Study on Implementing of an Ultrasonic Motor in Robotics

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Abstract: - This paper aims the studying, modeling and testing of models of linear motors which use ultrasonic waves to achieve the movement. The studied motors are characterized by the positioning accuracy, small inertia, wide speed control (does not require gears and gearboxes), easy control, high torque per unit weight, miniaturization, simple structure, low noise, decreasing time-speed characteristic. Theme is nature trans-disciplinary work, addressing elements of the electrical machines and electronics, electrical materials, mechanics, waves, computer and numerical methods, modeling of electromechanical systems and not least the technical and scientific creativity.

Key-Words: - Ultrasonic motor, linear motor, positioning accuracy, robotics, mobile element, stator vibrations

1 Introduction

Piezoelectric effect was described in 1880 by Curie and wife and consists in the occurrence of polarized electric charges on the faces of crystalline materials when mechanical action exerted on them. The direct phenomenon is accompanied by the opposite phenomenon, deduced mathematically by Lippmann in 1881 based on fundamental principles of thermodynamics. This phenomenon consists in the generation of mechanical tension or movement when an electric field is applied to a piezoelectric material. If this is an alternating electric field, the material vibrates with a certain frequency and amplitude.

The first applications of piezoelectric effect have been ultrasonic detector for submarines (1917).

In the years 1920-1940 were developed frequency stabilizers and quartz crystal resonators.

Between 1940-1965 researchers from the U.S., Japan and the Soviet Union developed the piezoceramics from the barium titanate family and lead zirconate, obtaining materials whose dielectric constant is over 100 times greater than natural crystals. By doping the piezoceramics have been optimized their properties and have been made materials specific for each application.

The period 1965-1980 was dominated by Japanese research and development of piezoceramic products market.

Piezoelectric actuators and motors convert the electrical energy into mechanical energy through the reverse piezoelectric effect, falling within the category of actuators which have active elements with limited and controlled strain [1].

The advantages of the piezoelectric actuators and motors are:

- sub-micron positioning accuracy;
- quick time response of the microseconds order ;
- energy efficiency around 50%;
- extended range of the input electrical signals (1 mV to 1 kV);
- large forces;
- possibility of miniaturization and integration in terms of energy and information;
- clearly defined dependence between applied voltage and changing the length of the active elements, not being required the equipping with sensors and transducers;
- insensitive to the operating environment;
- silent in operation.

Among the disadvantages are: the fragility of the piezoelectric materials, wear and fatigue caused by operational shocks and the need to transform the high frequency vibrations into continuous or intermittent motion [1].

Linear or rotary piezoelectric actuators with continuous or step-by-step motion can have in their structure one or more active elements. They can take the form of bars, strips, tubes or plates. Their controlled deformation can be used to drive the mobile element. Also, the mobile element can be driven by a traveling-wave, the movement being taken over by contact or shape. In this case, the overlapping of several stationary waves generated through control, inside the active element arises a

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traveling-wave that causes an elliptical movement of the contact points with the mobile element. Deformation of active elements can be perpendicular or parallel to the polarization axis.

Because the piezoelectric deformations are relatively small, in the structure of actuators, the active elements are placed frequently in the following configurations:

- in stack – with elements glued at high temperature, having metallic electrodes deposited on the two opposite sides. The achieved force may thus reach 5 kN for frequency of 50 Hz and voltage between 100 and 300 V.
- bimorph – the active element is composed of two piezoelectric lamellas glued together and powered with tensions equal but of opposite sign. As a result, occurs the contraction of one of the lamellas and the other's extension, the entire assembly becoming curved. The displacement of the free end of the bimorphe elements enclosured is proportional to the voltage, to the size of the lamellas and to the material characteristics. The displacements are of order of millimeters but the forces are relatively low (0,5 N). The force may increase significantly if a metalic lamella is introduced between the piezoelectric lamellas. Also, a support placed at the middle of length of lamella causes a double force at the free end.

