Improvement of MSPA: Module of Stepping Piezo Actuator

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Abstract:
Modular Stepping Piezo Actuators (MSPA) use the stick-slip principle to combine high resolution positioning (<µm) with long stroke (>cm). These motors provide unlimited motion in both rotation and translation. Fine mode allows precise positioning (<10nm). Since it is a module, it easily fits any existing devices requiring up to 25N of driving force with a speed up to 50mm/s. This motor module benefits the use of space qualified Amplified Piezo Actuators (APA®). It is then deemed a good candidate for severe environments such as vacuum, cryo, vibrations, nonmagnetic etc… This paper presents three technical challenges encountered for the development of MSPA product. The first one is the issue of noise resulting from stick-slip actuation below ultrasonic frequencies. The second is the miniaturization at low voltage: One is macro size (sugar cube) working at 45V is characterized, the other is micro size (grain of rice) powered at low voltage below 60V. The third challenge is the successful and reliable integration of the module within new customer applications and new Cedrat Technologies' products.

Keywords: Piezo Motor, MSPA, Stick-slip Actuators, APA®

Introduction

The EU project "EUREKA EUROSTARS ELVISA", coordinated by CEDRAT TECHNOLOGIES (CTEC) and involving Noliac CTS [3] (Denmark) has funded part of the development of this MSPA piezo driving module [1] (see **Fig. 1**). This paper presents the three main technical challenges encountered during the development of the product.

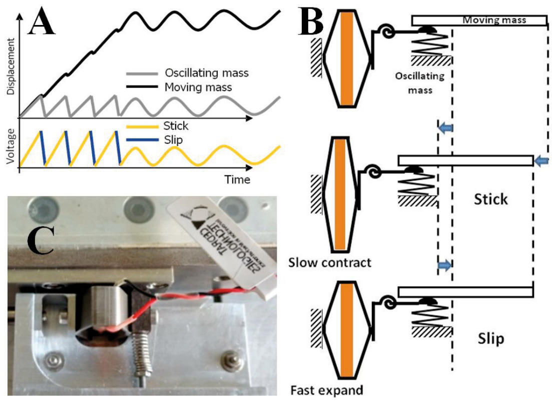

Fig. 1: MSPA macro base module principle and prototype

Challenging stick-slip noise

Firstly is the issue of the noise resulting from stick-slip actuation below ultrasonic frequencies [2]. The excitation from the contact can mainly be divided into two parts: i) the periodic components due to the frequency of the piezoelectric actuator (corresponding to the stick-slip frequency); ii) a large band excitation due to the impulsive excitation corresponding to each phase of macroscopic slip. In fact, the macroscopic slip phase corresponds to an impulsive release of elastic energy of the system, which occurs periodically. The immediate consequence of the excitation coming from the contact is both a localized acoustic emission from the contact interface and the vibration of the system components due to its dynamic response. These vibrations, in turn, are at the origin of the acoustic emission due to the noise radiation from the component surfaces. Several approaches are proposed to reduce the typical noise from 67dBa down to 45dBa for the micro rotary configuration, and from 82dBa to 75dBa for macro linear configuration. The approach leading to noise reductions consists in introducing decoupling features within the motors. These decoupling modules are used to damp undesired vibrations responsible for noise, without reducing the efficiency of the force transmission as well as the coupling coefficient with the load. The choice of material for the dampers is deemed critical, since its stability of performances over the lifetime is essential. The material could also have to remain compatible with thermal/vacuum environment for some applications, although current tests were only performed in ambient laboratory conditions, this thermal/vacuum compatibility will be further investigated. The base material considered for the test is a reinforced nitrile elastomer, various thickness and sizes are tested.

