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Measuring sub nanoradian angles

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Summary:

This paper describes the application of optical interferometry for high accuracy angle metrology to characterize the performance of Diamond Light Source's small angle generator NANGO that is used to support testing of x-ray optics. The optical interferometer offers a higher resolution and bandwidth than is achievable with commercially available autocollimators and was used to measure traceably nanoradian steps and sub nanoradian oscillations generated by NANGO.

Keywords: optical interferometry, angle metrology, traceability, picoradians, nanometrology

Introduction

Optical interferometry is an essential link in the traceability chain for length metrology [1]. Small angles are usually measured using autocollimators, however, since angle measurement is really a measurement of two distances, optical interferometry lends itself to angle measurement. In recent years there have been significant advances in the fields of small (nanoradian) angle metrology to support a range of applications [2,3]. One of the most demanding applications for angle metrology focuses on the metrology of X-ray optics where nanoradian metrology is routinely required.

Angle metrology at Diamond

Diamond Light Source is the UK's synchrotron light facility serving the UK's academic and industrial research communities. Nanoradian angle metrology is required both to position components in front of X-ray beams emerging from the particle accelerators and for the quality assessment of X-ray optics.

To meet the requirements for angle metrology, Diamond constructed NANGO [4], a flexure-based, small angle generator designed to provide angle metrology. Although NANGO has an internal encoder, independent verification of its performance was required.

NPL angle interferometer

The NPL angle interferometer is a homodyne interferometer that was originally designed as a one axis, high-resolution interferometer for measuring angular errors (pitch and yaw, depending on the orientation of the interferometer) in nanopositioning stages. A schematic diagram is shown in Figure 1. It comprises two components; a fixed part, and a moving part that sits on the rotating device, NANGO. The main components in the fixed part are two Kösters prisms that are cemented together. Prior to cementing the faces, a phase quadrature metal coating [5] was deposited onto one of the faces in order to form a beamsplitter to generate a phase difference between the transmitted and reflected beams. The design of the interferometer is symmetric. In the path of the interferometer, light emerges from the Kösters prism and is incident on a roof prism on the moving component. The light is reflected back to the fixed body and then re-reflected back to the roof prism at a lower level. The light is then reflected back into the Kösters prism before recombining with light at the beamsplitter that had passed through the other side of the interferometer. The returned reflected and transmitted beams are in approximate phase quadrature (i.e. 90° phase difference) allowing for bi-directional counting of displacement.

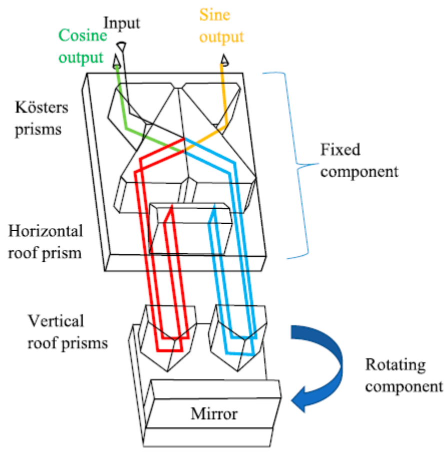

Fig. 1 The NPL angle interferometer

The interferometer design is such that as the moving component rotates, there are changes in the length of the two interferometer beam paths. If the separation of the two roof prisms is known, the angle of rotation can be calculated *i.e.,* the optical equivalent of a sine bar. The interferometer design is such that one optical fringe (158 nm) corresponds to ~ 4.8 µradians (1 arc second). This is dependent on the roof prisms' separation. A mirror is mounted on the back of the moving part to enable an autocollimator to directly determine the angle corresponding to one optical fringe.

Measurements of NANGO

Figure 2 shows the output from the optical interferometer when NANGO was commanded to generate 1.0 nanoradian steps. This represented the limit of NANGO's performance in closed loop due to the resolution of the control system for the actuators in NANGO.

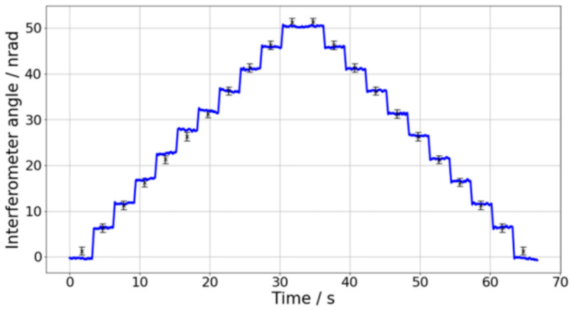

Figure 2: The interferometer output when NANGO was commanded to make 1.0 nanoradian steps

The higher bandwidth of the interferometer electronics (200 kHz) in comparison to the autocollimator (25 Hz) enabled the dynamic performance of NANGO to be investigated. Figure 3 shows the interferometer measurements of NANGO's rotation when NANGO was commanded to make a 300 nanoradian step.

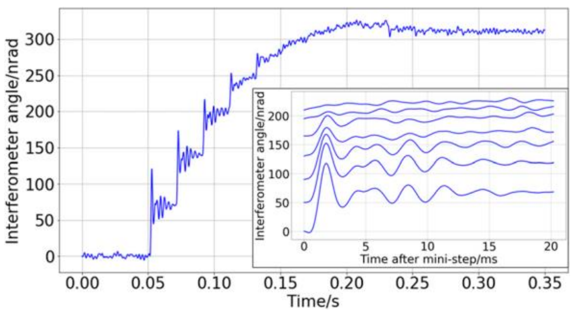

Figure 3: The dynamic behaviour of NANGO when making a 300 nanoradian step.

The step comprises a series of successively smaller steps, each slightly overshooting the target position. Sub nanoradian performance of NANGO was investigated in open loop; angular displacements were generated by applying a sinusoidal signal to the actuator. This had the advantages that smaller steps be generated and Fourier filtering could be used without any rounding to the signal.

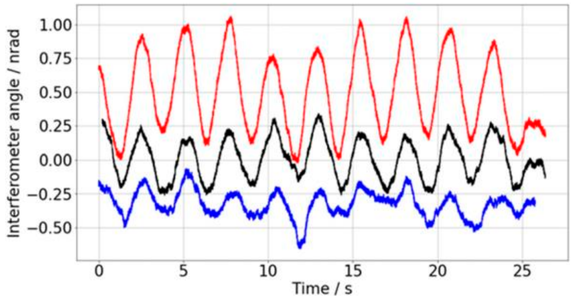

Figure 4. The interferometer signals as voltages were applied to NANGO's actuator to generate 500 picoradian, 250 picoradian or 125 picoradian steps. Note signals displaced vertically for clarity

Figure 4 shows the interferometer output when driving signals were applied to NANGO to generate nominal 500 picoradian, 250 picoradian 125 picoradians oscillations.

Conclusions

The NPL interferometer has validated the performance of NANGO at the nano- and sub nanoradian level. This enhances the metrological capability at Diamond for the evaluation of rotation stages and X-ray optics. Through this work, we have identified areas for improvement both in NANGO and the interferometer. Further details of this work together with an uncertainty budget can be found [6].

Acknowledgements

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