PICOSCALE Interferometer with chopped measurement beam

Abstract
The **PICO**SCALE *Interferometer* allows for high-precision position measurements based on a laser interferometer in a Michelson configuration. A laser beam is split into a (very short and stable) reference arm and a probe arm. After reflection on the reference and probe mirror, respectively, the beams recombine at the beam splitter. The **PICO**SCALE position calculation relies on permanent evaluation of interference patterns. It is, however, possible to track the probe mirror's position even when the laser beam is permanently interrupted, which is used in specific experimental setups.

INTRODUCTION

In specific experimental setups, a regular interruption of an optical path is required for lock-in techniques, for example. In these cases, the standard usage of interferometric readout of the path length is daunting as generally interference fringes have to be continuously logged and evaluated. However, the **PICO**SCALE interferometer is still able to track the displacement of the target by making use of the powerful *Advanced Trigger* firmware module.

1. SETUP

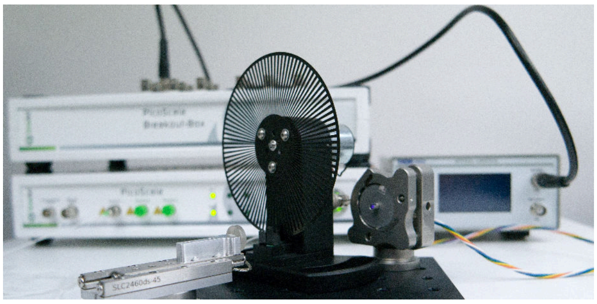

Figure 1. *Experimental setup.*

A proof-of-principle setup is shown in Figure 1. The probe beam of the **PICO**SCALE is regularly blocked by an optical chopping wheel, controlled by a dedicated driver. The chopper and its driver were kindly provided by the group for Attosecond Physics at the Max-Planck-Institute of Quantum Optics (MPQ) and Ludwig-Maximilians-Universität München. The target mirror is mounted to one of SmarAct's linear translation stages. Due to the frequent probe beam interruption, the standard calculation of the target mirror's position fails as it relies on continuous evaluation of interference fringes.

2. THE SOLUTION

2.1 Idea

As the **PICO**SCALE's period counter in this specific application cannot be used, the position calculation has to be bypassed. Therefore, the raw data of $S(\omega)$ and $S(2\omega)$ values must be polled in a triggered way. These are the data obtained from internal lock-in filtering of the received optical signal with the frequencies ω and 2ω, respectively. Generally, they are used inside the **PICO**SCALE controller to calculate the relative position of the target mirror. See **PICO**SCALE User Manual for further details. In Figure 2, the raw values of $S(\omega)$ and $S(2\omega)$ are shown together with the respective chopper state and while the probe mirror is moved by a few µm. Clearly, the expected sinusoids are overlapped with the chopper state so that the signals break down. (The data are 16bit unsigned integers so that bit 32768 corresponds to zero.)

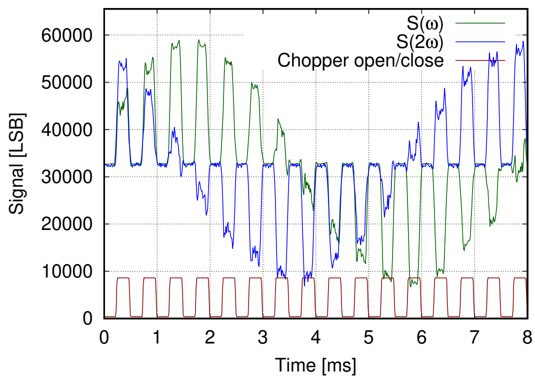

Figure 2. *Chopped* **PICO**SCALE. *Whenever the chopper interrupts the probe beam, the $S(\omega)$ and $S(2\omega)$ values reduce to zero (i.e. bit number 32768) and the internal position calculation of the* **PICO**SCALE *would become invalid.*

The idea of the approach to operate the **PICO**SCALE with a chopped probe beam is to only pick raw data points whenever the beam path is clear and undisturbed. This requires the *Advanced Trigger* module. A *triggered streaming* of raw data is set up and the position calculation is performed subsequently in post-processing[1].

