Characterization of a Capacitive Sensor used in an Indexed Rotary Metrology Platform

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Abstract

Nowadays, there has been an increasing use of non-contact sensors for measuring small displacements in the range of sub-micrometre and nanometre resolution in applications to fields such as nanopositioning, scanning, metrology, etc. Within this group of sensors, capacitive sensors are becoming more and more used due to their high accuracy and to the insensitivity to changes in magnetic field [1]. In the field of dimensional metrology applications, 3 capacitive sensors were used in the Triskelion ultra-precision probe to determine the X, Y and Z deflections of the probe tip of the ISARA 400 [2]. Nevertheless, as far as we know there aren't any references on the use of capacitive sensors in applications with portable coordinate measuring instruments, in particular, coordinate measuring arms or laser trackers. In this work, we present the characterization of a capacitive sensor and the use of six capacitive sensors to increase the final positioning repeatability of an indexed rotary metrology platform [3]. The purpose of this platform is to increase the final accuracy and simplification of the calibration, identification and the verification of geometrical parameters procedures of portable coordinate measuring machines (PCMM).

1 Methodology

The characterization of a capacitive sensor (Lion Precision Probe C5-E Compact Driver) is carried out using a laser interferometer (Hewlett-Packard HP 5528A) as a calibration device. The interferometer, reflector, capacitive sensor and capacitive sensor's target were fixed to a linear guide, with the reflector and capacitive sensor's target located on the moving part of the guide as shown in Figure 1. This way, both the reflector and target moved simultaneously, making it possible to record the laser interferometer and capacitive sensor readings and then compare them.

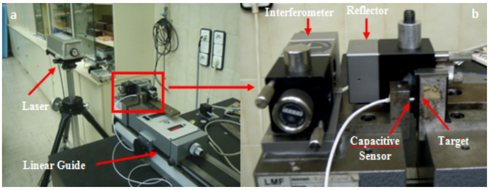

Figure 1: Experimental set up of sensor’s characterization tests

1.2 Experiments

In an effort to cover most of the capacitive sensor’s calibrated area (75µm - 100µm), tests were carried out in a range of 22µm inside the calibrated area of the sensor, taking 10,000 data every 2µm to calculate the sensitivity, sensitivity error, offset error and linearity error. To calculate the capacitive sensor’s repeatability value, 300,000 data were taken at three different locations inside the calibrated area of the sensor. The results obtained are compared when possible to the calibration sheet report obtained from Lion Precision.

2 Results

The sensitivity and sensitivity error calculated for the capacitive sensor were 0.8012 V/µm (0.8 V/µm Lion Precision data sheet) and 0.1497% respectively. The overall linearity of the capacitive sensor showed to be linear to within 0.09% (0.03% Lion Precision data sheet) over the entire operational measurement range covered by the sensor. Moreover, figure 2 clearly shows an offset error which could be attributable to the changes in temperature and to the mechanical errors in the linear guide.

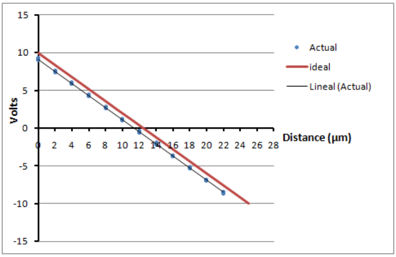

Figure 2: Offset error of capacitive sensor

Regarding the repeatability of the sensor, the repeatability values in each of the three locations (6V, 0V, -6V) were 0.010572, 0.008333 and 0.006147 µm respectively.

2.1 Mathematical model based on capacitive sensor readings

The indexed rotary metrology platform consists of an upper platform and lower platform, designed in such way that the upper platform rotates around the fixed lower platform and descends every 60°, resulting in six possible different positions of the upper platform with respect to the lower platform. To ensure the repeatability of each one of these positions, kinematics couplings of cylinders and spheres are set at 60° and 120° respectively [4]. To further increase the position repeatability of the upper platform with respect to the lower platform, six capacitive sensors are used. In order to determine the upper platform and lower platform reference systems in the calibration procedure, three spheres, located on the sides of the platforms, are measured with a Coordinate Measuring Machine. This way, the translation and rotation parameters between reference systems and the sensor readings are known for every position. The final goal is to calculate, from the sensor readings, the homogeneous transformation matrices that link the reference system of the upper platform to the fixed reference system of the lower platform for each of the six different positions, when using the platform in verification procedures of PCMM. For position 1, we can express the entries of the searched matrix as the unknowns of the $(6n)\times 36$ overdetermined linear system as:

$$\begin{bmatrix} v_1 & \bar{0} & \bar{0} & \bar{0} & \bar{0} & \bar{0} \\ \bar{0} & v_1 & \bar{0} & \bar{0} & \bar{0} & \bar{0} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \bar{0} & \bar{0} & \bar{0} & \bar{0} & \bar{0} & v_1 \\ v_2 & \bar{0} & \bar{0} & \bar{0} & \bar{0} & \bar{0} \\ \bar{0} & v_2 & \bar{0} & \bar{0} & \bar{0} & \bar{0} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \bar{0} & \bar{0} & \bar{0} & \bar{0} & \bar{0} & v_2 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ v_n & \bar{0} & \bar{0} & \bar{0} & \bar{0} & \bar{0} \\ \bar{0} & v_n & \bar{0} & \bar{0} & \bar{0} & \bar{0} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \bar{0} & \bar{0} & \bar{0} & \bar{0} & \bar{0} & v_n \end{bmatrix} \begin{bmatrix} a_1^T \\ a_2^T \\ a_3^T \\ a_4^T \\ a_5^T \\ a_6^T \end{bmatrix} = \begin{bmatrix} t_1^x \\ t_1^y \\ t_1^z \\ \theta_1^x \\ \theta_1^y \\ \theta_1^z \\ \vdots \\ t_n^x \\ t_n^y \\ t_n^z \\ \theta_n^x \\ \theta_n^y \\ \theta_n^z \end{bmatrix} \tag{1}$$

where $v_i = \left[l_i^1, l_i^2, \ldots l_i^6 \right]$, for i = *1,2,…,*n, is the vector of the six sensors read outs for the *i*th measurement of position 1; $a_j = \left[a_{j1}, a_{j2}, \ldots, a_{j6} \right]$, for j = *1,2,…,6*, is the vector corresponding to the *j*th row of the searched matrix; vector $\begin{bmatrix} t_i^x & t_i^y & t_i^z & \theta_i^x & \theta_i^y & \theta_i^z & \cdots & t_n^x & t_n^y & t_n^z & \theta_n^x & \theta_n^y & \theta_n^z \end{bmatrix}^T$ contains the translation and rotation parameters of the *i*th homogeneous transformation matrix and $\bar{0}$ is a 1 x 6 vector of zeros. During the verification procedures of PCMM, multiplying the quantities a_j by the sensor readings, will allow us to obtain the corresponding homogenous transformation matrix. The same procedure is done in order to find the a_j values for positions 2 to 6 of the platform.

3 Conclusions

In this work, the characterization results of a capacitive sensor have been presented and compared when possible, to the Lion Precision data sheet. Moreover, the application of the capacitive sensors in an indexed rotary metrology platform has been shown.

Acknowledgements

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