Module Stepping Piezoelectric Actuator - A Versatile Way of Micro-Positioning Actuation -

F. Dubois[1,2], F. Barillot[1], V. Thiebaud[1], C. Belly[1], T. Porchez[1], M. Barraja[1], A. Saulot[2], Y. Berthier[2].
[1]Cedrat Technologies SA, Meylan, France
[2]LaMCoS UMR 5259, Université de Lyon, INSA-Lyon, Villeurbanne, France

Abstract:
Stepping Piezoelectric Actuators (SPA's) – based on the Piezoelectric Friction-Inertial Actuation (PFIA) principle – are made from Cedrat Technologies Amplified Piezoelectric Actuators (APA). They use the stick-slip principle to couple high resolution positioning (<µm), long stroke (>cm) and low volume (<15cm^3). These motors are used in optronic, medical and military applications. However, current rubbing contact between the shaft and clamp limits the potential evolution of SPA's. In this paper, a new concept: called Module SPA (MSPA) – offering long stroke capabilities (>10cm), allowing easier multi-DoF mechanism developments and miniaturization possibilities – is presented. Results obtained on three innovative engineering models – linear long stroke, rotary and three-DoF actuators – are presented, giving the reader actual benefits of this concept and allow addressing new applications such as consumer goods and medical devices.

Keywords: Piezoelectric Motor, Micro-Positioning, Multi-DoF Actuation.

Introduction

Piezoelectric Friction-Inertial [1] SPA's use the stick-slip principle to have high resolution positioning (<µm), long stroke (>cm) and small size (<15cm^3) [2]. These motors are composed of four main elements: an APA, an inertial mass, a shaft and a clamp [3]. In this paper, firstly, current rubbing shaft/clamp configuration' limitations are highlighted. Then, the MSPA concept is detailed with its differentiating factors. Finally, three engineering models – linear long stroke, rotary and three-DoF actuators – are introduced to highlight the benefits of this concept and to prove a miniaturization capability.

Scientific context

PFIA principle
PFIA principle of SPA relies on the stick-slip effect. ***Fig. 1***.A-B illustrates the two phases needed to produce steps; from slow-fast alternation voltage order to friction drived step-by-step moving mass displacement. By repeating this operation, a stroke of several millimeters can be reached. The opposite motion is done by inversing the slow-fast voltage sequences. SPA's are suitable to offer a high blocking force at rest, micron and submicron positioning capabilities, high miniaturization potential and nonmagnetic properties.

Shaft-Clamp SPA configuration' limitations
In former Linear SPA motors, a shaft was enclosed in a clamp. The clamp was moved by friction at a variable distance from the APA. This introduced limits in stroke of the motor, and a reduction of force with the distance. Additionally, when integrated in a stage, hyperstatism appeared with the guidance. Additionally, noise and parasitic vibrations are amplified by the different casing parts of the stage.

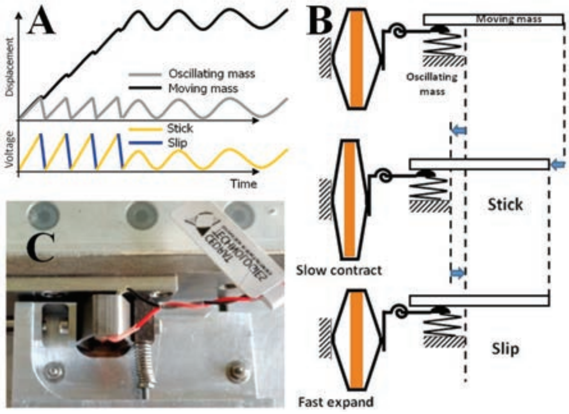

Fig. 1: *MSPA motor: A- Stick-Slip principle, B-scheme and C- preliminary breadboard.*

MSPA Concept

In comparison, MSPA frees the rubbing contact and distance between the friction force and the APA electromechanical force remains co-localized (see ***Fig. 1***.B-C). So, the payload can be driven by friction in a linear or rotary motion depending on the guiding. This configuration allows removing the limitations of the first generation of SPA's with largely extended stroke and higher versatility.
In addition, as in the shaft-clamp configuration, the main MSPA characteristics such as high force at rest, nonmagnetic properties, micron and submicron positioning are retained.

