Fine Stepping Piezoelectric Actuator (FSPA) for IASI-NG

A. Guignabert, F. Barillot, C. Belly, O. Freychet
CEDRAT TECHNOLOGIES S.A., Meylan, France

Abstract:
Many applications and more specifically space projects would have use of a stable sub-micrometre positioning actuator. In order to meet this need, Cedrat Technologies has designed the new FSPA brand. This linear stepping actuator offers sub-micrometric positioning resolution along 5mm stroke combined with high actuation force (>100N) and the ability to hold its position without power. Starting from the FSPA, a special version is being developed for the IASI-NG space instrument. This light (500g), fully redundant actuator is designed to achieve 150µm stroke with locking at rest, 60 N force with a 25-50 nm step resolution and resistance to launching. The paper presents the base FSPA actuator and the new high performance space variant.

Keywords: Piezo, Motor, High Resolution, Force, Holding Position, Space

Introduction

The paper presents the most recent developments and results on the standard Fine Stepping Piezoelectric Actuator FSPA technology with a newly developed demonstrator from CEDRAT TECHNOLOGIES (CTEC). A special FSPA version, developed for IASI-NG space instrument, is then presented and ongoing engineering qualification campaign main results are detailed.

FSPA new iteration

Based on the previous FSPA development campaign, presented in [1], and the identified limitations, a new FSPA was developed and is planned to become a new standard product: the FSPA35XS.

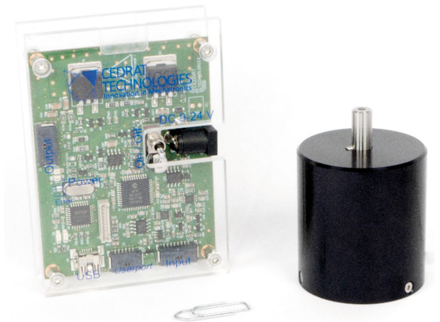

***Fig. 1:** FSPA35XS motor and its driver SPC45*

Its external dimensions have been lowered: 40mm diameter (down from 44mm), 45mm height (down from 50mm), while expecting an improvement on motor performances. The main improvement areas, identified via previous iterations are:

- further internal optimization to reduce parasitic displacement
- work on the backlash, higher positioning precision, backlash-free option
- axial preload of the moving part to improve step repeatability and smoothen the displacement

This motor is mainly proposed for industrial and laboratory applications, it can constitute an alternative to other piezoelectric motors [2]. Furthermore, the compact design and vacuum compatibility could be an opportunity for low cost space applications such as microsatellites.

Force/speed characterization

The motor is characterized to determine its maximum force and speed performances. The maximum force is reached when the moving part is blocked (no speed), inversely the maximum speed is reached without counter force. The test rig did not allow a precise mapping of the force/speed curve, hence the presented characteristics is an extrapolation of two tests: a static force measurement and a free speed measurement. The result can be considered conservative since we can expect the force/speed curve characteristic to be above the straight line, based on typical SPA motors results.

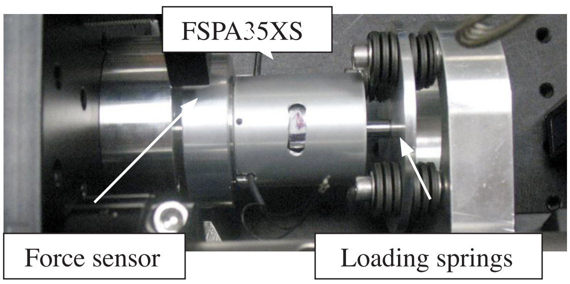

***Fig. 2:** Static force measurement test rig*

The blocked force measurement results are presented here after (Fig. 3):

