Development of a Thermally Stable 2D Calibration Setup

J.A. Yagüe[1], J.J. Aguilar[1], S. Ontiveros[1], M. Valenzuela[1], J.A. Albajez[1]
[1]*University of Zaragoza (Spain)*

jyague@unizar.es

Abstract

The utilization of 2D non-contact sensors for measuring displacements is a more and more used alternative for the development of several degrees of freedom precision systems. Inside this group of sensors, optoelectronic devices such as CCDs (Charge-Coupled Devices) or PSDs (Position Sensitive Detectors) are included. Nevertheless, characterizing and adequately correcting the error of those sensors is needed in order to achieve the expected accuracy. In this paper a 2D calibration technique is proposed to keep the traceability when calibrating 2D sensors. A thermally stable 2D calibration setup manufactured in Zerodur has been developed using laser encoders as a reference. This measuring system allows the compensation of environmental conditions such as temperature changes. The setup has been used to characterize and correct a Cross-Grid Encoder at different temperatures. The results of these characterizations are illustrated in this paper, analyzing the different influences on the final measurement uncertainty of the encoder.

1 Introduction

In recent years, 2D non-contact sensors have seen a great increase of their use in the micro and nano-technology such as six degrees of freedom devices where their degrees of freedom can be measured by different alternatives like capacitive sensors, laser, etc [1] or using three 2D non-contact sensor such as PSDs [2], being the last ones a low cost option.

A 2D Cross-Grid Encoder can be utilized as a calibration device to improve the accuracy of PSDs [2]. However, the calibration of those Cross-Grid Encoders itself is being done by the manufacturers in a separate way in each of the two axes by comparing the displacement in each of them to a laser interferometer and only along their central lines. Therefore, there are a big number of errors that cannot be determined by that traditional calibration. In this paper a 2D calibration technique is proposed to keep the traceability in case of using these systems as reference for the calibration of others, like PSDs, utilizing a laser encoders as a reference.

This measuring system allows the compensation of environmental conditions such as temperature changes. In addition, the calibration setup has been manufactured in Zerodur. These two features allow the system to keep stable at different thermal conditions, which has been used to characterize 2D measuring systems such as the 2D-Cross-Grid Encoder at different temperatures. This characterization and the consequent correction allow the Grid Encoder to be used as a measuring system in some nano-metrology applications where thermal conditions could not be kept perfectly stable in thermal chambers, but measured.

2 Experimental setup

The proposed technique used in this work consists of a Renishaw fiber optic laser encoder (RLE) dual axis system with nanometer resolution (10 nm), two plane mirrors, an independent thermal sensor in each axis and a 2D Grid Encoder KGM 181 from Heidenhain with nanometer resolution (±2 µm in accuracy) that includes a grid plate with waffle type graduation and scanning head. The calibration setup has been manufactured in Zerodur® allowing the compensation of environmental conditions such as temperature changes.

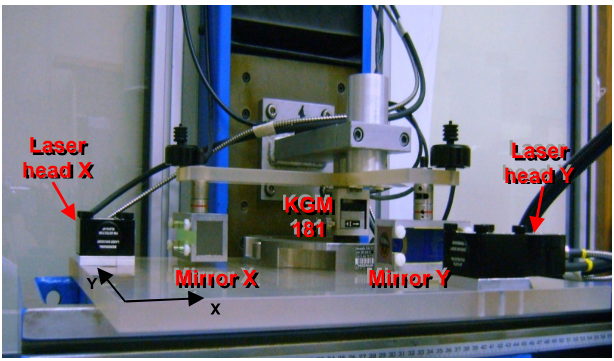

Figure 1: Experimental setup

The 2D stage setup presented in Figure 1 includes a Zerodur base where the X-Y laser detector heads and the KGM grid encoder are mounted. The main spindle holds the L-shape of Zerodur with the plane mirrors and the KGM scanning head.

In this setup the KGM scanning head and the laser detector heads are align to avoid Abbe errors in X, Y and Z axes. This metrology frame was kinematically coupled with a 2D moving table for the experiments.

2.1 Experiments

To evaluate the influences of the 2D calibration setup some experiments were made. Static tests of repeatability in different fixed points taking out 9000 data were made to study the stability of the system. The system did not show any systematic error, being the static stability on a single point better than 50 nm.

The 2D calibration method was carried out at three different temperatures (16, 20 and 24°C). 25 points inside an area of 60x60 mm were taken, monitoring the temperature, humidity and pressure by different sensors and compensating it by the Renishaw Compensation Unit for the Laser System. This experiment conditions imply the thermal stability of the calibration setup, but not of the sensor to be characterized (the Cross-Grid Encoder).

3 Results

The raw measuring data of the laser encoders and KGM were mathematically aligned and compared. The differences between the positions showed by the Lasers and the KGM are illustrated in Figure 2(a-c) for each of the 25 points taken.

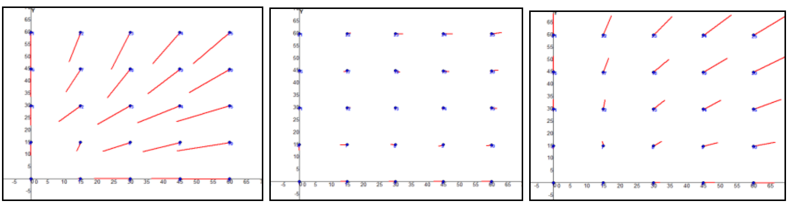

Figure 2: Error maps in mm with errors amplified by a factor of 3000 (Lasers vs. KGM). a) 24°C; b)20°C and c)16°C.

From the results in Figure 2 it can be observed a clear trend in the errors. A thermal correction was applied to correct this trend, showing that the correction factors for X and Y were very similar to the coefficient of linear thermal expansion of the Cross-Grid Encoder (around $8 \cdot 10^{-6}$ /ºC). After correction an uncertainty analysis of the KGM was carried out according to [3,4] for the three different temperatures. The main sources of uncertainty were temperature variations at every point, the calibration process, the laser uncertainty, etc. The results are shown in Table 1.

Table1: Uncertainty results in nanometers

24° C		20°C		16°C	
Ux(k=2)	Uy(k=2)	Ux(k=2)	Uy(k=2)	Ux(k=2)	Uy(k=2)
183	150	187	150	216	149

4 Conclusions

A thermally stable system that ensures traceability of 2D sensors has been develop in a measure range of 60x60 mm. The system shows a high repeatability and stability allowing a precise analysis of different error sources of the sensor to calibrate.

The adequate calibration and correction of 2D measuring systems using the setup here presented can open the field to use a higher number of sensors in nano-metrology applications.

References:

[1] M. Holmes, R. Hocken, D. Trumper, The long-range scanning stage: a novel platform for scanned-probe microscopy, Precision Engineering 24 (2000) 191-209.

[2] J.A. Yagüe, J.A. Albajez, M.A. Lope, J. Velázquez, J.J. Aguilar, Characterization and error correction of 2D low-cost opto-electronic sensors and applications to six degree-of-freedom probe, Proc. of the euspen conference, Zurich (Switzerland), 2008, 305-309.

[3] ISO/TR 230-9:2005 "Test code for machine tools. Estimation of measurement uncertainty for machine tools tests according to series ISO 230, basic equations".

[4] ISO 230-2:2006 "Test code for machine tools. Determination of accuracy and repeatability of positioning numerically controlled axes".