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Metrological set-up for calibrating 2-dimensional grid plates with sub-micrometre precision

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ABSTRACT

Calibration, performance verification and error correction of two dimensional (2D) optical metrology instruments, such as profile projectors, microscopes and "vision" systems are commonly carried out with the aid of calibrated 2D high-precision optical grid plates. This paper presents a high resolution 2D measurement instrument that has been developed for calibrating such grid-plates up to 300 mm × 200 mm in size and providing sub-micrometre measurement uncertainties. This instrument was specifically designed by the laboratory to ensure their calibration capabilities aligned with both the customers' technical requirements along with their budgets and expectations too.

1. Introduction

For quality control purposes, many manufacturing industries perform dimensional metrology checking processes that often necessitate the use of precision optical 2D measurement instruments, such as optical profile projectors, microscopes and "vision" systems [1]. The typical measurement accuracies of commercially available instruments are down to few micrometres. In order to assure traceability of measurements to the SI, the metre, these instruments are normally calibrated by using different precision optical scales, such as line-scales, stage micrometres, linewidth standards, 2D grid plates, and microscope slides often bearing a range of special features [2,3]. With these optical standards, a range of different kinds of vision systems, together with their associated internal reference scales and image processing algorithms can be evaluated and then verified [4,5].

Large corporate companies, often have their own internal accredited calibration laboratories, while for smaller companies calibrations are typically provided by an external provider, such as an approved accredited calibration laboratory. The measurement traceability for the precision optical scales used by an accredited laboratory, comes from a national metrological institute (NMI). Growing demands on the measurement uncertainty associated with such calibrations has fuels a demand to develop higher precision instrumentation, together with improved calibration methods and procedures. While very high accuracy level for the calibration of line scales is widely achievable [6–11], only a very few laboratories in the world are able to calibrate optical 2D grid plates with sufficient precision [12–19]. A preliminary survey on the calibration services offered by various NMIs, indicates that there are 37 institutes worldwide that offer calibration of line scales (20 of which are European), while only six NMIs worldwide offer calibration of grid plates [20] (3 of which are European). On closer inspection, it is apparent that only one European NMI offers calibration services for 2D optical grid plates having dimensions as large as 200 mm × 300 mm. Such services are normally delivered using modern digital 2D Cartesian coordinate optical measurement instruments.

The number of accredited laboratories offering high precision 2D optical grid plate calibration services is thus limited and so consequentially the performance verification of 2D optical instruments can be weak. This is particularly true in the case of Slovenia and to that end during the past few years, its national metrology laboratory for length put considerable effort into initially developing instrumentation and procedures for calibrating linear line standards. A few years ago this linear instrument was commissioned and accredited to provide calibrations for line scales up to 500 mm in length [21]. The Slovenian Laboratory for Production Measurement (MIRS/UM-FS/LTM) is a EURAMET designated institute and was the pilot laboratory in the EURAMET CL-K7 inter-laboratory comparison on line scales [11]. Following this it

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have now been intensively exploring the possibility extending the capability of the linear instrument in order to provide the calibration of optical 2D grid plates with an area up 200 mm × 300 mm in dimensions. This decision was made as a result of a number of requests from both its accredited calibration laboratories and industrial companies. Many advanced technologies employ measurement systems [22] that require precise calibration of their optical components. The research presented in this paper describes a new configuration of line scale facility at MIRS, combined with the necessary supporting procedures. An application for an extension to the scope of their accreditation has already been sent to the Slovenian national accreditation body. The further development of the instrumentation has been successfully achieved in collaboration with University College London, Faculty of Engineering Science.

2. Measurement set-up

2.1. Two dimensional numerically controlled stage

The updated configuration of the instrument consists of a high-precision air bearing x-y motion stage which is used to position a grid plate, a z-Tip-Tilt (ZTT) theta stage for adjusting the grid plate in the measurement direction and a motorized z-axis stage to which a digital video microscope system is mounted for locating measurement targets (line cross-sections) on the grid plate. The maximum area the system can measure is over 1000 mm × 350 mm (Fig. 1). Positional data for the three axes is obtained using three built-in incremental Heidenhein LIDA 403 linear encoders, which each have a resolution of 5 nm.

The stage was specially manufactured for MIRS by Newport Micro-Controle Spectra-Physics [23] who had some particularly demanding metrological design criteria. The stage needed to be the foundation of a multi-purpose universal instrument for both calibrating optical standards, such as line scales and grid plates, as well as tactile probing one-dimensional mechanical artefacts such as rings, plugs and step gauges.