ISBN 978-3-933339-30-0

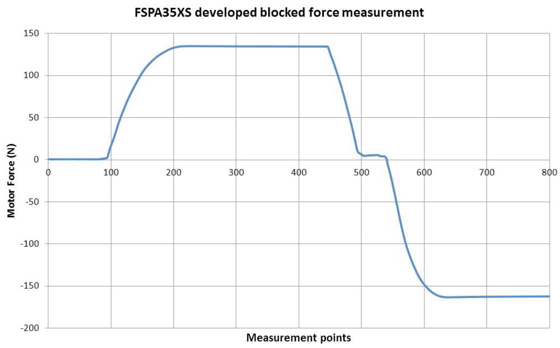

Fig. 3: *Measurement of the generated blocked force*

It can be noticed a slight dissymmetry between outward (135N) and inward (-163N) generated force in blocked condition. Such a dissymmetry is usually expected for FSPA motors and can also be noticed for step size difference in other piezo motors [3].

The force/speed result with the optimal actuation signal is the following (Fig. 4):

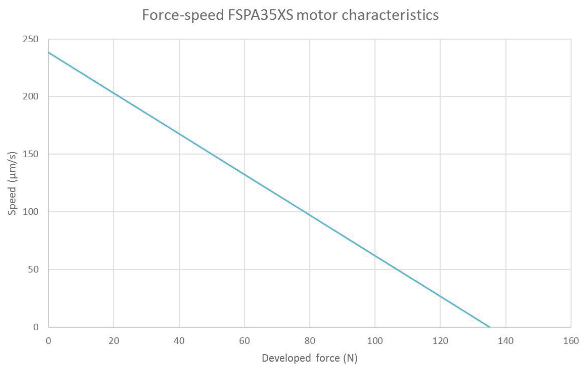

Fig. 4: *FSPA35XS force/speed characteristics*

With a recorded maximum speed of 238µm/s, this is a noticeable improvement compared to the previous design which "only" reached 82µm/s (see [1]). This is mainly allowed by the optimization of internal inertias, enhancing step control and reducing parasitic displacements.

Stepping resolution

One of the main interest of this motor technology is to be able to generate stables sub-µm displacement steps for fine positioning requirements.

Two options were tested here: with or without a moving part axial preload, created with a spring element. The test consist in going through a large portion of the motor stroke, with a fixed number of steps (2000 steps in both directions, corresponding to 800-1000µm stroke). The average step size is then calculated for both outward/inward direction (Table 1):

Table 1: *average step size and speed with/without axial preload*

Configuration	Without axial preload	With axial preload
Average step size - outward direction (nm)	414	477
Average step size - inward direction (nm)	545	562
Outward speed (µm/s)	193	222
Inward speed (µm/s)	253	261

It can be noticed that the addition of a preload allows to significantly lower the inward/outward average step size difference from 131nm without preload to 85nm with preload. Since the speed is directly dependent on the step size, motor speed symmetry is also positively impacted by the addition of a preload.

Step size and thus motor speed can be adjusted through the supply signal maximum voltage (Fig. 5):

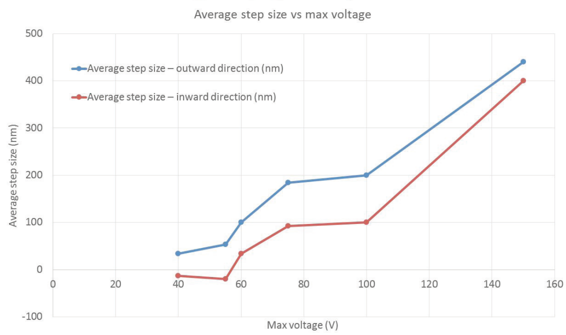

Fig. 5: *Average step size vs supply signal max voltage*

As it can be noticed, the displacement direction is no more controllable under 60V, the motor then only goes outwards. The lower controllable average step size (ie the step resolution) for both directions is then around 100nm at 60V.

Fine stepping mode

A fine stepping mode has been tested and verified. It is achieved by applying a quasi-static voltage on the motor (no friction, direct driving of the rotor). Results for a 0-35V triangular 2,5Hz supply are presented in Fig. 6.

