Multi-channel Optical Fiber Based Displacement Metrology

P-F Braun and K. Karrai
attocube systems AG, Königinstr. 11a, D-80539 München, Germany

khaled.karrai@attocube.com

Abstract

The need for multi-channel, compact, non invasive and accurate displacement sensing solutions dramatically increased in just the past couple of years. Ultra-high precision systems such as metrologic atomic force microscopes [1], deep-UV mask aligner, ultra-large telescopes or 50 km long particle accelerators are just few examples of ongoing international projects with extremely ambitious specifications for nm accuracy and sub nm sensitivity. Often enough the requirements are such that the position of tens of different key components of such complex apparatus must be tracked simultaneously in environments as demanding as ultra-high vacuum or cryogenic temperatures and this with a required immunity against drift on the scale of sub nanometer during hours and days. The increasing complexity of the systems dictates that there is very little space available for the large number of sensing heads that can be added while at the same time keeping a tight control on energy budget and financial costs. In this presentation we discuss novel original technological solutions that were recently developed to address the abovementioned challenges.

1 Specifications and system requirements

The multiple-channel sensor system is entirely based on optical fiber technology operating at telecom wavelength, and its sensing heads are small enough (typically sub-cm) to conveniently fit in tight or constrained spaces. The optical signal containing the interferometric information is collected remotely through the same telecom fiber that ports the laser light to the sensing head. A quadrature signal of the interferometric beats is generated using a novel patented technique allowing measuring both the displacement and its direction [2]. Our architecture consists of two subsystems. The first consists of a multitude of very compact and passive interferometer displacement sensing heads (up to nine in our current system) all of them fiber connected. The second consists of a central laser and electronic control unit capable of analysing simultaneously the displacement each interferometer head channel and this with a 1MHz bandwidth. The sensing heads are passive and made only of a single mode fibre and a collimating lens tube. The sensing head is non invasive as it produces nor heat nor electromagnetic disturbances. All heat sources are concentrated in the multichannel control unit placed remotely from heads. Using telecom laser wavelengths allows for operation with large distances between the sensor head and the control unit. We have verified the functionality of our displacement sensing system with up to 1 km of fiber length connecting the sensor head to the control unit. To insure a wavelength accuracy of better than 0.5 ppm the telecom laser was actively locked to a NIST traceable molecular absorption gas cell. The accuracy could in principle be much more improved if required but involving increasing costs.

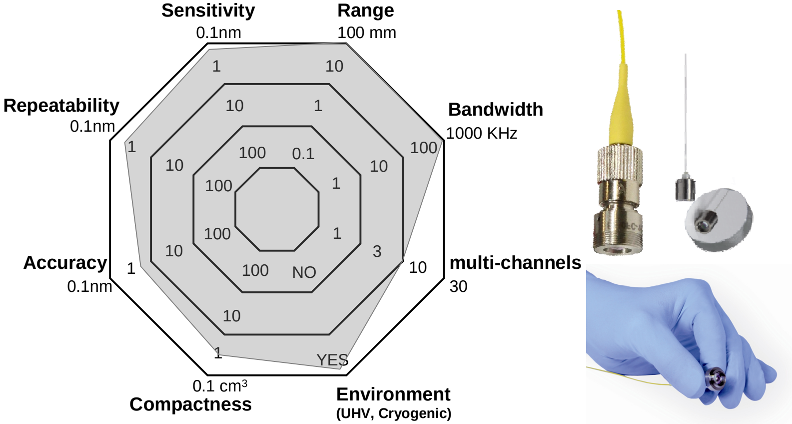

Figure 1: Left: specification chart for the multi channel interferometer. The shaded area corresponds to the specifications reached in this work. Right top: two different sensor heads. The hand is shown holding the larger of the two sensor heads.

A number of specifications, all shown in figure 1 in a form of a specification map, were required for the displacement sensor to comply with our applications in ultra high resolution scanning probe microscopy in extreme environment. All of them were reached for our needs. The number of channels simultaneously measured were limited to 9 as we did not require more.