2.2 Implementation

The implementation has fully been realized within the **PICO**SCALE graphical user interface (GUI) and a small *python* program was used for the post-processing. The GUI was set up as follows:

2.2.1 Define two clocks in the PICOSCALE

In the *Modules* section of the GUI, two clock generators of the same frequency (here: 2000 Hz) are defined. One is used to trigger the driver of the chopper, the other triggers the stream generator of the **PICO**SCALE. To synchronize data extraction and chopping, the phases of the clock generators are adjusted.
In the *Interfaces* section of the GUI, the two clocks are output at two Digital IO pins. Using the **PICO**SCALE *Breakout Box* (BOB), one of the pins is connected to the *EXT INPUT* pin of the chopper driver (System MC2000 from Thorlabs). The chopper driver is set up to use *EXT INPUT* as clock reference for chopping.

2.2.2 Configure internal trigger

Within the *Advanced Trigger* firmware module of the **PICO**SCALE, it is possible to define triggers and logically relate many trigger sources almost at wish. Here, only one trigger is required that will start and stop the data stream extraction. In the *Advanced Trigger →Trigger Sources Configuration* panel a *GPIO Trigger* is used as event for Trigger Source 1 and *Positive Level* is chosen as trigger condition.

2.2.3 Configure stream generator

In the *Advanced Trigger →Stream Generator Configuration*, the conditions for the triggered data extraction are set up. The previously defined Trigger 1 is used both as *Start Trigger Index* and *Stop Trigger Index*. This configures a stream generator that, with each trigger event, records the specified number of data frames from the **PICO**SCALE. Here, a *Post Frame Count* of 1 is used.

2.2.4 Stream data

In the *Stream Monitor* the data extraction has to use the configured stream generator configuration. Therefore, *Triggered Streaming* is chosen in the appropriate *Stream Mode* menu. The frame rate has to be significantly higher than the chopping frequency (here: 156.25 kHz).
As the idea was to bypass the internal **PICO**SCALE position calculation, *Sw Raw* and *S2w Raw* are chosen as data sources in two graphs. By clicking the *Activate* button, the streaming will start.

[1] An online calculation of the positions is also possible in customized LabVIEW™ modules, or similar, which is beyond the scope of this note. Alternatively, please refer to [1], where the entire position calculation is triggered.

2.2.5 Phase alignment

It may be necessary to adjust the relative phases between the chopper and the stream generator. The clock generator of the **PICO**SCALE allows to shift the generated signals by setting the phase and therefore synchronization of chopping and data extraction is possible with built-in modules. This way, the triggered stream can be optimized such that no beam interruptions are visible anymore. When this is achieved, streaming and beam interrupts are perfectly asynchronous.

2.3 Measurement

While moving the linear stage, the raw values of $S(\omega)$ and $S(2\omega)$ are sampled. When the measurement is done, the streaming is stopped and the date can be stored in a file.

2.4 Post-processing

In the post-processing, actual position data are calculated from the raw data. This may be performed with any programming language on a PC. After offset correction and normalization one obtains $S_N(\omega)$ and $S_N(2\omega)$ with a value range of $[-1, 1]$ each.
Second, the angle between the vector, which is defined by $S_N(\omega)$ and $S_N(2\omega)$ needs to be calculated

$$\alpha = \angle[S_N(\omega), S_N(2\omega)] \qquad (1)$$

which is a simple arctan function. Proper quadrature recognition and angle unwrapping of the result has to be performed.
Finally, the relative position of the probe mirror in the Michelson interferometer can be calculated as

$$x_{\text{rel}} = \frac{\alpha}{4\pi}\lambda, \qquad (2)$$

where α is the angle as calculated in Eq. (1) and λ is the laser wavelength (1550 nm).

