High resolution and repeatability of a linear drive through the use of Piezo Actuator Drive (PAD)

C. Mangeot[1]
[1]*Noliac A/S, Denmark*

cm@noliac.com

Abstract

High precision positioning tasks require a challenging combination of speed and precision. They find applications typically in medical, optical or imaging fields. In this paper, a simple driving method is devised, providing high precision without sacrificing speed.

The solution is based on the Piezoelectric Actuator Drive (PAD) technology. Thanks to its high torque, low inertia and form-fit principle, implying a direct relationship between the applied electrical signals and the position of the motor, PAD is a good candidate to the replacement of electromagnetic motors in linear positioning applications.

Several prototypes have been designed and produced in Noliac according to requirements for an existing application. The design includes a reduced gear ratio, so that backlash is halved and inertia is reduced by a factor 200 compared to an electromagnetic solution. The new design demonstrates unequalled resolution and repeatability. Test results indicate sub-micron resolution and peak-to-peak repeatability under 2,5µm without any position feedback, which represent very good results for that class of equipment and a improvement of several orders of magnitude compared to the existing solution for the considered application.

1 The Piezoelectric Actuator Drive and its advantages

Piezoelectric Actuator Drive (PAD) [1] is a drive technology transforming the linear motion of high performance piezoelectric multilayer actuators into a powerful and precisely controllable rotation. The PAD was developed by Siemens AG in 2000-2008. A partner was needed for commercialisation, and Noliac A/S acquired the PAD technology from Siemens AG in 2010. The particular features of the PAD are its high torque, low inertia and form-fit principle, implying a direct relationship between the applied electrical signals and the position of the motor. The benefits of PAD for positioning applications are obvious, but some development was required to scale dimensions and performance to the specific application [2].

2 Development of a specific PAD for positioning application

2.1 Architecture

The motors are included in a simple architecture. The rotation of the motor is converted into a linear motion through a pinion-rack mechanism. The rack is guided in a linear movement with a series of plain bearings.

2.2 PAD motor

Several prototypes have been designed and produced in Noliac according to the requirements for the application. The process included the design and manufacture of specific multilayer actuators providing the required mechanical energy, as well as high precision mechanical parts converting the movement into a controlled rotation. The design includes a reduced gear ratio, leading to a reduction in backlash and inertia by a factor of 2 and 200 respectively compared to an existing electromagnetic solution. Improved dynamics lead to reduced start/stop times and to a wider controllable speed range. Furthermore, the use of PAD can allow a simplification of the system, with the suppression of a position feedback sensor and the corresponding control loop.

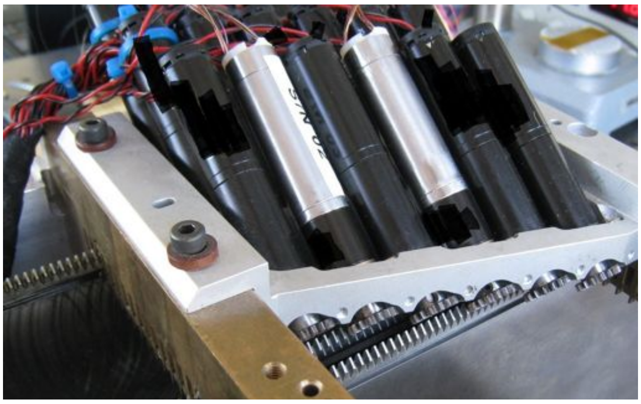

Figure 1: Two PAD (metallic cylinders) on a test bench. Note the simple rack-pinion mechanism transforming the rotation into a linear movement.

The PAD prototypes were mounted on a test bench (fig. 1) and tested in various conditions. The linear position was measured using a high resolution LVDT sensor.