2 Long term stability tests

The challenge in this type of metrology is to demonstrate the immunity against drift of the whole chain of detection from laser to photo detector, from signal amplification to demodulation while maintaining the required accuracy and sensitivity. In order optimize the complete chain of detection we cooled down the position sensor head as well as the target at cryogenic temperature (5 K). This is done in order to freeze all sources of thermal and mechanical drifts.

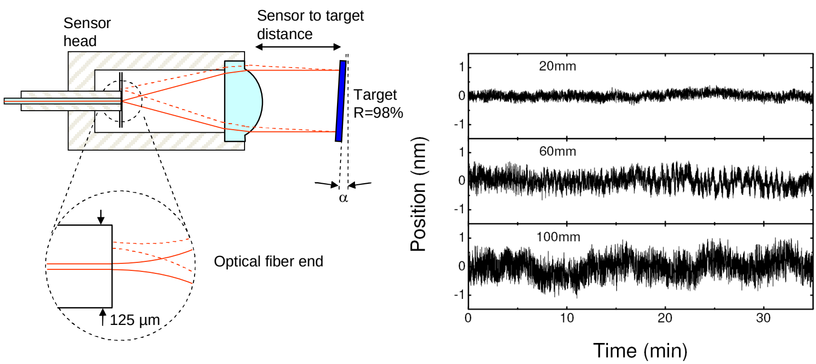

Figure 2: Left: schematics of the sensor head and mirror target. The patented double-pass confocal arrangement allows for a comfortable tolerance of α ± 0.4° within which the interference signal is optimal while allowing a target motion up to 100 mm. Right: stability test (100 Hz band width per data point) for three pairs of target / sensor systems with different distances. The three systems were placed at low temperature (5K) to eliminate thermal drifts. During the measurements, the temperature of the room in which the electronic and laser control unit was located was made to fluctuate by ±2°.

Our stability test system was made out of four reflecting mirror targets placed respectively at 10, 20 ,50, and 100 mm distance form four different sensor heads. All four systems were cooled simultaneously placed in a cryogenic chamber at low pressure of helium exchange gas insuring a homogenous cooling down to about 5K. Such optimization steps turn out to be crucial in order to really trust the measurement chain. The stability measurements showed excellent long term immunity against drift. The measured position noise increased with the target distance indicating that the limiting factor is in large part due to the residual fluctuation of the wavelength. The 2σ position noise was 0.25 nm, 0.57 nm and 0.80 nm for the 20 mm, 50 mm and 100 mm target distance respectively

3 Velocity tests

Because our novel displacement sensing technique being based on a fast demodulation technique [2] we needed to verify the tracking velocity of our sensors. Here a target was mounted on a magnetic linear drive and was oscillated with velocities in excess of ± 1/2 m/sec. Figure 3 shows convincingly that the demodulation is fast enough to insure proper tracking.

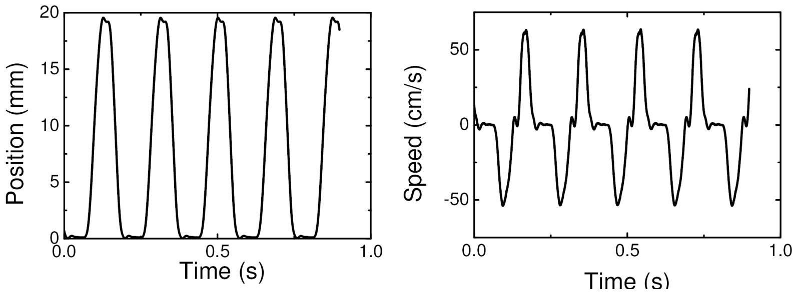

Figure 3: The target was moved periodically with amplitude of 20 mm and a velocity in excess of 600 mm/sec.

References:

[1] G. Dai, H. Wolff, F. Pohlenz, and H-U. Danzebrink Rev. Sci. Instrum. 80, 043702 (2009)

[2] K. Karrai, P-F. Braun "*Ultra-compact Non-invasive Interferometric Displacement Sensor"* Proceedings of the euspen International Conference – Delft – June 2010.