Designs

Three engineering models have been developed to highlight the benefits of this concept. From one design (see ***Fig. 1***.C) different directions can be actuated, depending on the guidance.

Linear MSPA preliminary breadboard

In case of linear guidance, Fig. 2 illustrates a 10cm-stroke linear MSPA preliminary breadboard. This stroke can be reached with a pin-on-pad contact. Since there is no more hyperstatism due to redundancy between shaft-clamp rubbing contact and linear guidance, tolerances in parallelism are easier to maintain.

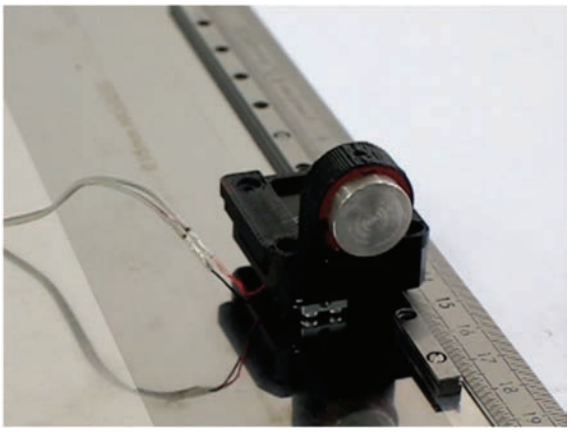

Fig. 2: *10cm-stroke linear MSPA preliminary breadboard*

Therefore, instead of a slight dissymmetry between positive speed (16.9mm/s, see Fig. 3) and negative speed (16.3mm/s), MSPA configuration has the benefit of having a magnified stability in terms of speed and actuation force, but are also easier in terms of conception, manufacturing and integration.

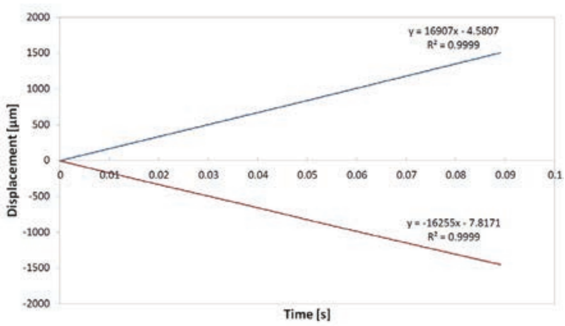

Fig. 3: *Back and forth displacement curves*

Rotary MSPA engineering model

In case of bearing, Fig. 4 illustrates a rotary MSPA. As with the previous linear preliminary breadboard, the stroke is in the region of 10cm.

Fig. 4: *Long stroke rotary MSPA engineering model*

Contrary to classical step-by-step SPA, this rotary MSPA has been designed to have a constant positive and negative speeds without backlash (see Fig. 5). Additionally, a high resolution linear position sensor has been implemented and a closed loop has been developed. So, RMS error measured on full stroke gives control accuracy and thus repeatability comprised between 0.0010° and 0.0036°.

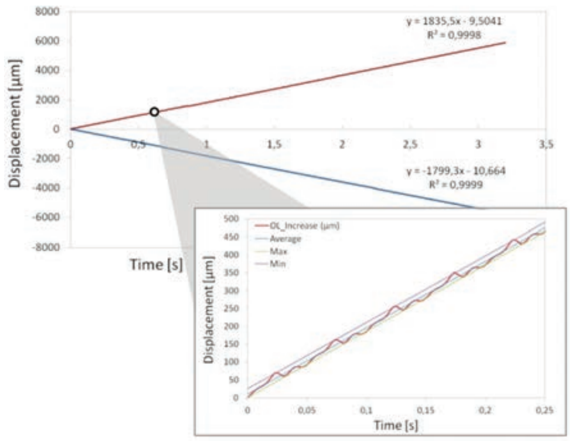

Fig. 5: *Back and forth displacements curves + focus on almost-linear step pattern*