2.2. Laser interferometer (LI) and reference mirror

Since the outcome of an error mapping process (see Section 3) which was initially intended to be applied to the y-axis of the ball-bearing guideways did not meet requirements, it was decided to employ a linear laser interferometer in combination with a plane mirror. This was instead of relying on the stage's built-in incremental measurement encoder system for measuring *Y* coordinates of targets on a grid. To achieve this, a 600 mm long Zerodur plane mirror was acquired and both this and a grid plate under test were mounted to the machine's base. As discussed further in Section 4, the straightness and alignment deviations of the mirror were measured before each calibration and thus eliminated from the final calibration results. The laser interferometer configuration is shown in Fig. 2.

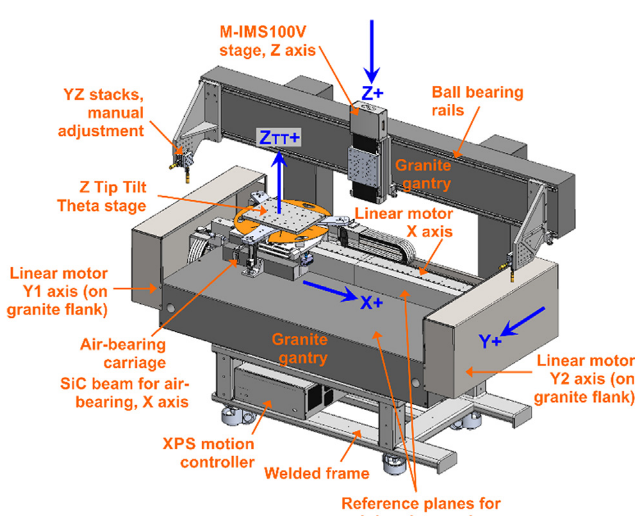

Fig. 1. Two dimensional numerically controlled stage.

2.3. Digital video microscope for locating measurement targets (line cross-sections)

A digital video microscope employed for detecting the mid-position of the cross type targets as shown in Fig. 3 (intersect of two lines) consists of a zoom microscope and a CMOS digital camera. The camera is connected to a computer via a USB 3.0 port. The CMOS camera captures images of the grid's targets and the data is then processed by some custom analysis software developed at MIRS. Using target detection criteria defined by the operator, the software analyses the images and determinates the middle of the target in the measurement window (Fig. 3). The software calculates the distance in pixels from a reference position marked with the blue line (see Fig. 3), to the middle of the measured line marked with the red line (also see Fig. 3). The CMOS digital camera takes 15 monochrome images per second each with a resolution of 2592 pixels × 1944 pixels. The software analyses the images in real time and the distance which is calculated in pixels is converted into micrometres. The software for calculating the distance between lines is further detailed in [24].

3. Calibration and error mapping of the guide way of the x-axis

In contrast to most advanced and precision measuring systems for calibrating grid plates, this system was not originally designed

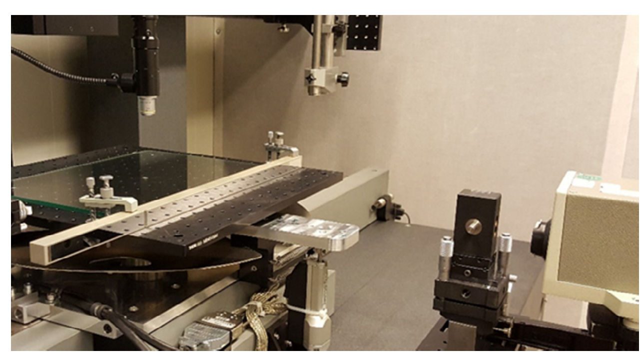

Fig. 2. Laser interferometer set-up.

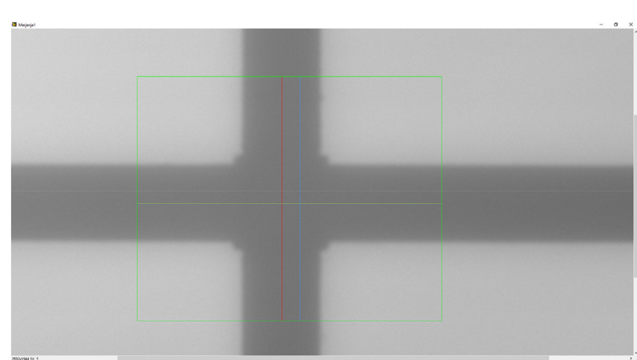

Fig. 3. Screen image of the vision system for detecting line position.