Force Stepping Piezo Actuator: a Motorised Solution for High Resolution Positioning and External Forces Resistance

C. Belly, F. Barillot
Cedrat Technologies SA, Meylan, France

Abstract:
Typical holding force of piezo motors is defined by friction force, required to make motor move. However, increase of friction force is not inconsequent for motor performances in terms of speed, max motion force and lifetime (tribology).
In this paper, a new motor, offering high resolution positioning and holding position when unpowered, is presented. Based on a Stepping Piezo Actuator [1] at its core, this new design decouples the outer forces from the most sensitive parts of the motor. This allows the motor to propose a high force/mass ratio and sustain even higher forces without supply. Results obtained on prototype are presented, giving the reader the benefits of proposed technology.

Keywords: Piezo, Motor, High resolution, Force, Holding position

Introduction

The paper presents state of the Art of piezo motors and interest in increasing motor stepping resolution and forces (blocked force and unpowered holding force). Innovative configuration is implemented within two different sizes prototypes, based on well established motors. Experimental results are shown. Benefits are finally listed facing several domain constrains.

Piezoelectric motor core

As it is well known, APA® shape is offering benefits within piezo motor configurations [2]. Amplification and preload are key points that lead to obtain good stepping motor characteristics. Stepping Piezo Actuators (SPA) are inertial stepper motors. They are composed of four main elements: an actuator, a shaft, a mass and a clamp. The principle of such motors is simple and relies on stick-slip effect and dissymmetrical accelerations. ***Fig. 1*** shows the two phases needed to produce one step. By repeating this operation, stroke of several millimetres can be reached. The opposite motion is done by inversing the two sequences. This motion is called "Stepping Mode".

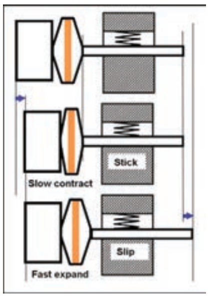

Fig. 1: *SPA motor principle*

Linear and rotating configurations have been developed, targeting camera refocusing, long stroke shutters or even medical applications [3]. However, some applications may be limited by unpowered holding force. This force is limited by axial friction force. An improvement possibility is to increase preload of the motor. This leads to higher friction force but may also have a strong impact on motor performances. Whereas there are optima for motor speed and force, it is easy to understand that if friction force is infinite, motor won't be able to perform steps, so becomes inefficient. The proposed motor is using mechanical architecture in order to decouple external force from motor its self. This leads to compliance with extreme load facing size of motor. Moreover, high resolution and large actuation force can be achieved. Those aspects are detailed further.

Prototypes #1

Two prototypes have been developed into order to settle technology potential. First one is based on three APA40SM and presents an objective of resolution down to 100nm, actuation force above 40N and resistance of 1.8kN. It is 85mm height for 67mm in diameter (see ***Fig*** *2*.). External force compliance is shown using mechanical design and safety margins. Typical ECSS (European Cooperation for Space Standardization) margins [4], from space design rules are considered in this design. Moreover, according to actuation force, a 200N force is recorded facing motor while displacement still occurs, oversizing the 40N goal.

Fig. 2: *FSPA motor based on APA40SM*

Stepping resolution

In order to prove motor resolution, step by step signal is applied and position output is controlled using capacitive sensor. Those sensors are facing output axis of the motor, with a 50µm/V gain.

Fig. 3 presents results obtained on motor, using a 75Vpp signal @ 1Hz. Resolution of steps below 20nm is shown. This corresponds to a 1.2µm/min speed. Speed reached with a 20Hz and full voltage amplitude signal (150Vpp) is 75µm/min. Showing speed control capability.

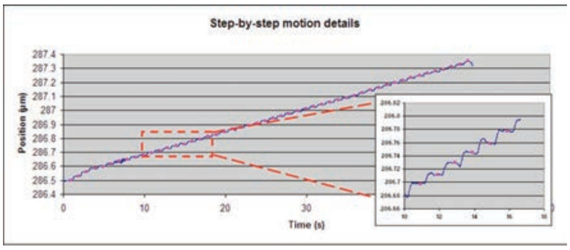

Fig. 3: *Motor resolution (mean step 20nm)*

Other experimental results, as max force and short term cycling, will be presented in final paper.

Step size repartition

Step size repartition is presented on ***Fig 4***. It can be seen that step size is following a Gaussian repartition *(red= negative, purple positive)*. This means that open loop cannot be considered as a control strategy (in comparison to electrical stepper motor) but average speed is remaining constant. The second information is about difference between one direction and the other one. As it is also seen in ***Fig. 5***, dissymmetry is observed. This behaviour is noticed in several piezo motors [5].

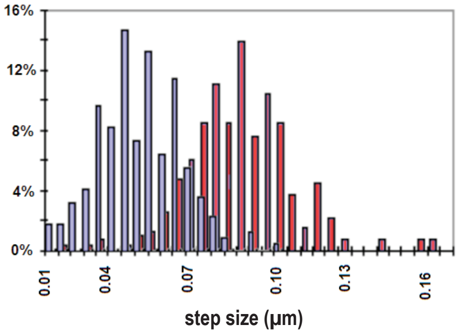

Fig. 4: *Motor step size repartition*

Short terms lifetime testing

Some very resolute application can be seen is optical fine tuning, and/or structure deformation apparatus. Those kinds of application can (but are not limited) be performed in a very limited actuation number. A short lifetime actuation test has been performed at maximal voltage amplitude. 110 back and forth actuations have been performed showing following behavior (see ***Fig 5***).