Three-axes MSPA engineering model

By using the ‘force at rest’ characteristic of SPA concept, friction interface itself can be used as a guidance. With two rotations and one linear vertical displacement, Fig. 6 illustrates a three-axes MSPA. Vertical displacement is actuated as well to finally perform horizontal displacements Tx and Ty by combining Ry, Rx and Tz displacements. As for rotary MSPA, each actuator is equipped with high resolution sensors.

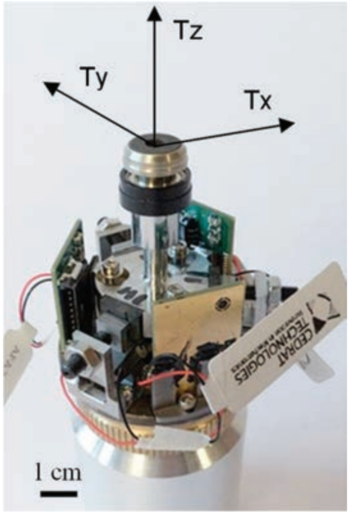

Fig. 6: *Three-axes MSPA engineering model*

The three-axes MSPA, and typically Stepping Piezo Actuators, are well known for their possibility to offer very high resolution motions together with large stroke's. This possibility is due to the combination of stepping and deformation mode. Characterization of repositioning capabilities of the mechanism has been carried out. To measure small angular displacements, an autocollimator from TriOptics is used. This one gives sub µrad resolution, useful for the three-axes actuator measurements. Fig. 7 illustrates angular repositioning of the mechanism after an external disturbance. Median level is similar for the two Rx and Ry rotations with a 4µrad value. Likewise, half of the measured repositioning is comprised between 2.5µrad and 9.5µrad (respectively 1µrad and 7µrad) for the Rx axis (respectively Ry axis).

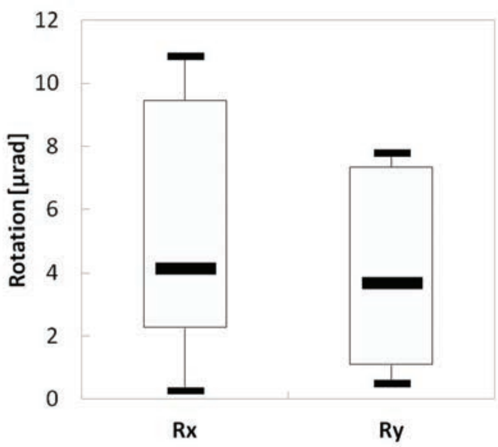

Fig. 7: *Precise angular repositioning in closed loop after external disturbance*

Technological limitations and perspectives

Further developments consist in
- Validating working in harsh environment,
- Extending lifetime,

To do so, first, the temperature-vacuum chamber at Cedrat Technologies will be used to characterize the MSPA in harsh working conditions to test thermal and wear stability during the lifetime of the actuator. Once these steps are realized, tribological study is going to be carried out to extend lifetime of MSPA in harsh environment.

Conclusion

This paper presents a new concept of micro-positioning actuation by introducing a pin-on-pad rubbing driving contact and test results; three mechanisms based on this concept are presented.
As with previous SPA designs, this new concept retains high force at rest, high positioning resolution, reliability, sensor integration and miniaturization potential.
Additionally, longer strokes are reached and are no longer limited just by the size of the guidance in the linear case. Since, redundancy between guidance and actuating axes are improved, stability on speed and force are increased all along the stroke. Conception, manufacturing and integration are made easier. Finally, versatility of such a concept allows also quick and effective specific multi-DoF designs as well as miniaturization capability.

References

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