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ULTRA-PRECISION SET-UP AND REVERSAL TECHNIQUE FOR THE ERROR MAPPING OF A 2D SENSOR

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Abstract: In this paper a calibration technique for the error mapping of a 2D sensor - a cross-grid encoder – is presented. A reversal technique to assess the squareness errors is used. The calibration set up includes a metrology frame made of Zerodur®, a very low coefficient thermal expansion material in order to reduce thermal errors. Additionally, an analysis by means of finite element method is carried out for an adequate design of the set up. Finally, the uncertainty values for the 2D cross-grid encoder system are calculated.

Keywords: Calibration, Reversal Technique, 2D Sensor, Zerodur, Uncertainty.

1. INTRODUCTION

The use of 2D cross-grid encoders is not only limited to the area of machine-tool calibration [1], but also applied to metrology precision applications, such as scanning measuring machines analysis [2] and 2D optoelectronic sensors calibration [3]. This sort of sensors is very suitable to be used in micro precision systems. However, their calibration is done by the manufacturers just in their main two axes separately, which can be an accuracy limitation in some precision applications.

In order to solve the calibration problems of these sensors, a calibration technique was proposed [4]. In this calibration technique a mathematical model was developed to correct alignment and squareness errors that may have been introduced during the calibration of 2D cross grid encoder assembly setup. This model took as a squareness reference the grid plate, according to the specifications of the manufacturers. But if this grid is not perpendicular enough this error can also be a source of influence in the final uncertainty.

To solve the aforementioned problem, an application of a reversal technique to assess the squareness error of the 2D grid plate is proposed. Generally, with the reversal calibration method a 2D system may be calibrated by measuring an un-calibrated grid plate in different views [5]. A similar principle will be used here to find the squareness error of the grid plate.

However, in order to meet nanometer accuracies in this calibration, the use of very low thermal expansion materials and temperature, humidity and pressure control are necessary. Additionally, the evaluation of the stress of the metrology setup is presented to justify its design. Finally, the uncertainty values for the 2D cross grid encoder system are calculated.

2. METROLOGY FRAME DESIGN

Due to the increasing necessity of working in the nanometer range, metrology frames made of low thermal expansion coefficient materials are needed in order to reduce thermal errors introduced by changes in temperature. According to the latter, Zerodur® is the material used in this work due to its very low coefficient of thermal expansion in addition to its light weight which is necessary to the assembly.

The Zerodur metrology frame consists of two parts, a base and a top plate. Since the top plate is exposed to compression and tensile stresses, an analysis by means of finite element analysis was carried out to determine if the top plate is capable of withstanding the forces acting on it (due to the brittle nature of Zerodur®), Ansys Workbench is the software used in this work.

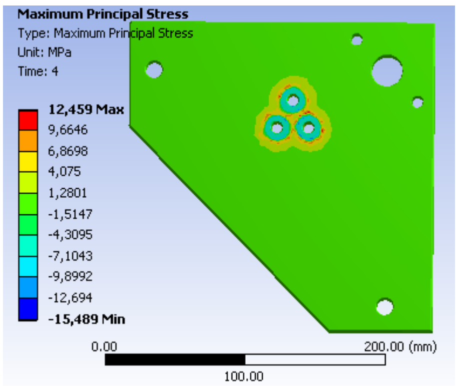

Fig. 1: Tension and compression stress acting on Zerodur top plate.

According to the technical information available [6] and the simulations carried out, the results show that the Zerodur top plate geometry is adequate to withstand tension and compression stresses. In Fig. 1 tension (positive values) and compression (negative values) stresses acting on the Zerodur top plate are shown.

Prior to the stress analysis of the Zerodur top plate some experiments were done. First, it was decided how to couple the Zerodur top plate to the spindle of the setup machine taking into account that Zerodur® is a brittle material, therefore this should be handled with care. Some test clamping the Zerodur piece to the spindle were done using one or three screws and plastic or rubber washers. Then, to know how stable the setup with each of the assembly options is, two capacitive sensors were used. After analyzing the results it was decided that the best option to our application consisted of using three screws and plastic washers. The stability test setup with screws and washers is shown in Fig. 2.