It is used less frequently the transversal mode of excitation of piezoelectric lamellas which determines a typical transversal contraction of 50 μm/kV.

Application of alternative voltage leads to variations in size of the active elements with the same frequency as of the applied voltage. Multiple regimes of vibration are possible, depending on the assembly form and the angle between the applied voltage direction and the polarization direction. Mechanical resonance occurs at a frequency determined by the size of the assembly. At this frequency, the deformation is amplified by a mechanical quality factor Q (which has values between 100 and 1000). This effect improves considerably the conversion efficiency of electrical energy into mechanical energy.

For the ultrasonic applications are used pretensioned active elements. These consist of two discs of piezoelectric material placed between two pretensioned metalic pieces (sandwich structure) to avoid the tensions in the piezoelectric material [3].

The rotary piezoelectric actuators with traveling-wave are based on a set of two overlapped piezoceramic discs, consisting of modules whose polarity alternates. By activating the two discs with alternative voltages shifted by 90°, in the stator assembly will appear a wave that is transmited in a certain direction. Overlapping over this assembly (stator) another disc (rotor), this will be driven in rotating in opposite direction to the propagation direction of the wave.

The principle of piezoelectric ultrasonic linear actuator with traveling-wave is presented in the following figure.

The mobile element is pressed onto the stator and driven through friction, the stator vibrations being transformed into a macroscopic motion of the mobile element. The points from the stator surface have an elliptical motion obtained by the overlapping of two orthogonal oscillations. These actuators develop forces up to 30 N under the conditions of a speed greater than 200 mm/s, for a frequency between 30 and 70 kHz (fig. 1).

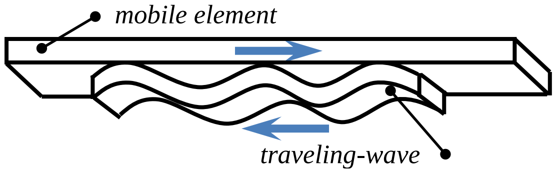

Fig. 1 [2]

2 The PiLine P-653.0D Actuator [4]

P-653 PiLine (Fig. 2) is an actuator with piezomotor dedicated to applications where space is limited and where are positioned pieces of small weight. These small linear positionings allow the replacing of some clasical actuators with rotary motors and systems for transforming of the motion from rotation to linear. The system is designed for moving small objects such as optical fibers, optical systems, micromechanical and electromechanical systems, with great speed and precision. The motor has a mounting system and is mounted on a board together with the electronic unit, the command being achieved through voltage signals of 5 Vdc.

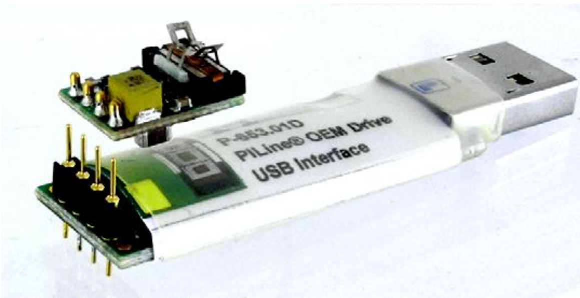

Fig. 2. P-653 PiLine [4]

The slider is used as mounting interface for the moved element.

Electronic control system has a digital control interface. Input signals are short pulses of voltage,

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the movement being dependent on the duration and frequency of these pulses.

The moved element is fixed only on the mounting system of the cursor. P-653.01 produces a 0,15 to 0,4 W thermal dissipation in operation, heat that must be dissipated. Although theoretically a piezomotor is silent, operational noise may occur.

The USB interface receives commands from the software installed on the PC and converts them into control signals for the electronics of the driving motor. It also provides 5 Vdc supply voltage for the electronic unit.

The control signals for moving left and right are short voltage pulses (5 V), the displacement being dependent on the duration and frequency of these impulses. The electronic unit converts these voltage controled signals into alternative current with ultrasonic frequency, which produces the oscillations of the actuator.

