Fig. 1). There are a few commercialized and experimental inertial piezomotors, but all of them operate in a quasistatic mode. In order to increase efficiency of inertial piezomotors, we propose a resonant driving method. The suggested piezoceramic actuator makes non-harmonic (saw-tooth) vibration possible at the resonance by superimposing multiple vibration harmonics. From the Fourier transformations we know that the saw-tooth vibration can be comprised of multiple harmonics:

$$x(t)=\sum_{k=1}^{n}(-1)^{k+1}\frac{2}{k}\sin(k\omega t), \qquad (1)$$

where ω – the frequency of the first harmonic, n – the integer number.

To simplify the design, only two longitudinal modes (Fig. 2) were chosen for a rotational motor prototype (Fig.1).

The bulk piezoceramic actuator (Fig. 1) has two pairs of electrodes, which are excited by synchronized harmonic voltage signals at the first and the second resonant longitudinal modes. Motor's rotation is reversed by shifting the second signal 180 degrees relatively to the first one. Experiments made with 60x3x3mm sized piezoceramic, excited at 28 kHz and 56 kHz, proved its feasibility (Fig. 1b).

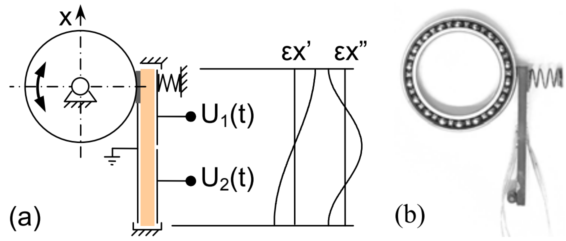

Fig. 1. **Inertial piezomotor's schematics (a) and prototype (b)**

In order to simplify the electrical circuit and to obtain the vibration shape as close to saw-tooth as possible, there is a possibility to drive the actuator by a single saw-tooth electrical signal, exciting all corresponding resonant frequencies of the actuator at the same time (Fig. 2b). However, there are difficulties at controlling amplitudes of the higher harmonics using this approach. The problem might be solved by varying the cross-section shape of an actuator, applying a constant voltage/strain at dedicated electrodes or by applying (removing) mass at vibration nodes of the actuator.

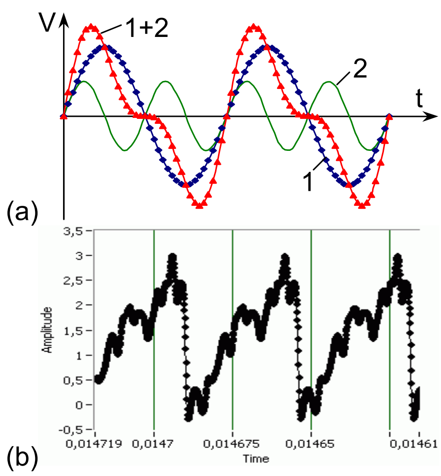

Fig.2. **Approximation of saw-tooth oscillations comprised of two harmonics (a); experimental response of the actuator driven by a single saw-tooth signal (b)**

Such actuator's main advantage is that it does not have strict dimensional and contact area constraints (only length of the actuator depends on the desired performance) and can be made limited in two dimensions (needle like). Other efficient characteristic of the actuator is that both its ends force the driven object in the same direction (Fig. 3). Due to the mentioned characteristics the actuator is most suitable for a high precision linear actuation, where a limited cross-section size of the actuator is a must.

