Interferometric Closed-Loop Piezo Positioning

Ultra-Precise Closed-Loop Position Control with attocube’s AMC100 and IDS3010

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Introduction

Downscaling reaches nearly every area in our life. This trend is visible in multiple industries from semiconductor manufacturing equipment to advanced fiber optics assembly and pushes the limits of positioning precision towards ever higher levels. Piezo-based positioners are the preferred choice for reliable nano-motions, but eventually the achievable repeatability is limited by the integrated closed loop sensor. Increased positioning performance can only be achieved in combination with sensors with a magnitude of higher precision, ideally with the ability to measure as close as possible at the point of interest. attocube’s IDS3010 interferometer is perfectly suited for this task and the miniaturized and modular design allows straight forward integration and operation of ultra-precise positioning systems.

For applications like the assembly and alignment of fiber arrays (Figure 1), multi-axis positioning with the highest repeatability and accuracy is key. The array is placed on a xyz positioner stack and to ensure ideal transmission of light, the signal intensity of each fiber core (diameter less than 100 µm), has to be scanned with an external probe. Allowing a high resolution image of the detected intensity distribution, the relative movement between probe and fiber core has to be repeatable within 25 nm. Furthermore, to enable the inspection of all fibers in the array, highly accurate movements of up to several millimeters are essential.

This application note presents a closed loop positioning system consisting of a piezo-based positioner ECSx3030 in combination with a Fabry-Pérot interferometer (Figure 2). The IDS3010 has a resolution of 1 pm and enables precise nano-positioning up to 5 meters, with a repeatability of few nanometers. The ECSx3030 positioner is designed for industrial applications and offers linear bearings for high stability, a travel range of 20 mm, a maximum velocity of 4.5 mm/s and high loads up to 9 kg.

Encoder Options

attocube’s positioners can be used with different encoders. The resistive encoders have a resolution of 200 nm and a repeatability of 1-2 µm. They are often used in low-temperature environments, for example at 4 Kelvin. The optoelectronic encoders with a resolution of 1 nm and a repeatability of 50 nm are used for attocube EC* series positioners and are designed for vacuum and room temperature applications. These encoders are integrated into the individual positioner, which simplifies the setup, but also increases the distance between the point of interest (*e.g.* the sample) and the sensor’s measurement point. Using the laser based IDS3010 as an external sensor offers the possibility to measure directly on or very close to the sample. This significantly improves the true positioning precision. Furthermore, in an xy application the squareness of the motion is no longer limited by the tolerances of the encoder or a positioner mounting. Lateral runouts and their amplification by a lever can be measured and compensated by the IDS.

Figure 1: Interferometric closed loop control of an XYZ positioner stack using the AMC100 and the IDS310. The fiber array and a mirror block are mounted on the top positioner. The 3 miniaturized sensor heads measure the XYZ displacement close to the point of interest (= fiber array).

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Moreover, any changes (e.g. thermal drifts) of the setup are also compensated at the point of interest. Overall, with an orthogonal alignment of the sensor heads, both the repeatability and the accuracy in respect to external references can be significantly improved.

Setup

The setup consists of a linear ECSx3030 positioner driven and controlled by the AMC100 position controller and the closed loop position feedback was measured with the IDS3010 using a D4/F17 sensor head focusing on a mirror target on top of the positioner. Figure 2 shows the setup. The shown measurement results were performed at ambient conditions on an optical table.

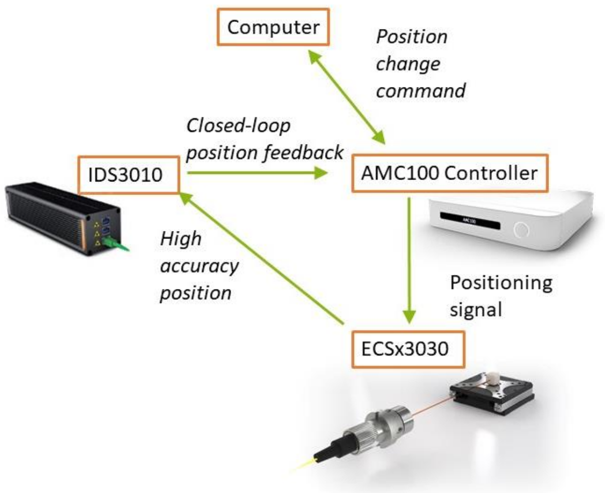

Figure 2: Setup for real-time positioning tracking of an x-positioner system and extendable with y- and z-direction. The grey cube presents the point of interest, where the sample is placed.

The measurement requires a very stable setup and good temperature stability in order to prevent mechanical oscillations. To prove the achievable precision, the position of the stage was recorded with a second independent IDS with 50 kHz bandwidth. The measured data, sampled down to 625 Hz by averaging, are shown in Figure 3.