ISBN 978-3-933339-30-0

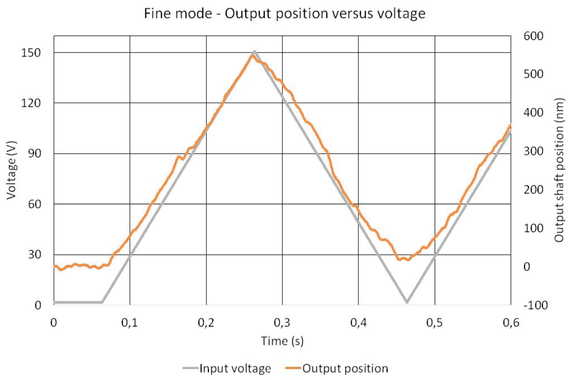

Fig. 6: FSPA35XS fine mode

Different levels of voltage were tested, and the corresponding displacement gain is calculated

Table 2: fine stepping mode displacement gain vs voltage

Voltage (V)	Displacement gain (nm/V)
150	3.6
50	3.1
30	2.3

Although this fine stepping mode allows to reach a few nanometers resolution, the fact the actuators are in direct drive prevets the motor from functioning against an external force in this mode. Therefore, this resolution can only be considered into fine positioning of inertial loads (such as a mirror, a probe, a sample …).

Performances summary and future work

The overall performances of the FSPA35XS are summarized in the following table (Table 3):

Table 3: Fine stepping mode displacement gain vs voltage

	Units	FSPA Motor
Travel range	mm	5
Actuation Force (1)	N	>100
Holding Force (2)	N	200
Typical min step size	nm	<100
Fine mode resolution	nm	< 5
Typical max speed	µm/s	200
Typical lifetime (3)	cycles	100
Total mass	gr	160
Volume	mm^3	Diam 40x54
Operating temperature	°C	[0 : 50]

(1) Blocked force, no more displacement
(2) Unpowered
(3) Back and forth 1mm, static load

One of the main interest of this technology is the ability to hold its position while powered off, even under an external force multiple times the actuation force (twice for the FSPA35XS).

Special FSPA version for IASI-NG

A dedicated version of this actuator is currently being developed by Cedrat Technologies with Airbus Defence and Space (ADS) to be used in the Infrared Atmospheric Sounding Interferometer New Generation IASI-NG instrument program developed by CNES. The IASI-NG instrument is based on a Mertz Interferometer allowing compensation of the Self Apodization issue.

The two Beam Steering Mechanism Actuators (BSMA) are used to perform the fine alignment of the beam splitter during AIT operations, maintain its alignment during launch and then perform in orbit fine corrections as needed during flight lifetime.

Fig. 7: IASI-NG instrument (courtesy of AIRBUS DS)

Based on the FSPA35XS, this special version has its core principle slightly changed to allow compliance with space requirements (specifically ECSS motorization margins).

This fully redundant actuator is designed to achieve 150µm stroke, 30 N force with a 25-50 nm step resolution. The actuator remains rather compact: two motors (for redundancy) are integrated inside the 85 mm x 70mm x 70mm casing for a total mass below 500g. All the design development is planned to deliver a fully ECSS compliant, spatial compatible and redundant product.

This model also includes a PPA piezoelectric actuator for short stroke positioning and higher bandwidth actuation as well as an Eddy Current Sensor (ECS) to detect the steps with nanometer resolution (reachable under some conditions).

BBM: Stepping resolution

A Breadboard Model (BBM, see Fig. 8) has been built and tested to demonstrate the motor's capability to operate in vacuum and perform very small steps. The motor capability to execute 50nm steps has been verified. The BBM was tested in vacuum where it even showed improved performances.