The software offers several options for controlling piezoelectric motor movement. To familiarize the parameters can be changed to see the effects of changing. Current parameters are displayed in bottom half of the window.

To see a brief description of the fields will hover over the zone of interest of the control element. Electronic unit connected to the PC can be software controlled through a COM port. This COM port can be identified in the Device Manager menu of the PC (Start – Settings – Control Panel – System – Hardware – Device Manager).

Mechanical properties: the braking force at the supply interruption 0,3 N; the tractive force 0,15 N.

Control: the resonance frequency of the piezoelectric system 515 kHz; the type of the piezoelectric motor – PiLine P-653; the voltage of the electronic system 5V; current consumption 0,1A; the control voltage of the piezoelectric device 5V TTL.

Very compact, the integrated piezomotor can generate speeds up to 200 mm/s, has a high-resolution positioning and a high force. Design ensures a great force when the device is idle, resulting a high stability of positioning, without the heat dissipation, as happens at the conventional motors. In operation, the oscilant piezoceramic elements propels the cursor as long as they are supplied. No need mechanical elements or control systems to obtain the parameters listed above.

High-frequency oscillations of the order of nanometers (~ 500 kHz), of which the piezoelectric motor needs are created by the electronic system, which self-adjusts the output frequency depending on the resonance frequency of the ceramic motor. The electronic system is controlled by short pulses of voltage. Integration of the motor into an application is simple due to the system architecture. Electronic unit is included on the same board with the motor and requires a supply voltage of 5 Vdc. The motors are designed to move quickly and accurate small objects such as optical fibers, optical or micro-electro-mechanical systems.

At each oscillation cycle the mechanical part runs a step of nanometers order that leads to a macroscopic result as smooth motion, with virtually unlimited field. The driving force is taken from the longitudinal oscillation component. The transverse component is used to increase/decrease the friction force with the mobile part. The transverse oscillation energy determines the maximum friction force and therefore the shutdown force and the operating force of the system. Normally the ultrasonic motors can produce accelerations up to 20g and speeds up to 800 mm/s. The force generated by these motors made a great step forward. Motors with a single active element can produce forces up to 50 N [4].

The ultrasonic motors used for linear displacement can not provide unlimited resolution. The system of displacements achievement using the friction can do movements with a satisfactory repeatability if the resolution is up to 50 nm.

3 Presentation of the Experiment

To evaluate the performances of the ultrasonic linear motor in open loop configuration was made a stand that amplifies its small displacements. The experimental stand is based on an optical system (Fig. 3) meant to amplify the linear motor motion, used by placing a light source onto its cursor. The following figure presents the principle scheme of the experimental stand and the forming of the optical image. The optical source is a miniatural LED supplied from the source of the electronic driver. This moves into the domain given by the motor, between the limits S and S1, on both sides of the optical axis of the system. The stand is based on an optical system of convex lens type (L) with focal points F1 and F2, placed at the distance d1 from the light source and at the distance d2 from a screen (E). The movement of the light source along the distance D, between the points S and S1, will lead to the obtaining of an inverted and amplified bright image onto a screen between the points S'and S'1.

If we consider that d1 = 30 mm and d2 = 600 mm, results an amplification factor of movement A = 600/30 = 20. By reading thus the position of the bright reference onto the screen, one can highlight and evaluate the small distances done by the ultrasonic motor cursor. In the following figure it is shown an image of the stand with the specification of its components.

The range of image displacement on the stand screen is 40 mm, and the maximum range of cursor displacement, according to the manufacturer's catalog is 2 mm. The reading on the screen was made with a resolution of 0,25 mm resulting the following data (Fig. 4).

In figures 5, 6 and 7 are shown the graphs obtained from the tests achieved using pulses trains with fixed duration and in the fig. 8 is shown the window of the software control application of the motor. Was also determined the polynomial function that determines the value of the step done by the motor for each situation in part.