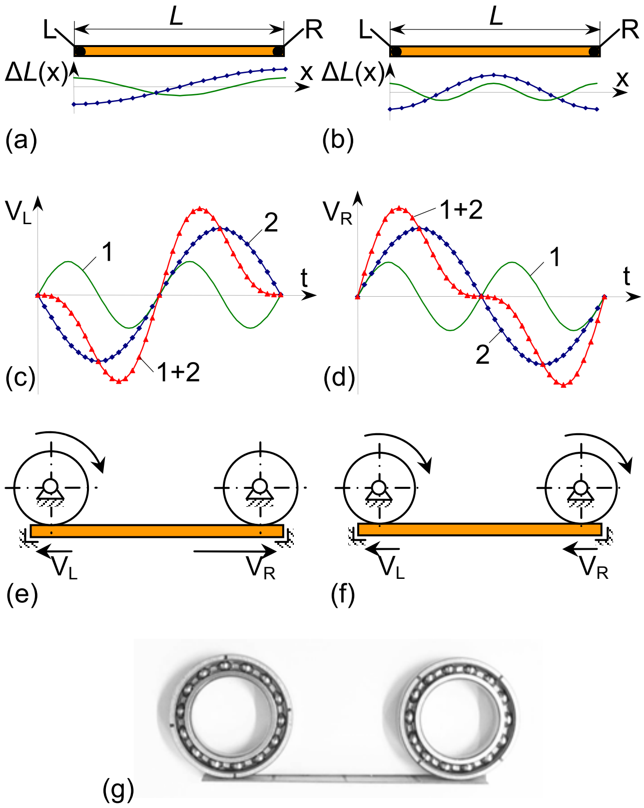

Fig.3. **Actuator's strains (a), speeds (c,d) and synchronization (e) with the first and the second longitudinal modes superimposed; strains (b), speeds (c) (same for "L" and "R") and synchronization (f) with the second and the fourth longitudinal modes superimposed; motor's prototype (g)**

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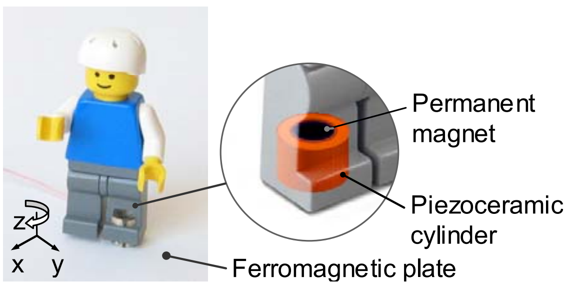

Fig. 4. **Prototype of the "smart" minifigure**

Multi-degree-of-freedom piezomotors application in "smart" toys is shown by a piezo-actuated LEGO™ construction block and minifigure prototypes (Fig. 4-6). As the first approach to creating a "smart" LEGO™ component, a problem of moving a standard LEGO™ minifigure on a passive plane has been chosen (Fig. 4). It was accomplished by mounting a tiny (6x5x6mm) (D x d x h) piezoceramic cylinder into a leg of the 38 millimeter tall figure. A permanent neodymium magnet has been placed inside the cylinder to ensure stability of the figure on a ferromagnetic plane. The electrical interface consists of a ground electrode on the outer surface of the cylinder and the inner electrode sectioned into 3 symmetrical parts (3x120°). The configuration of the electrodes enables generation of three component oscillations in the contact zone between the cylinder and the passive plane, leading to reversible rotation or desired displacement on the plane.

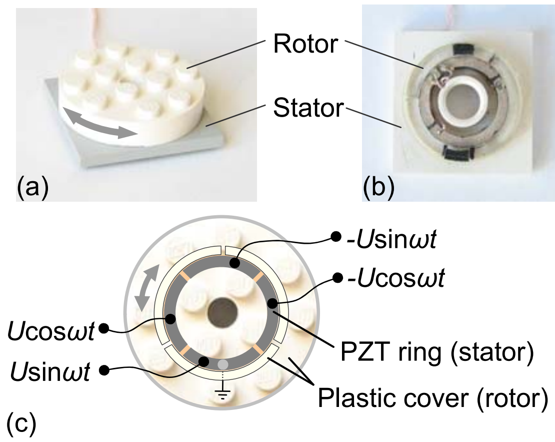

Fig.5. **Prototype (a) and schematic (b, c) of the rotational "smart" brick**

Two modifications of a standard LEGO™ brick have been developed and tested (Fig. 5, 6). In the first modification (Fig. 5) the passive brick is transformed to a rotational motor. Such a motor is made only of piezoceramic ring and two plastic components. Its operation is based on a traveling wave, excited in 20 x 15 x 3mm (D x d x h) piezoceramic ring by electrical signals with the 90° degree phase shift (Fig. 5b). Initial characteristics of the motor: are the following up to 300 RPM; ≈ 0.001 Nm torque, depending on the initial elastic force; 9V DC power supply; 18V-40V on the electrodes of piezoceramics.

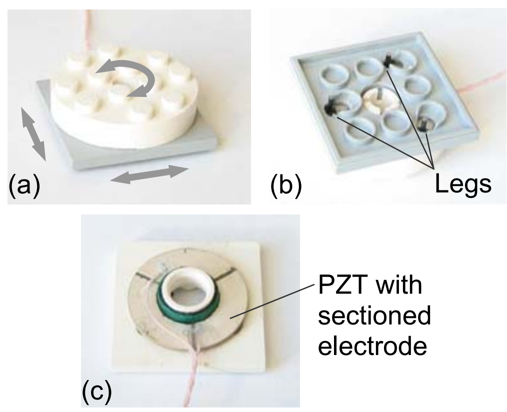

Fig.6. **Top (a), bottom (b) and setup (c) views of the three degree-of-freedom "smart" brick**

The second modification (Fig. 6) transforms the brick to the three degree-of-freedom positioning stage on a plane. The piezoceramic plate has three pins (Fig. 6b) (corresponding to three pairs of electrodes), ensuring stability and vibrations transfer to a plane. Such a design is made only of casing and piezoelement.