2.5 Results

The target mirror was translated back and forth by 2 µm while tracking the raw data of the **PICO**SCALE with chopped probe beam. For reference, the same experiment and data analysis was performed with the probe beam undisturbed. The results are shown in 3. It can be seen that there is no additional disturbance visible, when the probe beam is chopped!
During the measurement one must provide that the position does not change too fast during one chopping period as information might get lost. In Figure 4, the probe mirror was translated with different speeds and it turns out that at a speed of 1 mm per second, the calculation of positions becomes invalid, due to the limited chopping frequency.

2.6 Discussion

This application note demonstrates that the **PICO**SCALE can be used in setups with chopped probe

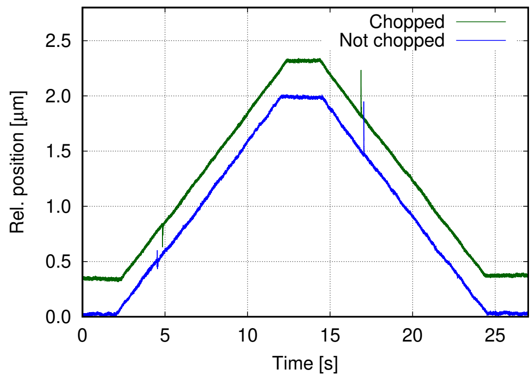

Figure 3. *Relative position of a probe mirror that was moved 2 µm back and forth with the probe beam undisturbed (blue trace) and chopped (green trace). For better visibility an offset was added to the green trace. The tiny spikes during the movement are induced by the stick-slip motion of the piezo positioner.*

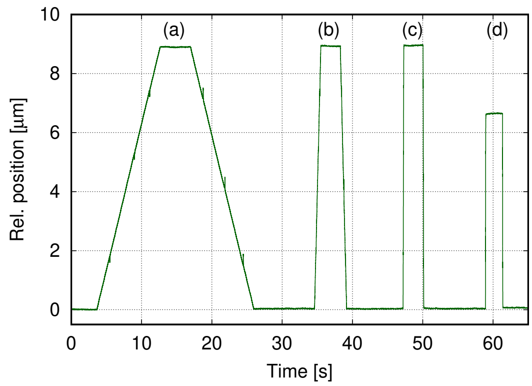

Figure 4. *Measurement of the relative position of a mirror with chopped probe beam (chopping frequency 2 kHz). The target was moved by 9 µm back and forth and the translation speed was set to (a) 1 µm/s, (b) 10 µm/s, (c) 100 µm/s, (d) 1 mm/s.*

beams. Due to the chopping, the translation speed of the probe is limited. However, a higher chopper rate would result in higher trackable speeds of the target mirror. In the measurement presented above a chopper frequency of 2 kHz was used, but it was also successfully performed with a chopper frequency of 10 kHz, which was the highest frequency the chopper driver was able to follow. The **PICO**SCALE itself allows triggering with much higher frequencies (up to 10 MHz).

3. CONCLUSION

In this application note a **PICO**SCALE *Interferometer* with chopped measurement beam is used.Therefore, only raw data are streamed and the position calculation is performed in post-processing methods. Please note, that the accuracy and acquisition speed are very limited with the methods presented here compared to the **PICO**SCALE *Interferometer* in it's standard position calculation mode.

4. RELATED APPLICATIONS

Please also see Application Note AN00051 [1], where the **PICO**SCALE *Interferometer* has been used with an electro-optical switch. The entire position calculation was triggered which allows for even more accurate displacement data. This way the average power in the optical beam could be reduced by two orders of magnitude.
Please also see a related publication [2], where the **PICO**SCALE *Interferometer* was used with chopped beam.

5. ACKNOWLEDGEMENTS

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REFERENCES

[1] SmarAct. PICOSCALE displacement measurements with low output power using an optical switch. *SmarAct Application Note*, May 2019.

[2] Wolfgang Schweinberger, Lenard Vamos, Jia Xu, Syed A. Hussain, Christoph Baune, Sebastian Rode, and Ioachim Pupeza. Interferometric delay tracking for low-noise Mach-Zehnder-type scanning measurements. *Opt. Express*, 27(4):4789–4798, Feb 2019.

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