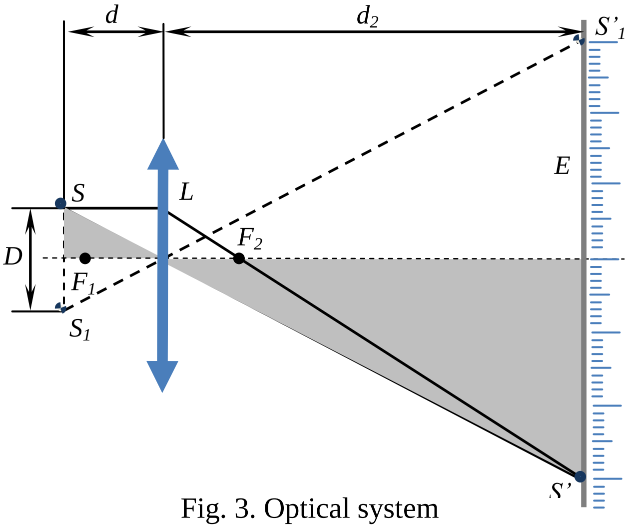

Fig. 3. Optical system

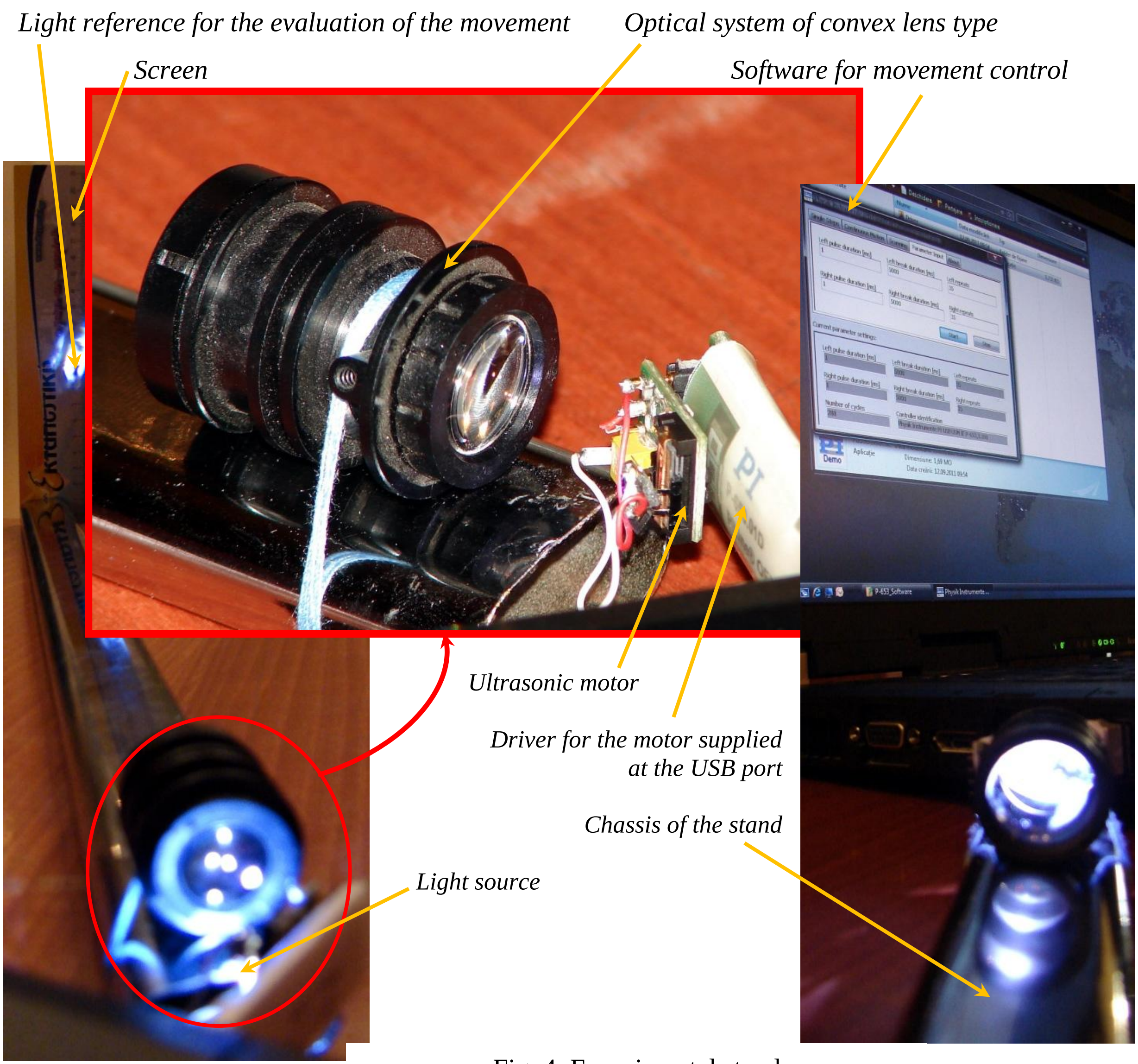