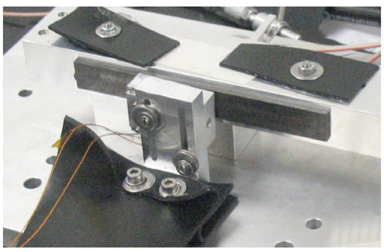

Fig. 2: Testing of decoupling features for linear macro MSPA test bench

 ISBN 978-3-933339-30-0

Noise eventually arises from the vibration of the plate on which the elements are fixed. This vibration is transmitted from the MSPA to the moving part/ bearings and to the base plate. The aim is to add a decoupling damping element between the main vibration source (the MPSA) and all the components in contact (moving part and the base plate). The decoupling option was preliminary investigated for both macro linear MSPA (see Fig. 2) and its rotary micro MSPA counterpart (Fig. 6). The main results are indicated in the following table (Table 1):

Table 1: *Comparison results with/without decoupling features for the MSPA macro linear test bench*

	Rigid mounting	Decoupled assembly (2mm elastomer)
Average max speed (mm/s)	17.5	17.6
Average max force (N)	1.5	1.3
Generated noise (dBa @50cm from MSPA)	82.5	75

The decoupled configuration consist in the addition of a 2mm layer of elastomer between the MSPA and the base plate, and between the moving part and its linear guiding. The decoupled configuration keeps almost the same performances as the rigid configuration. The maximum speed is very close, although we can notice a 13% decrease in the generated force. The maximum force decrease can be explained by the fact the elastomer layers are reducing the actuation stiffness, hence there is slightly less coupling between the MSPA and the moving part. The noise reduction allowed by this simple addition is -7.5dBa, which is very noticeable, given the logarithmic nature of the measurement scale.

On this basis, another solution to reduce the noise is to reduce the size of the base plate, since less surface means less radiated sound power. This option was tested in the rotary micro configuration and allowed a noise reduction from 50dBa to around 45dBa at 50cm.

The challenge of miniaturization and low voltage

The second challenge for MSPA motors is the miniaturization of the components and switching to a low voltage supply: Several prototypes are being designed. One is macro (sugar cube size) working at 45V, the second is micro size (grain of rice) powered at low voltage below 60V (45V prototypes are being developed). It is proposed to address the limitations by means of technological investigation: For macroscopic application a preliminary test bench is realized, using one preliminary breadboard module of an MSPA, associated with off the shelf long stroke linear guiding. Such a test bench (Fig. 3) is useful to extract data and prioritize limitations. In that regard, measurement of noise, linearity, repeatability and accuracy is established as the base line performances. The scope of this bench is to run the life time endurance testing before designing a final prototype.

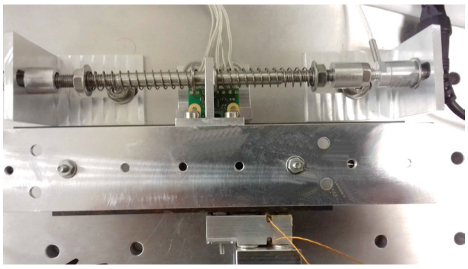

Fig. 3: *MSPA characterization and lifetime testing rig*

The macro MSPA module was subjected to a long distance lifetime test, in ambient conditions, under nominal actuation signal. Working against two low stiffnesses springs, the MSPA is cycled from one side to the other until the maximum force is reached. The maximum force is characterised by springs max compression force when moving part halts. With the nominal settings, the MSPA travels 100mm per cycle. A total of 28km was covered through the test, corresponding to around 700.10^6 MSPA steps.

The MSPA travelled that distance without any issue, although the test had to be stopped to switch to other tests. No specific variation of performances was noticed, average force and speed remained stable for a given excitation signal and preload. Although some evolution was noticed on the speed for example (see Fig. 4), as well as a slight dissymmetry typical for this stick-slip technology.