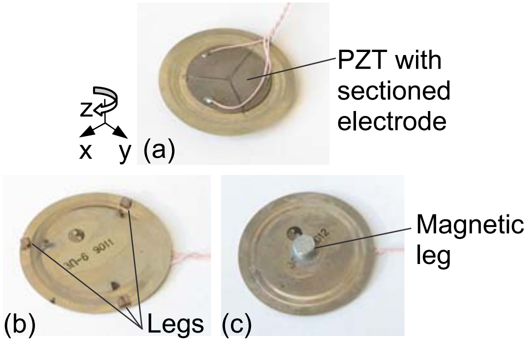

Fig.7. **Top (a) and bottom (b-c) views of the three degree-of-freedom simplified motor**

Also very simple designs of a three degree-of-freedom piezoelectric motors for translation/rotation on a passive planar surface have been investigated (Fig. 7). Motors were made from a standard tweeters, consisting of a thin brass metal disc <0.1mm (due to low hysteresis loss) with PZT disc applied on it. The electrical interface consisting of the sectioned electrode (3x120°) on a top of the PZT disc and ground electrode on the metal disc. Configuration and number of the electrodes enables oscillations that lead to a desired displacement on a plane. Rotation on the plane is produced when traveling wave oscillations are generated in the PZT disc. To exclude an acoustic noise, higher forms of oscillations were generated. The frequency of an electrical signal was in the range of 65-80 kHz, the voltage in 30-80V. Most experiments were carried out using 10mm diameter and 0.1mm thickness piezoelectric discs.

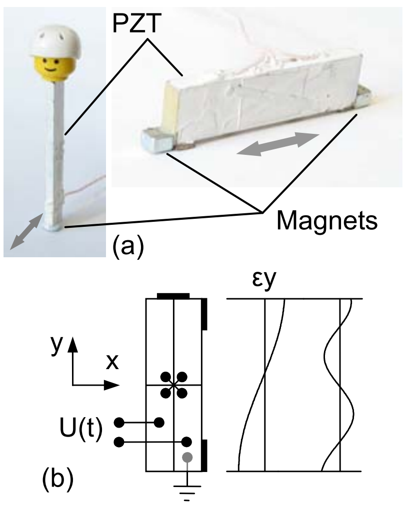

Fig.8. **Prototypes (a) and schematics (b) of the linear piezoelectric motor**

The concept of linear positioning on a plane is shown by a multilayer piezoceramic actuator, excited at the first longitudinal and the second bending modes (Fig. 8b) (frequency range 45-80 kHz), resulting in elliptical oblique impacts at the contact zones. Again, in order to ensure the stability of the piezoelectric actuator on a ferromagnetic plane, two neodymium magnets were attached to the ends of the actuator (Fig. 8a). This type of a piezoelectric motor could be used as a module to actuate any object, both in a toy industry and for more general applications in mini and micro-robotics. Velocity of the motion could easily reach the value of 0.8m/s, which practically covers velocity range required for all presently known applications.

Conclusions

Some new approaches on a resonant non-harmonic vibration excitation in a piezoceramic actuator were proposed. Their application has a potential of high resolution rotational and linear piezomotors performance improvement. Possibility of multi-degree-of-freedom piezomotors application in mass-consumer devices was shown by standard LEGO™ toys modification.

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Ultragarsiniai varikliai masinio vartojimo prekėms

Reziumė

Pristatomi nauji aktyvių kinematinių porų žadinimo būdai, kurie leidžia periodinius neharmoninius porų virpesius versti į kryptingą judesį. Šių būdų taikymo pjezovarikliuose pranašumas yra tas, kad tokie varikliai gali būti gaminami santykiškai labai mažo skerspjūvio ploto. Pateikiama pavyzdžių, kaip toks variklis leidžia kurti kompaktiškas daugelio laisvės laipsnių linijinio ir kampinio pozicionavimo sistemas, kaip daugelio laisvės laipsnių pjezovariklius galima taikyti masinio vartojimo gaminiams, tokiems kaip standartinės LEGO™ kaladėlės ir figūrėlės.

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