 ISBN 978-3-933339-30-0

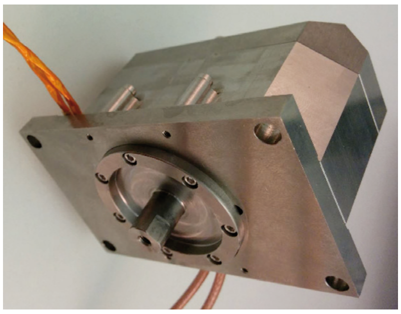

***Fig. 8:** BBM overview*

Steeping resolution results achieved with the BBM are presented hereafter (Fig. 9):

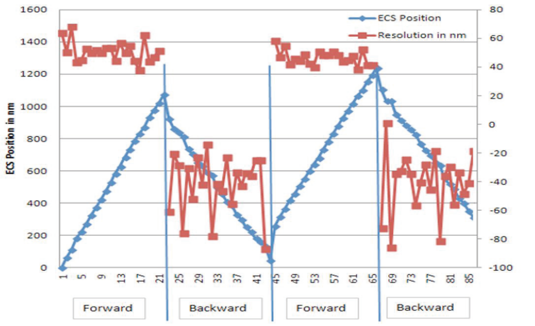

***Fig. 9:** Monitoring 20 steps forward / backward movements and step size*

As it can be noticed, the average step size is quite reproducible for each forward/backward direction, at around 40-50nm per step. The backward motion presents a greater dispersion for which no precise explanation could be provided.

EM: Improvements and ongoing tests

Based on the result and lessons learned from the BBM, the design was improved to build two Engineering Models (EM), see Fig. 10. A particular attention was given to improve internal stiffness.

Additional improvements include the addition of a connector for easier integration and of a particle filter to comply with higher level cleanliness requirements.

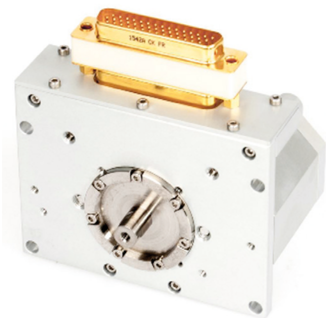

***Fig. 10:** BSMA Engineering model 1 (EM-1)*

EM tests were performed in ambient laboratory conditions. The motor is actuated on each direction for the full stroke (+/-75µm) for a total of 10 cycles. The results are compiled on the following graph (Fig. 11) plotting the evolution of motor step versus its position along the actuation stroke. The displacement measurements are performed using the built-in CTEC ECS Eddy Current Sensor [4].

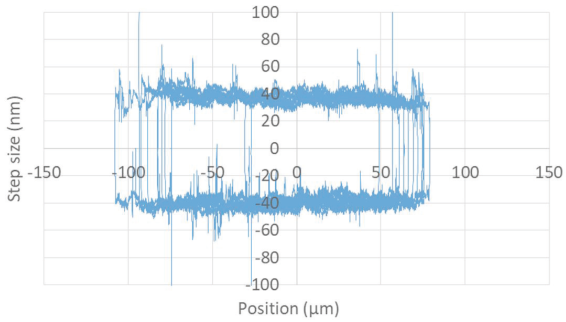

***Fig. 11:** EM-1 step size vs stroke for both directions (averaged over 21 steps)*

The motor is able to generate steps with an average value of 40nm. The dispersion of the averaged step size over the 10 full stroke cycles is in the order of magnitude of 10 nm, which is not surprising, due to the dispersion of the mechanism and the noise which makes ECS output difficult to process and analyse. The local spikes are currently assumed as "acquisition noise" (external electrical spikes for ex.) because they seem to occur randomly and are not repeated over the 10 cycles.

Conclusion

Two prototypes based on the FSPA technology are presented in the paper: the FSPA35XS which is to be CTEC main FSPA product and a special version for the IASI-NG satellite. Large forces (holding force without power and actuation force) are proposed using this technology, coupled to very high resolution (down to a few dozens of nanometres), demonstrated through test campaigns performed on the prototypes.

References

[1] Belly et al., Stepping Piezo Actuator: a motorised solution for high resolution positioning and external forces resistance, Actuator 2016.

[2] Spanner, K. and Koc, B., 2010. An overview of piezoelectric motors. In *Actuator conference*.

[3] 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

[4] Sosnicki et al, Eddy current sensors on Printed Circuit Board for compact mechatronic application, Sensor & Tests, proceedings 2010

ISBN 978-3-933339-30-0