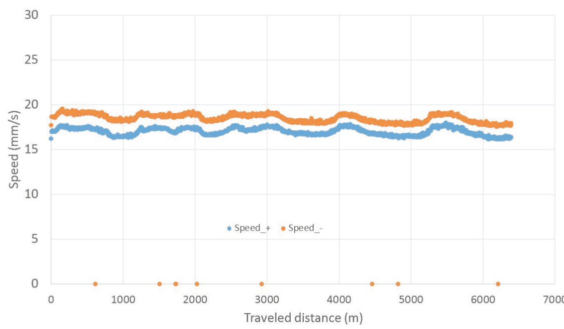

Fig. 4: *Macro MSPA speed evolution during lifetime test (6km span)*

The noticeable dispersion is probably mainly influenced by external conditions (temperature, humidity) and resulting local contact slight modifications, although temperature and hygrometry were not recorded thus no specific correlation could be established. This dispersion of the speed value could be easily compensated by a closed-loop control which was not used for this test, excitation signal remaining unchanged.

ISBN 978-3-933339-30-0

Also, a specific short stroke test was performed, to investigate the possible risk of digging of the friction pad when actuating in the same position. The MSPA was cycled over a 0,5mm stroke with nominal speed signal. A total travel of 3,3km was performed during this short-stroke test, corresponding to 8.10^6 MSPA steps. In the end the friction pad was locally marked but no noticeable digging could be observed, and the MSPA movement was not affected.

For microscopic applications the idea is to get the smallest available low voltage piezo material from Noliac and to prove the possibility to manufacture and mount the mechanical parts of the motor. The machining feasibility is evaluated using electro-discharge machining. Beyond the manufacturability, method there is also the requirement to assemble the micro actuators and achieve the correct preload.

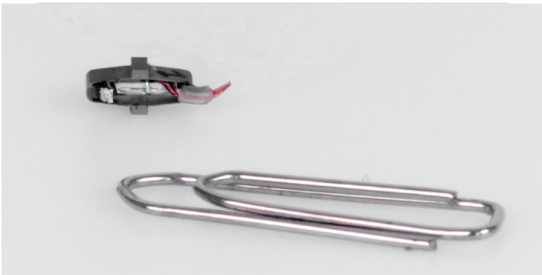

Fig. 5: *Micro sized low voltage APA® for MSPA module*

The result is an APA® with the following performances

Table 2: *Micro APA® performances*

Dimensions (mm)	8.3x3.75x2.5
Blocked force (N)	1.5
Displacement (µm)	39
Supply voltage (V)	45 - 60
Capacitance (nF)	56
Resonance frequency blocked – free (Hz)	3396.5
Resonance frequency free – free (Hz)	11626
Interface	Flat surface

The micro APA was subjected to a lifetime test. Actuated at 2kHz with a full stroke rectangular signal, a total of $12,5.10^9$ cycles were performed, without any issues.

Integration into new customer applications

The third challenge is the successful and reliable integration of the module within new customer applications and new Cedrat Technologies' products.

Rotary micro MSPA stage

A demonstrator is developed in order to evaluate performances of a micro MSPA (using the micro size APA) used for a rotating stage (see Fig. 6).

Fig. 6: *Rotating MSPA30UXS*

A polarizing cube of 1cm^3 is placed directly on the bearing to add an inertia representative of the final load. The aim of working on a small radius bearing is to have a high rotation speed (keeping the same linear speed at a different radius). Rotation speed up to 2.5 rad/s are achieved. However, the motor is noisy at around 67 dBA at 50 cm, therefore it has been decided to introduce decoupling technics for noise insulation: The result is currently 50 dBA at 50 cm. A test aimed to evaluate the maximal speed and acceleration of the micro rotary stage has been performed. It consisted in a back and forth motion while driven at optimal performance signal. Results are shown in Fig. 7.