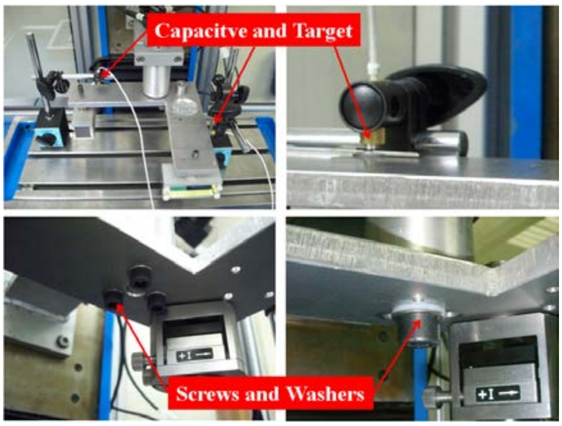

Fig. 2: Stability test setup with one or two screws and plastic or rubber washers analyzed by two capacitive sensors.

Once the the coupling of the top plate was disposed, its final form was analyzed using the Ansys Workbench software. In Fig. 1, the optimum design form for the Zerodur top plate obtained from the simulations is shown.

3. EXPERIMENTAL SETUP

The proposed setup shown in Fig. 3 is mounted on a 2D moving table and it includes the metrology frame described above, the 2D sensor to be calibrated and the 2D laser encoder as a reference instrument.

The reference instrument is a Renishaw fiber optic laser encoder RLE dual axis system with nanometer resolution that includes three RLD laser detector heads (two for X axis and one for Y axis), two plane mirrors and two RCU compensation unit of environmental conditions as pressure, temperature and humidity.

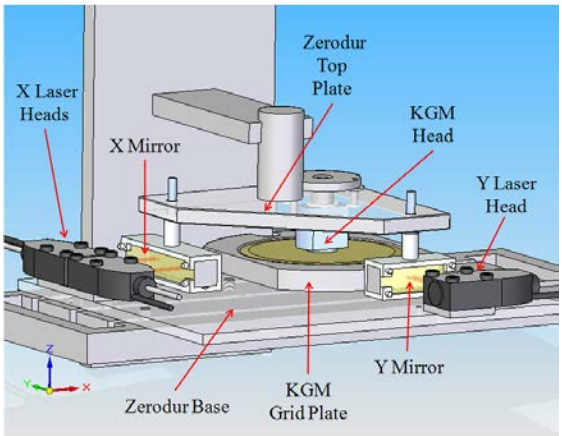

Fig. 3: Proposed setup

The 2D sensor to be calibrated is a Heidenhain grid encoder KGM 181 with nanometer resolution - comprising a grid plate with waffle type graduation and a scanning head.

On the Zerodur base the 3 laser encoder heads and the KGM grid plate are mounted and this in turn is coupled in the moving table of the machine. The spindle of the machine holds the Zerodur top plate with the KGM scanning head and the two mirrors of the laser system.

The 2D setup configuration was designed to avoid Abbe errors in X, Y and Z axes by aligning the laser and the KGM scanning head. Moreover, this setup was designed to minimize environmental conditions by using a Zerodur metrology frame and sensors and compensation devices of the laser systems.

4. EXPERIMENTS

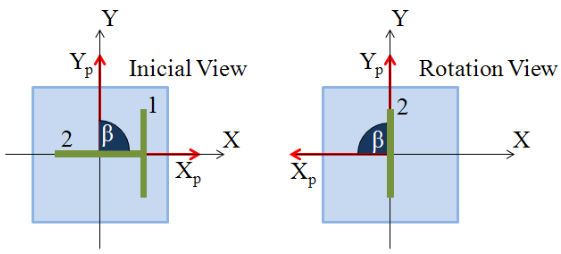

Fig. 4: Example of some of the views used by the reversal technique

First, the orientation of the KGM grid plate in the setup (Fig. 3) is called the view 0, where the KGM grid plate X axis is aligned with the machine´s X axis. Based on the reversal technique proposed in [5], the geometrical centre point of the KGM grid plate is defined as the origin of the plate and the rotation views of the KGM grid plate are around this center point of the KGM as shown in Fig. 4. The analysis of the results in different views of the grid encoder may be used to find some of its errors.