3 Measurement results

3.1 Resolution

With the current PAD driver, the theoretical resolution is down to 11 arc-seconds at the motor shaft, corresponding to 66nm at the output. In order to assess performance, the motor was driven to achieve a displacement of about 1mm in one direction (in order to take-up any backlash), then two “steps” of 10 increments corresponding to 660nm. The test was repeated for “steps” of 330 and 132nm. Results can be seen on figure 2.

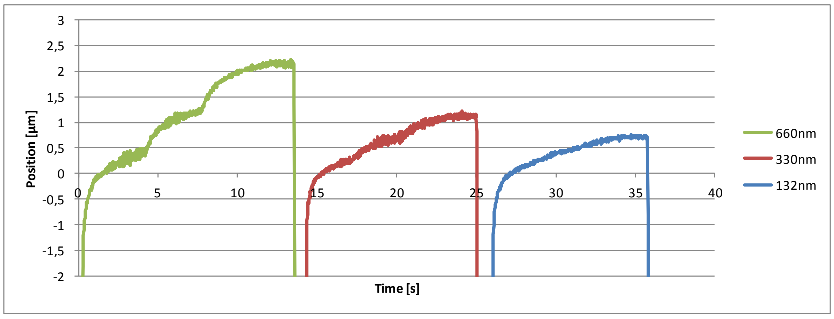

Figure 2: Resolution experiment. Close-up of the smallest “steps”.

Due to noise on the measurement and due to the dynamics of the output such as viscous friction, resolution is difficult to demonstrate below 500nm. This represents however a remarkable result for this application.

3.2 Repeatability

In order to assess repeatability, the motor was driven with a specific “staircase” profile, repeated typically 20 times (figure 3). For each of the 4 positions on the profile, repeatability can be assessed (see example on Table 1).

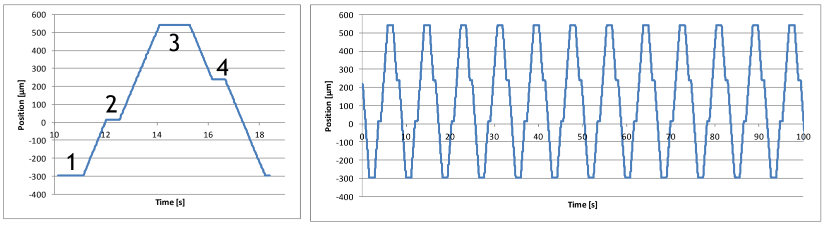

Figure 3: Template and repeated profile for repeatability assessment.

Table 1: Repeatability results for the profile shown on figure 3

Noliac A/S • Hejreskovvej 18 • DK-3490 Kvistgaard • Denmark • Phone: +45 4912 5030 • Fax:+ 45 4912 5031 • Web: www.noliac.com

Position number [-]	1	2	3	4
Average position [µm]	-296,18	14,84	543,34	239,35
Standard deviation [µm]	0,242	0,258	0,271	0,232
Peak-peak error [µm]	0,808	0,786	0,768	0,726

The standard deviation on most positions is about 250nm, with a peak-to-peak error under 1µm. Some positions however are less stable, with a peak to peak value up to 2,5µm, probably due to local discontinuities (friction, gearing). This is anyway several orders of magnitude better than required for the application.
For this simple rack-pinion system, the results have to be mitigated by the relatively large backlash of 220µm measured on the output and mostly due to the gap in the mechanism.

4 Conclusions

With a sub-micron resolution and repeatability in the micron range, the PAD technology demonstrated its advantages for positioning applications and can therefore lead to a significant performance improvement for future products. Development is still ongoing in order to reach an optimal and production mature solution as well as for developing specific solutions (size, performance).

References:

[1] PAD – Piezoelectric Actuator Drive, Kappel et al., Actuator 2006
[2] PAD - A Scalable Drive Technology, Kappel et al., Actuator 2008

Noliac A/S • Hejreskovvej 18 • DK-3490 Kvistgaard • Denmark • Phone: +45 4912 5030 • Fax:+ 45 4912 5031 • Web: www.noliac.com