Fig. 4. Experimental stand

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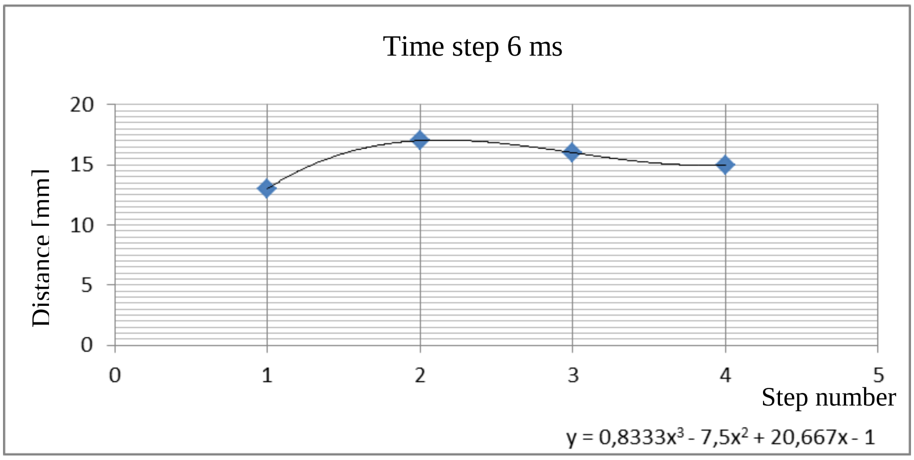