A working area of 60 mm X 60 mm around the geometrical centre of the KGM grid plate is defined, working on a grid of 13 x 13 points as shown in Fig. 5. Then, to verify the stability of the whole area static tests of repeatability are done taking out data from some fixed positions during 60 seconds.

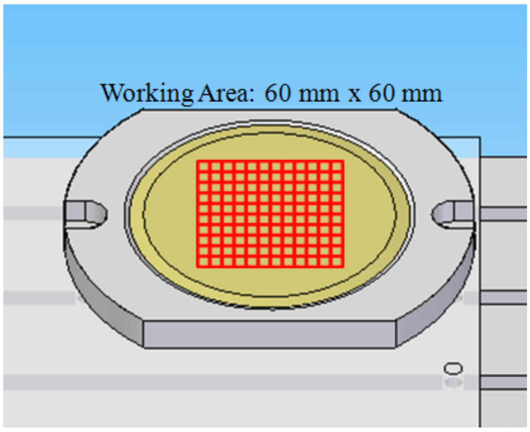

Fig. 5: Working area of 60 mm x 60 mm of the KGM with a grid of 13 x 13 points

Afterwards data from the 13 x 13 points grid were collected from view 0. Then the KGM grid plate was positioned in other views to collect the data of the same 13 x 13 points. Finally, an uncertainty analysis of the KGM is performed according to [7-8].

5. RESULTS

The preliminary results the error mapping at some points (X and Y errors) of the 13 x 13 grid are shown in Fig. 6.

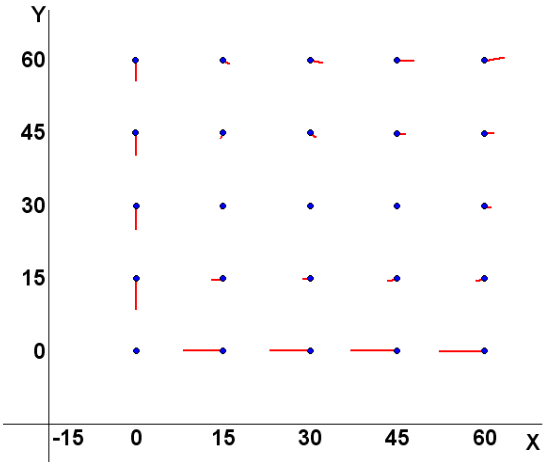

Fig. 6: Error map (axes in mm) with errors amplified by a factor of 3000.

Once the error maps of the grid encoder are calculated, an uncertainty analysis of the 2D cross grid encoder was performed according to [7-8], showing that the uncertainty budget of the 2D KGM grid encoder is composed of: reference 2D laser encoder uncertainty (U_0), the calibration process (S_C), temperature variation at every point (U_T) and the 2D KGM grid encoder resolution (r), as shown in equation (1).

$$U(k=2) = k\sqrt{\left(\frac{U_0}{k_0}\right)^2 + \frac{S_C{}^2}{n_c} + u_T{}^2 + \left(\frac{r}{2\sqrt{3}}\right)^2} \quad (1)$$

The uncertainties calculated at each point to both X and Y axes are around the 300 nm.

Finally a comparison of the results with and without KGM grid plate squareness correction is done.

6. CONCLUSIONS

The calibration of a 2D system is presented in this work using a 2D laser system as a reference system. The reversal technique is used to evaluate the squareness of the grid plate. Finally, it is shown that the grid encoder can be used as a reference device of 2D sensors in an area of 60 mm x 60 mm and as a complimentary measuring system in the development of a 2D nanometre stages.

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