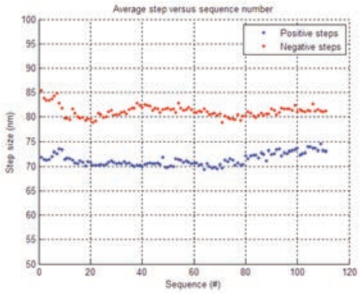

Fig. 5: *Cycling test results*

Constant step size is shown along cycles, with a small variation. Dissymmetry of step facing direction (classical in stepping piezo motor) is also visible, but is not an issue in piezo motor field.

Prototypes #2

Second prototype is based on smaller amplified piezo actuators, derived from standard APA35XS. Goal of this motor is not to reach very low resolution but to anticipate consequences of down scaling. Specifications are to perform sub-micronic steps with maximal force facing volume. Its size is 50mm height for 44mm in diameter (***Fig. 6***). It allows 6mm in stroke.

Fig. 6: *FSPA motor based on APA35XS*

Stepping mode

Stepping behavior is validated onto one internal component. This gives typical stepping example (***Fig** 7*). It can be seen that on current test sequence, voltage is limited to 80Volts, compared to full 170Vpp amplitude of piezo component. This will constitute a further step in order to characterize the motor final performances. With this reduced voltage, 25N actuation force is recorded.

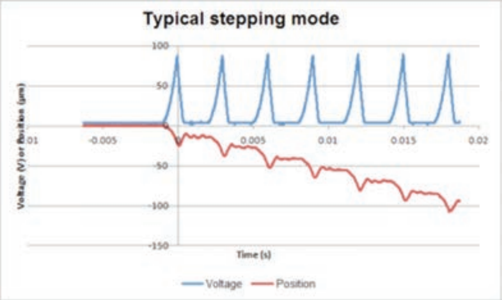

***Fig.** 7: Typical stepping motion example*

On output shaft, the displacement is presenting resolution close to 250nm. On Fig. YY output shaft displacement and step size is visible. Variation of step size is fully comparable with results on step repartition results obtained on ***Fig 4***.

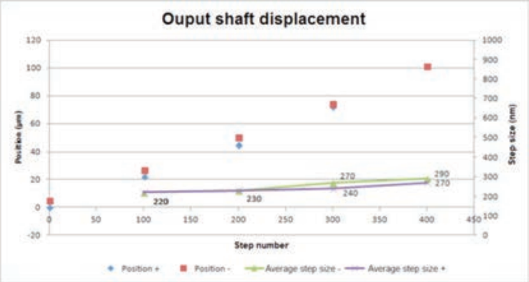

***Fig. 8:** Motor output displacement*

Performances summary and future work

Obtained performances on second prototype are consistent facing forecast as it can be seen on

***Table 1:** 2nd prototype summary*

	Unit	Target	Measured
Step size (typ.)	nm	<1000	250
Typical step frequency	Hz	>50Hz <500Hz	333
Output speed	µm/s	>8.5 <88	82
	mm/min	>0.5 <5.0	4.9

Future work will held on full voltage amplitude characterisation. Indeed, speed and force should take benefit to increase of APA displacement and force. This should lead to larger actuation force.

Fields of application

Applications of FSPA motor are foreseen in instrumentation, optics and space. Potential use in thermal vacuum environments [6] is fully correlated to SPA thermal vacuum behaviour. Therefore, such environment constrains is also targeted by FSPA.
FSPA motor is well suited for example to tune arms' lengths of interferometers, to align sensitive elements, to control shape of optical components (adaptative optic), etc.
The motor being self-locking and vacuum compliant, it is well suited for demanding environments as found in space applications where unpowered locking is required during launch. Non-magnetic version of FSPA can also be used in high magnetic field (MRI) or high sensitivity applications.

Conclusion

Two prototypes of proposed technology are presented in the paper. Large forces (holding force without power and actuation force) are proposed using this technology, coupled to very high resolution (down to a few tens of nanometres). Due to FSPA core performances, opportunities in optronics in space environment are already considered.

References

[1] F. Claeyssen et Al., Stepping Piezoelectric Actuators based on APAs, Actuator 2008
[2] C. Belly et Al., Benefits from Amplification of Piezo Actuation in Inertial Stepping Motors and application for High-performance Linear Micro Motors, Actuator 2010
[3] C. Belly et Al., Micro and Macro piezo stepper motors: from biomed to space applications, ISOT2011
[4] ECSS-E-30 Part 3A
[5] V. Bhatia et Al., Efficient and compact green laser incorporating adaptive optics for wide operating temperature range, SIS Intern. Syp. Digest of Technical papers, p962
[6] M. Buttery et Al., Thermal vacuum behaviourof stepping piezo actuator, ESMATS 2011