Fig. 5

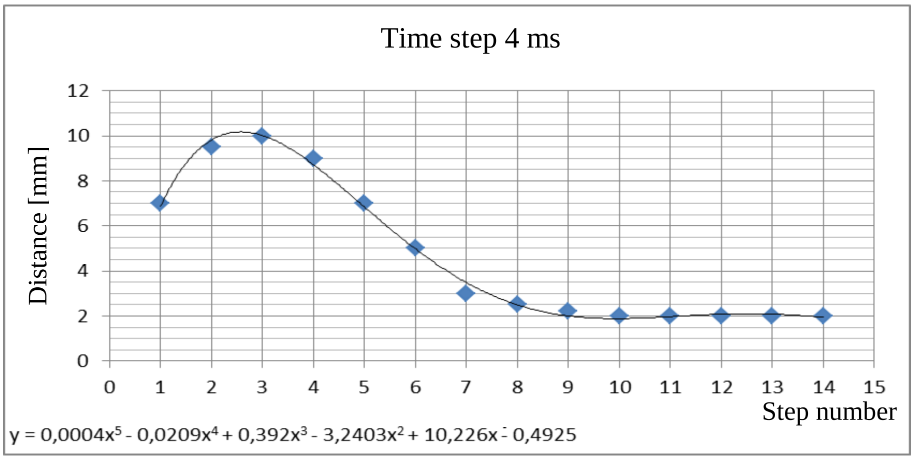

Fig. 6

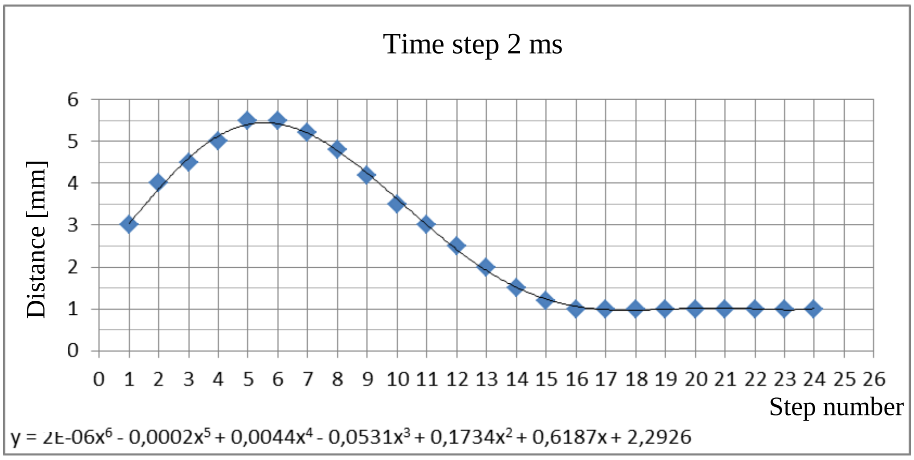

Fig. 7

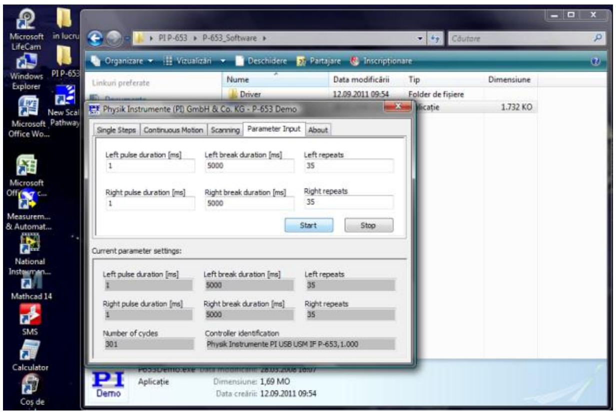

Fig. 8.

4 Conclusion

Using of this type of motor in robotics is recommended because of:

- Minim inertia: acceleration, speed and high resolution. PiLine reaches speeds of up to 800 mm/s and accelerations up to 20g, the movement being made with small steps and speed, providing a resolution of 0,05 micrometers. The system requires no lubrication and there is not rotational inertia to limit the acceleration and deceleration.

- Compact size given by the direct driving principle.
- Very good power-weight ratio: the motors are optimized for high performance with minimum size.
- Safety in operation: minimum inertia; together with a system of coupling type provides a faster and safer stopping.
- Self-locking element: the motor can create a braking force when it is under voltage, without using conventional mechanical brakes. Other benefits of the self-locking feature are given by the absence of heat dissipation.
- Vacuum compatibility: the motors can operate inside of vacuum precincts.
- These systems does not create disturbing electromagnetic fields and are not influenced by them, a decisive advantage in many applications.
- Solutions/flexibility for equipment manufacturers: the piezoelectric motors are available in open or closed loop configuration, but also as OEM components.
- Posibility to adjust the speed by changing the frequency or amplitude of the two signals applied to coupled discs, the position of the support point and the phase shift between signals, if the discs are supplied to the same frequency.

The disadvantage is the inability to control precisely the step using only the control time. One can observe the shape of the taken graphs, which involves using a high precision displacement sensor to obtain minimum positioning error.

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