Spacial positioning correction for multi-axis nanopositioning stages

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Introduction

All moving systems have unwanted motion that causes positioning errors. This is most significant for longer-range stages, and can be the limiting factor in positioning accuracy.

Linearity corrections for a single-axis are common, but the complexity of measuring and compensating for repeatable errors in multi-axis systems is considerably more challenging.

Queensgate's multi-axis flexure stages with ranges 400 µm – 800 µm in all axes have had their positioning errors measured using interferometry. Higher order polynomials have been used to apply a novel 3D real-time correction, that reduced stage errors by an order of magnitude.

Stages evaluated

Two stages were selected: a prototype QGSPXY600Z600 with scan range 600 µm in X, Y and Z axes, was used for primary testing of the 3D correction algorithm.

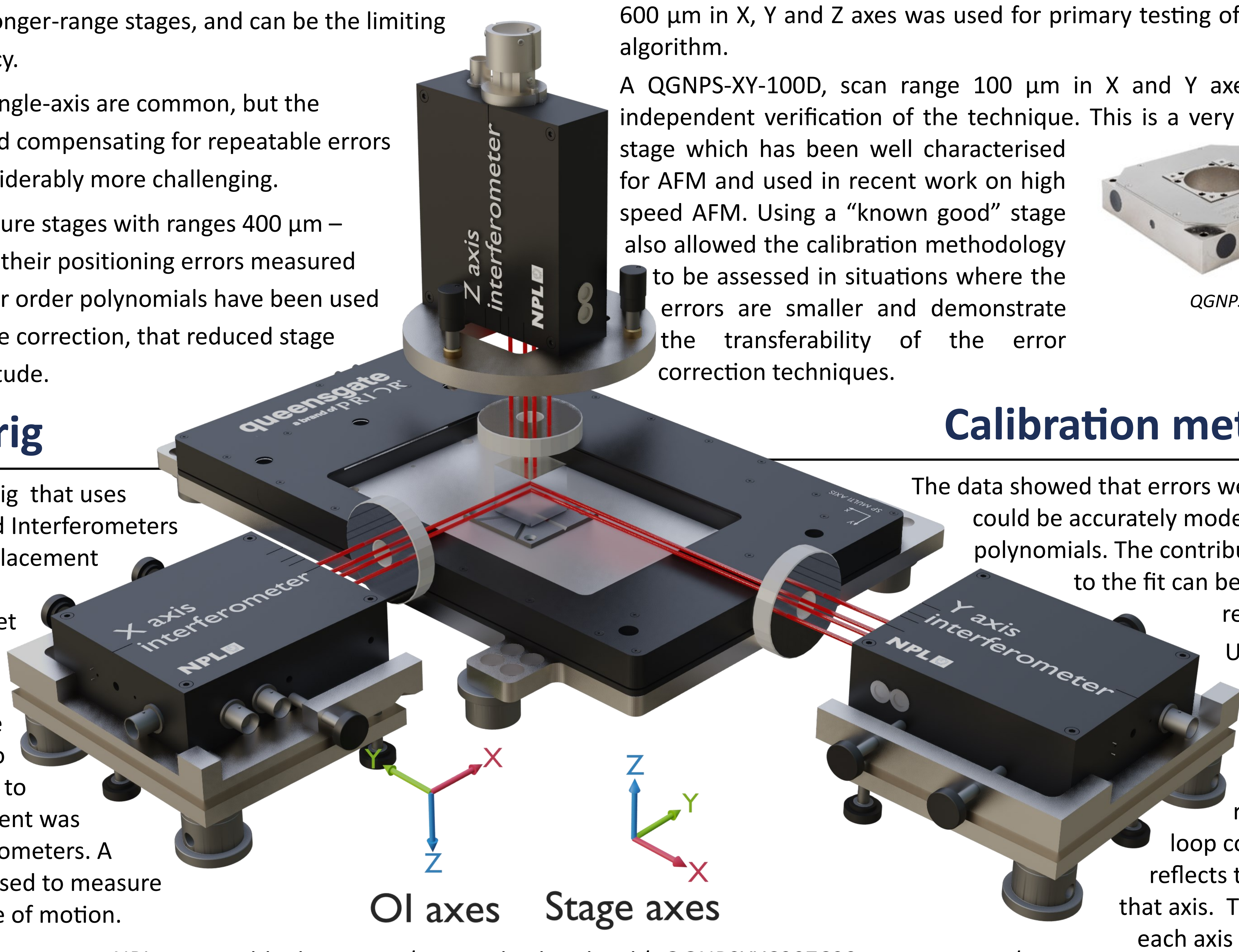
A QGNPS-XY-100D, scan range 100 µm in X and Y axes, was used for independent verification of the technique. This is a very high performance stage which has been well characterised for AFM and used in recent work on high speed AFM. Using a "known good" stage also allowed the calibration methodology to be assessed in situations where the errors are smaller and demonstrate the transferability of the error correction techniques.

QGNPS-XY-100D

The NPL stage rig

NPL has developed a stage rig that uses three orthogonally mounted Interferometers to measure the relative displacement between a mirror cube mounted on a stage and a set of reference mirrors.