Measurement Results

The measurement starts at a reference position set to zero. Then 1 µm steps are executed every 10 seconds. Figure 3 depicts all position steps in the top graph. The graphs below show the zoom in of each relatively constant position. The averaged data shows that a repeatability of 5 nm at ambient laboratory conditions is possible. First the positioner overshoots the target position in the moving direction up to 100 nm due to the piezo slip-stick movement. Due to the fine positioning the target position is reached.

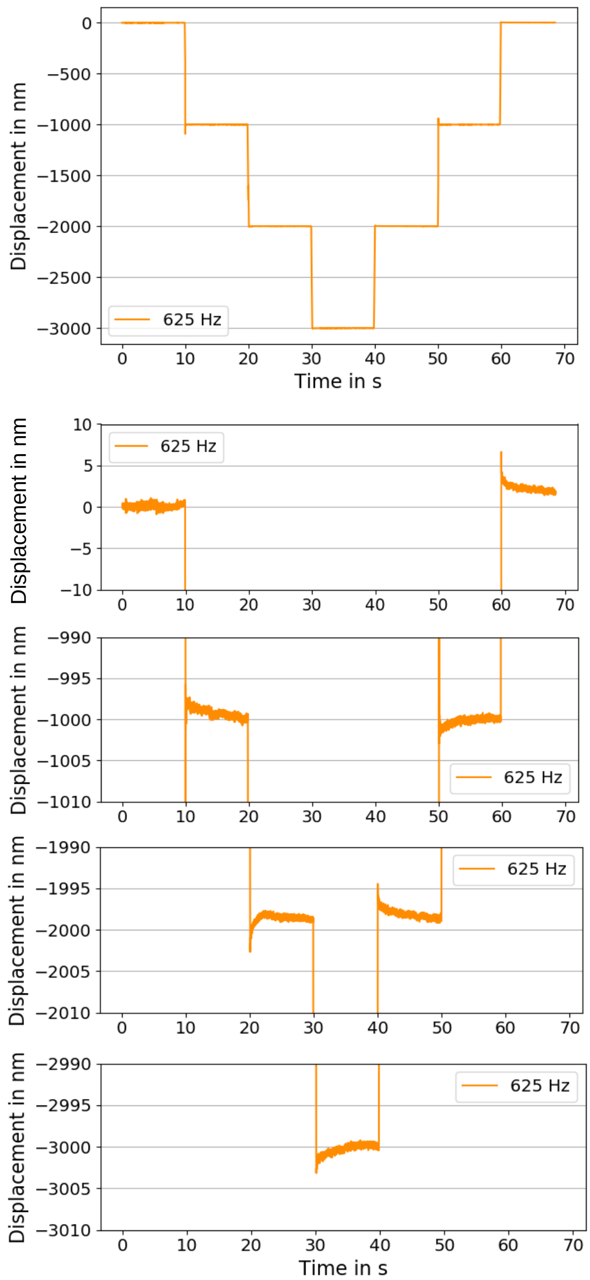

Figure 3: Measurement result of 1 µm steps and a repeatability better than 5 nm.

Next, we present a nanometer closed loop measurement. While the AMC100 controller outputted signals for 9 incremental 1 nm steps within ~35 seconds, the IDS3010 has detected a total displacement of around 8.8 nm (see Figure 4). Position steps with around 1 nm in average are visible in the 625 Hz signal.

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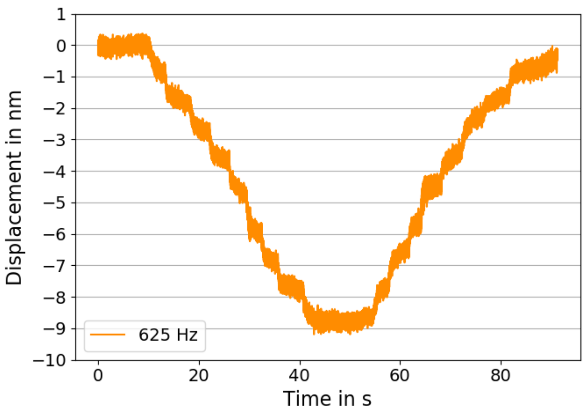

Figure 4: Measurement result of incremental 1 nm steps.

Conclusion

Using the IDS3010 as an external closed loop sensor for attocube's positioners, positioning targets with 5 nm repeatability and 1 nm steps at very stable ambient laboratory conditions could be realized. The systems can also be used in vacuum, which gives the opportunity to realize even higher precision due to the reduction of air and temperature fluctuations. The miniaturized and modular sensor design allows a user-friendly integration into the machine or setup, which again facilitates measurements close to the point of interest.

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