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Positioning sensor with nanometric performances over centimetric range for nanotechnology sample-holders

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Abstract—We developed a very simple optical sensor for centimeter range measurements with nanometric resolution, planned to be used for sample-holding in nanotechnology. In this work, the principle is detailed and experimental results are pointed out. The compact system is composed of a laser-diode module and a photodiode array leading to a non-contact sensor. With a corner cube configuration, it is not sensitive to most of main mechanical defects of the mobile platform. The use of an optical fiber and a normalization process inspired from classical four-quadrant detectors allows high repeatability and minimal drifts. Nanometric resolution is achieved experimentally over centimeters range.

Keywords—*high resolution sensor; nanodisplacement; low noise electronic*

I. INTRODUCTION

Nowadays, nanometer resolution and accuracy in many nanotechnology processes are required. But accuracy is in general opposed with range. High resolution over a wide range has been made possible using interferometric translation stages, in other words by combining metrology with classical mechanical motions. The interferometry is obviously a good solution. Nevertheless, its sensitivity to the medium index and its price make it prohibited in many applications. In parallel of several works on interferometry, a lot of studies have been started to develop simple sensors or measurement systems gathering simplicity, high resolution over long range and low price potentialities [1-7].

We developed an optical sensor for centimeter range measurements with nanometric resolution. Simulation and modeling can be found in [8]. Here, the principle is detailed and experimental results are pointed out according to modeling results. We plan to use this sensor with a nano-displacement platform for nano-manipulation and for a sample-holder in microscopy or lithography process [9-10].

II. SETUP OF THE EXPERIMENT

The sketch of the sensor is illustrated on Fig. 1a. The laser source is composed of a laser-diode module and a lens allowing the tuning of the focal length and the size of the spot at a distance of a few centimeters. An attenuating plate is also included to adjust the intensity of the spot, and to avoid reflection and feedback disturbances on the laser-diode. The sensitive part is a photodiode array (S4111-35R from Hamamatsu) composed of 35 adjacent photodiodes. The geometry of the photodiode elements is represented on Fig. 1b. Each photodiode has a height of 1.45 mm and a width of 0.90 mm, with a gap of 100 μm between two elements. The size of the spot is tuned to be smaller than two elements in height and width (ellipsoidal shape for the example on the figure). The global principle of the sensor is like a four-quadrant photometry system, *i.e.* the detection of the displacement of a spot over the photodiodes. The 35 elements ensure the centimeter range. The nanometric resolution is obtained thanks to the sensitivity of the photodiodes and the optimization of the signal to noise ratio, depending on the characteristics of the electronics board and the laser spot. An optical fiber (not represented on the figure for clarity) ensures a Gaussian mode at the output of the laser, which allows a good knowledge of the amplitude spatial distribution.

The sensor can be adapted in two configurations. The first one, called direct configuration, for which the emitting source is fixed and the photodiode array is moving. In that case, the spot of the source illuminates directly the array. The second configuration is called corner cube configuration and is represented on Fig. 1a. The source and the receiver are fixed, and the moving part is composed of a corner cube. In the corner cube configuration, the sensitivity is multiplied by a factor of 2 thanks to the optical properties of the cube. Each photodiode is connected to a transimpedance amplifier to convert the current to a voltage. The outputs of the amplifiers are measured with a high precision scanning voltmeter (Keithley 2700, 20 bits acquisition converters) controlled by a computer unit via a GPIB interface. For faster acquisition rates, the scanning voltmeter can be replaced by an NI data acquisition card (NI-PCI 4472, 24 bits, maximum sample

Figure 1. Schematic diagram: (a) the sensor is composed of a static part: laser diode source and tilted attenuator for the emitting elements, and photodiode array and electronics for conditioning signal board; the mobile part is made of a corner cube. (b) Face view of the photodiode array and a theoretical ellipsoidal shape spot for clarity. (c) Measurements of the resolution of the sensor depending on the integration time.

Figure 2. Measurements of the resolution of the sensor depending on the integration time.

frequency of 45 kHz). The measurements are normalized with the total measurement power of the laser spot, similarly with four quadrant systems.

III. MEASUREMENTS AND RESULTS

To test the displacement performances, the mobile part is moved with a double stage actuator. The first stage is a piezo-electric actuator. It controls fine displacements of nanometer or micrometer range. This piezo-electric actuator is mounted on an air bearing stage moved by linear motors (ABL2000 from Aerotech). Its range of displacement is 10 cm, with a repeatability of 0.2 μm over the full range. The motion axis is referred as x in the Fig. 1a. The centimetric measurement is possible by switching photodiodes on the array when detecting the laser spot.

The resolution is mainly limited by the noise of the system, either the electronic noise or the shot noise of the spot. Fig. 2 illustrates the noise measurements in a static position. The outputs of the sensors are recorded and the normalization process performed. Each point of measurement is integrated over an integration time τ by the Keithley system or the data acquisition card. A large set of data is recorded so that the position is measured for several seconds or minutes. If the distribution of the set of data is Gaussian shape, the standard deviation is the resolution of the measurement. One can see that with a 100 ms integration time, a resolution of 1.2 nm is reached, and the flicker noise is around 1.1 nm. Note that these measurements have been done in the direct configuration. In the corner cube configuration, the resolution would be twice better, *i.e.* 0.6 nm.

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