For each point in the stage volume of motion, the stage was commanded to move to a position and then allowed to settle. The actual displacement was then recorded from interferometers. A basic raster scan path was used to measure over all points in the volume of motion.



NPL nanopositioning stage characterisation rig with QGNPSXY600Z600 stage mounted. (Optomechanics for mounting mirrors and z interferometer omitted for clarity.)

Calibration methodology

The data showed that errors were repeatable and could be accurately modelled with 5th-order polynomials. The contribution of each point to the fit can be weighted to allow rejection of outliers.

Using the calibrated polynomials, a correction is calculated so that the (x,y,z) position reported to closed-loop control for each axis reflects the true position in that axis. The control loop for each axis can then servo the stage to achieve the desired true position.

Results

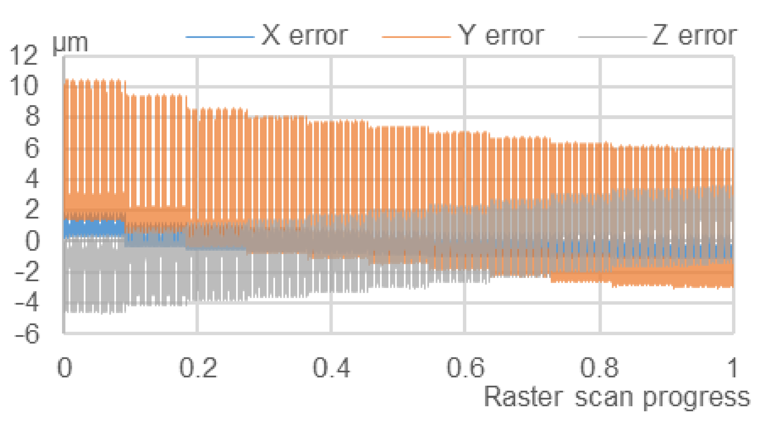
QGNPSXY600Z600

Before correction

Axis of motion	Error
X	5 µm
Y	9 µm
Z	5 µm

After correction

Axis of motion	"Fast" axis	Error peak-to-peak	Fraction of original
X	X	0.5 µm	10%
Y		6 µm	33%
X	Y	2 µm	40%
Y		0.5 µm	6%
Z	Both	2 µm	40%



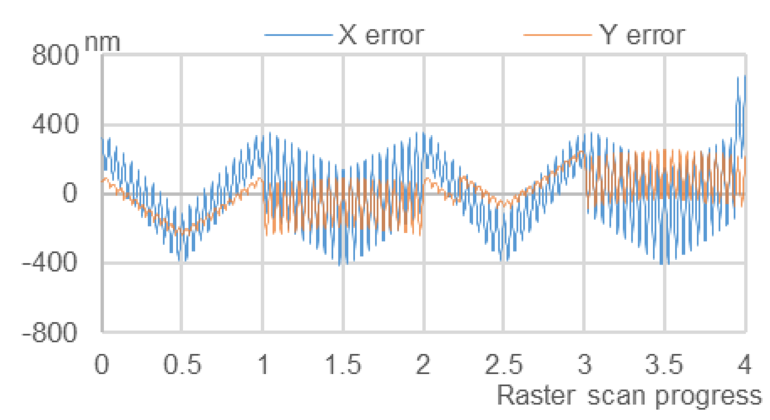
QGNPS-XY-100D

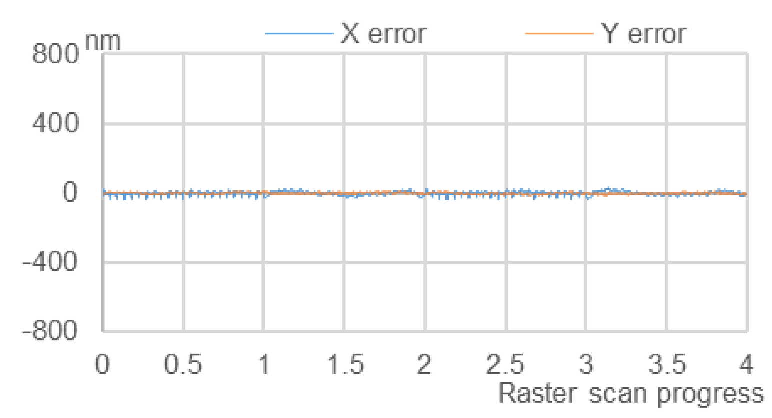
Before correction

Axis of motion	Error
X	800 nm
Y	400 nm

After correction

Axis of motion	"Fast" axis	Error peak-to-peak	Fraction of original
X	X	30 nm	4%
	Y	70 nm	9%
Y	Both	30 nm	8%





Conclusions

This work has demonstrated that significant reduction in spacial positioning errors for multi-axis stages can be achieved with a measurement and calibration methodology which is practical for production.

It should be noted that the improvement on the large multi-axis stage achieved performance in-line with the uncompensated shorter range XY stage. This achieves performance on a large range stage suitable for use in high precision applications such as AFM. Further improvements are likely using the more typical unidirectional imaging. It is also anticipated that the correction will be more effective on the XY only version, the QGSPXY700, as it is stiffer and has fewer degrees of freedom.

Department for Business Innovation & Skills
FUNDED BY BIS
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