High resolution differential measurements with the PicoScale laser interferometer

Abstract
This Application Note shows how the PICO SCALE laser interferometer can be used to carry out high resolution measurements in the sub-nanometer range. By using a differential setup, noise caused by environmental influencing factors can be reduced to a minimum.

1. INTRODUCTION
The PICO SCALE interferometer developed by SmarAct is a high-resolution displacement sensor based on a Michelson interferometer. Relative differences in the optical path length between a beam splitter as well as the target and reference mirror are measured. Typically, the reference mirror is integrated into the sensor head to build an intrinsically stable reference arm.

Now SmarAct presents a sensor head without reference mirror, allowing differential measurements between a target mirror and a reference mirror whose location can be freely chosen by the user. This allows measuring displacements relative to a certain fixed point of an experimental setup, as well as minimization of noise. Both arms are aligned in order to reduce environmental influences as much as possible.

2. SETUP
A SmarAct SLC-1730 piezo positioner was placed on top of an aluminum block, see Figure 1.

![Figure 1. Experimental setup. The laser light coming from the PICO SCALE controller is split in a beam splitter. One part is directly guided to a target mirror at the base plate of the sample (reference beam). The other part (probe beam) is deflected by a prism and guided to the actual target which could be actuated.](image)

The target mirror was mounted on top of the positioner, whereas the reference mirror was attached to the aluminum block. The reference beam was guided towards the reference mirror with the help of a carefully aligned prism glued to the sensor head holder. This setup ensured close to equal optical distances between sensor head holder and targets for both the target and the reference arm of the interferometer. (Please note, that a minimum optical path difference of 13 mm is required for operation of the PICO SCALE.

In this setup the target beam's arm was 13 mm longer by folding it via a prism.) In order to generate a measurement signal, a sinusoidal voltage signal with an amplitude of 10 mV and a frequency of 0.5 Hz was applied to the positioner, resulting in a periodic displacement of the target mirror with an amplitude of much less than one nanometer. The streaming frequency of the PICO SCALE was set to 19 Hz.

Such a small, low-frequency signal is very hard to detect because usually, it would be masked by temperature and air fluctuations, leading to a change in the refractive index of the air, and thus the optical path length. Moreover, temperature fluctuations affect the distance between the sensor head and the target itself due to thermal expansion of the whole setup. The following results show that by using a differential measurement principle, the fluctuations are effectively canceled out, drastically reducing noise and enabling a measurement resolution of far below one nanometer without any additional signal processing.

3. MEASUREMENT RESULTS
The time signal of the measurement over more than 16 minutes is shown in figure 2. It is worth noting that the drift of the measurement signal is on the order of a single nanometer during this time under atmospheric conditions. On the right hand side of figure 2 a zoomed-in view of 10 seconds is shown, clearly showing the sinusoidal displacement of the piezo positioner. The red lines in the graph underline the fact that the peak-to-peak amplitude of the signal is way below 1 nm.

A Fourier transform of the time signal is shown in figure 3, showing the signal at 0.5 Hz and the absence of any other significant low-frequency noise which would usually be present. This shows not only the potential
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Figure 2. Left: Time signal of the piezo displacement over 1000 seconds as described in the text. Note the very low drift of the signal over that span of time. Right: A zoomed-in plot of the time signal clearly shows the 0.5 Hz sub-nanometer oscillation. A 1 nm range is indicated by the red lines.

Figure 3. Fourier spectrum of the time signal shown in figure 2. No post-processing of the data was performed despite normalizing the FFT amplitude.

Figure 4. Environmental fluctuations of the experimental setup, measured by a sensor head with internal reference mirror.

of the differential measurement, made possible by the fact that the PICO SCALE interferometer relies on the Michelson principle, but also the very low noise of the electronics inside the PICO SCALE controller.

4. COMPARISON WITH STANDARD MEASUREMENT

For comparison, a measurement over 1000 seconds was carried out with a standard PICO SCALE sensor head (with integrated reference mirror). The experimental setup was the same as described above despite the use of the reference beam measuring the movement of the base plate. The piezo oscillation was turned off in order to measure only the environmental influence. The results are shown in figure 4. Although the stability of the experimental setup is obviously very good with only 5 nm of drift over that span of time, and a noise level below 1 nm, a tiny signal of interest as shown above could not be easily measured that way. It would need to be extracted by averaging over a large number of Fourier spectra. At the same time, the extremely low drift of the differential measurement is very interesting for mid- and long-term stability investigations.
# High resolution differential measurements with the PicoScale laser interferometer

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