High resolution optical displacement measurements of a piezo scanner

INTRODUCTION

Precise positioning of samples is of paramount interest in a variety of applications. While positioning systems with stick-slip piezo technology offers versatile possibilities, the slip-behavior is undesired in some applications. In that case, piezo scanners show their full potential as they can position a sample very accurately over a range of a few micro meters.

SETUP

In the experiment a piezo scanner\textsuperscript{1} from SmarAct is equipped with an optical encoder and the feedback loop is closed with a motion controller (MCS2, SmarAct). The voltage leading to expansion of the piezo ceramics is controlled with a 16-bit digital-to-analog converter. The scanner has a total scan range of 55 \( \mu \)m, which sets the smallest theoretical stepsize achievable with a 16-bit resolution to about 55 \( \mu \)m/\( 2^{16} \approx 0.85 \) nm. In order to verify the positioning resolution, a PICO\textsuperscale Interferometer (V2) is used. A sensor head is aligned to a mirror mounted on top of the piezo scanner. Consequently, the interferometer will measure the displacement of the scanner via the mirror. A photograph of the setup is shown in Figure 1, the PICO\textsuperscale Interferometer V2 is shown in Figure 2.

![Image of experimental setup](image1.png)

Figure 1. Experimental setup. Three PICO\textsuperscale sensor heads (labeled 1-3) are aligned to a mirror, which is mounted on the piezo scanner. The PICO\textsuperscale measures out-of-loop. The effective working distance of the interferometer (i.e. distance from sensor head to target mirror) is about 56 mm.

![Image of PICO\textsuperscale V2](image2.png)

Figure 2. The PICO\textsuperscale Interferometer V2. Up to three sensor heads can be connected to the controller, which contains a laser source, detection electronics, FPGA-based fast data processing and several interfaces.

RESULTS

The scanner was commanded to perform a motion sequence of 10 steps back and forth with a stepsize of 1 nm and 2 nm every second. The position of the scanner was controlled with the internal optical encoder and measured with the PICO\textsuperscale (see Figure 3).

![Image of measurement results](image3.png)

Figure 3. Measurement of 10 steps back and forth with a stepsize of 1 nm and 2 nm respectively. The measurement is taken 1.5 mm above the top-plate of the scanner and evaluated at the scanner center position by averaging channel 2 and 3 of the PICO\textsuperscale. The measurement bandwidth is \( \approx 35 \) Hz and the mean position data points are determined by averaging 10 individual position data points in the center of each step. The data are corrected by a linear drift between sensor head and mirror (\(< 0.1 \) nm s\(^{-1}\)).

In Figure 4 a close-up to the steps around the turning point are shown. The steps can clearly be identified. The apparent noise on the data is mainly caused by the drive voltage resolution of the digital-to-analog converter (0.85 nm per bit as shown above), noise from the optical encoder reading and residual vibrations in the setup. The sensor noise of the interferometer is expected to be less than 0.2 nm\(_{\text{rms}}\) [1].

\textsuperscript{1} in development
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Figure 4. Zoom into the steps, which can clearly be identified. The errorbars indicate the averaging length in time (350 ms) and the standard deviation of the signal within this time.

The stepsize of the piezo scanner was analyzed by averaging the data in each plateau as shown in Figure 4 and evaluating the difference between two subsequent steps. The results from both stepsizes are summarized in Table 1 and Table 2 respectively.

Table 1. Statistics of the 2 nm-steps (10 in each direction).

<table>
<thead>
<tr>
<th></th>
<th>Backward</th>
<th>Forward</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step size</td>
<td>-2.00 nm</td>
<td>1.96 nm</td>
</tr>
<tr>
<td>Standard deviation (1σ)</td>
<td>0.15 nm</td>
<td>0.25 nm</td>
</tr>
</tbody>
</table>

Table 2. Statistics of the 1 nm-steps (10 in each direction).

<table>
<thead>
<tr>
<th></th>
<th>Backward</th>
<th>Forward</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step size</td>
<td>-1.01 nm</td>
<td>0.97 nm</td>
</tr>
<tr>
<td>Standard deviation (1σ)</td>
<td>0.24 nm</td>
<td>0.21 nm</td>
</tr>
</tbody>
</table>

High performance positioning solutions require high precision metrology during development and quality control. In this application note we show a qualification measurement with the PICO SCALE Interferometer. The closed-loop motion was verified with sub-nanometer resolution, qualifying both the piezo scanner as well as the metrology equipment for high precision positioning applications.

REFERENCES


FEEDBACK

“The PICO SCALE Interferometer V2 with its very low intrinsic noise allows me to look much deeper into the characteristics of our piezo scanners. This will boost the development and provide high quality specifications which our customers will certainly appreciate.”

Hendrik-Marten Meyer, Development Engineer Positioning Technology at SmarAct
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SmarAct Metrology GmbH & Co. KG develops sophisticated equipment to serve high accuracy positioning and metrology applications in research and industry within fields such as optics, semiconductors and life sciences. Our broad product portfolio – from miniaturized interferometers and optical encoders for displacement measurements to powerful electrical nanoprobers for the characterization of smallest semiconductor technology nodes – is completed by turnkey scanning microscopes which can be used in vacuum, cryogenic or other harsh environments.

We maintain the complete production in house for a high level of customization so that we can always provide you the optimal individual or OEM solution. We also offer feasibility studies, measurement services and comprehensive support to accompany you along your projects.

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