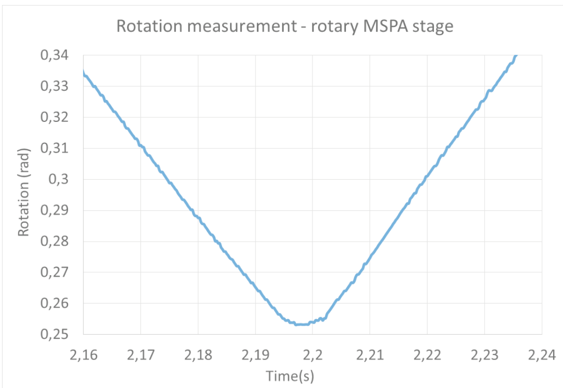

Fig. 7: *Back and forth movement with optimal signal*

The tests allowed to measure a maximum speed of 2,5 rad/s (24rpm) and an acceleration of 500 rad/s². The CTEC Micro rotary stage is still in the first design iteration and the incoming testing development campaign will aim to improve the torque, among other characteristics. Moreover, a higher angular speed can be achieved thanks to the APA® amplified technology.

 ISBN 978-3-933339-30-0

Linear macro stage

Based on the macro size MSPA base module (Fig. 9), a linear stage was developed (see Fig. 8) with the aim of tackling industrial and space linear positioning needs for long stroke (100mm+). A prototype is being manufactured and will be fully characterized by the end of the year.

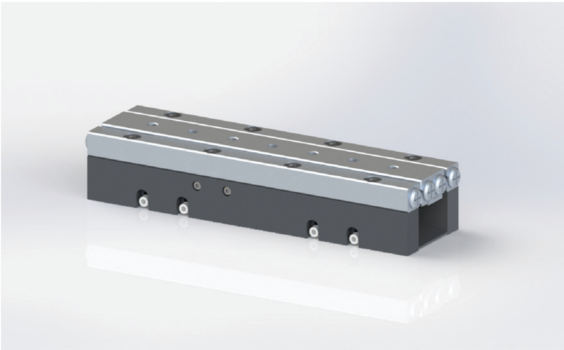

Fig. 8: *CAD of Linear macro stage overview*

The expected performances, based on MSPA module test results and model predictions are listed in the following Table 3.

Table 3: *CTEC MSPA macro stage performances*

	CTEC MSPA macro stage
Holding force (N)	6
Max. Lift force (N)	3
Max. speed (mm/s)	50
Travel range (mm)	100
Dimensions (mm3)	160x44x28
Positioning accuracy (µm)	2
Supply voltage (V)	45

The stage will incorporate noise reduction solutions, as presented in this paper, and limit emitted noise to around 70dBa. Other solutions will be investigated with the macro stage to try to further reduce the emitted noise, like using rigid polymer material for the base part and the MSPA frame in order to increase vibration damping.

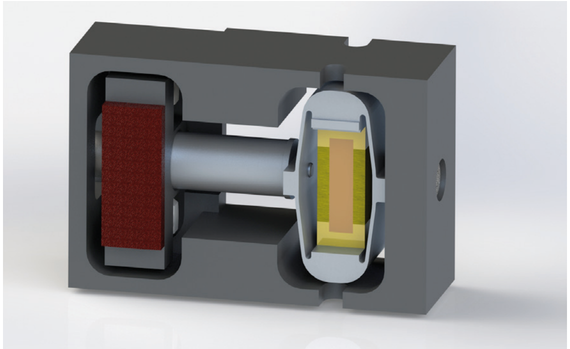

Fig. 9: *CAD of macro size MSPA*

Conclusions

This paper presented some of the most recent MSPA developments, achieved in the frame of the “EUREKA EUROSTARS ELVISA” project. A first important step is the development of some efficient means of noise reduction, allowing noticeable impact on this criteria which can be a constraint for some specific applications.

Another challenge that was tackled is the miniaturization of the MSPA, for both the size and the supply voltage. The smallest CTEC APA was designed by CTEC with a micro sized piezo ceramic (1x1x5mm), with low voltage 45-60V supplied by CTS-NOLIAC.

Two MSPA based products were designed and are currently in production at CTEC: a linear stage with long stroke (100mm) and precision positioning (µm level accuracy) based on the macro sized MSPA module, as well a rotary stage based on a micro sized MSPA module, all functioning at low voltage (45V) and including noise reduction solutions.

References

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[3] http://www.noliac.com/

 ISBN 978-3-933339-30-0