Towards the realization of the new INRIM angle comparator

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Abstract

A new angle comparator is under construction at INRIM. The goal uncertainty is 0.01 arcsec (50 nrad). The device will be based on a double pneumostatic air bearing and will exploit the rotating encoder principle. A prototype has been built to demonstrate the effectiveness of the principle and to test electronics and software. The prototype and preliminary results are presented as well as the design of the comparator.

1 Introduction

Angle measurements is one of the critical issues in precision mechanics metrology. All modern angle measurement instruments are based on state of the art angle encoders. Technological progress achieved in the last decades has allowed tremendous improvement in the encoder performances. Resolutions down to 0.01’’ and accuracy better than 1’’ are commonly achieved. The calibration of such divided circles is a basic task of angle metrology. Hereby, calibration means the determination of the division errors as deviations from nominal circular division. The main error sources of angle encoders are the non-uniformity of the grating spacing (due to manufacturing errors or misalignment) and the nonlinearity occurring when subdividing the grating pitch in small parts (fringe interpolation error).

The realization of rotary tables (RT) having extremely high accuracy is the preferred solution for this kind of calibration. Main national metrology institutes have designed and realized their own unique instrument based on different technological solutions to achieve this goal [1,2].

Until now the encoder calibration facility at INRIM was based on precision index tables that, although having excellent accuracy, require extremely long fully manual procedure. INRIM has recently afforded the realization of a novel high precision automated RT. A preliminary demonstrator has been built and described in the next section.

2 The prototype

The measurement principle is sketched in figure 1. The instrument is based on a principle pioneered by E. W. Palmer in 1984 [3]. A pair of continuously rotating encoders read by two pairs of heads, one fixed with respect to the laboratory frame and a second rotating with the measurement drum. The angle measurement is based on the phase difference between the fixed head signal (used as a reference) and the rotating head. The phase measurement is intrinsically free from nonlinearities and the encoder errors are cancelled by the average made each complete revolution of the encoder.

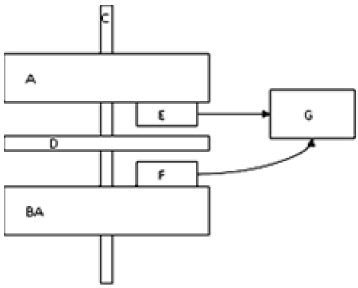

Figure 1: Schematic of the rotating encoder principle. D continuously rotating optical encoder; F: reading head fixed to the reference frame BA; E: reading head fixed to the measuring table A; G: phase measurement.

2.1 Mechanical structure

The demonstrator is based on a Heidenhain ring encoder (model ERA 4200, 40000 lines with 20 µm spacing), mounted on a precision air bearing (Precision Instrument Inc.), driven through a belt by a microstep motor (Oriental Motors). Two heads are faced to the ring about 180° one respect to the other. One is fixed to the table and represent the reference head of the system. The second is mounted on a piezo-capacitive transducer (PI P-753) capable of 25 µm displacement, representing the moving head of the comparator. A controlled movement of the piezo actuator simulates a movement of the comparator corresponding to an angular rotation of 1.62 arcsec each micrometer of the actuator.

Each head generates two quadrature sinusoidal signals. Said signals are amplified and sent to an analog to digital converter board (ADC, NI-USB-6259 BNC).

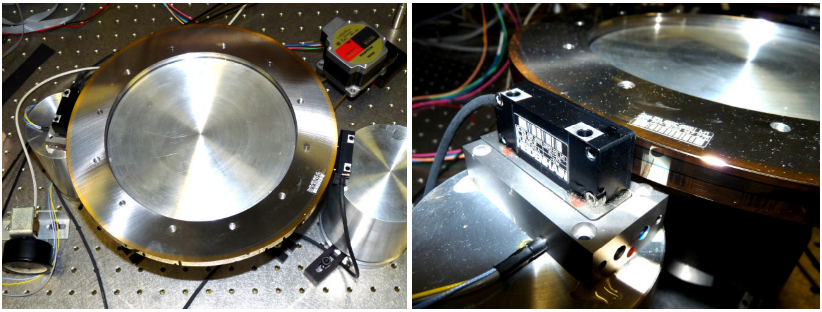

Figure 2: A) picture of the prototype. In the center the rotating ring encoder mounted on the pneumostatic spindle. Upper right corner the microstep motor. Right the fixed head. Left the moving head. B) detail of the moving head mounted on the piezo-capacitive actuator capable of simulating microradiant rotations.

2.2 Electronics and software

The purpose of the electronics is the conditioning of the signals generated by the heads and the generation of a trigger signal for the ADC. The differential signals coming from the heads are amplified by low noise and fast differential amplifiers built to the purpose. The conditioned signals are sent to the ADC board having 16 bit resolution and a maximum sample rate of 1.25 MS/s. The encoder is rotated at 90°/s so, the base head signal has about 10 kHz frequency. The signals are sampled at 8 points per cycle (80 kHz). In order to avoid spurious noise coming from the beat of the sampling frequency and the signal, we decided for a synchronous sampling of the reference signal. A Phase Locked Loop (PLL) circuit has been built to the purpose.

The software (based on LabView®) elaborates the signals captured with the ADC boards and triggered with the phase locked clock according the following simplified steps. The reference signal is mixed (multiplied) with the sine and the cosine signals of the measurement head. The two quadrature signals now represent the phase vector which carries the angular information. Each complete phase revolution corresponds to a shift of one encoder line (32.4 arcsec). A Matlab® based algorithm calculates the instantaneous phase angle. The phase is than averaged over the entire revolution of the encoder. A counting logic measures the integer part of the phase (the number of complete phase revolutions) and adds or subtract the integer to the fractional measurement. The final value is converted in arcseconds and the result is stored.

3 Results

We have performed two tests. The first is to check for the long term stability of the device. In figure 5 two typical long term acquisition runs are captured. The long term stability is around 0.01 arcsec per hour. That corresponds to a mechanical drift of the two reading heads better than 10 nm per hour, compliant with the expected thermal drift of the overall structure.

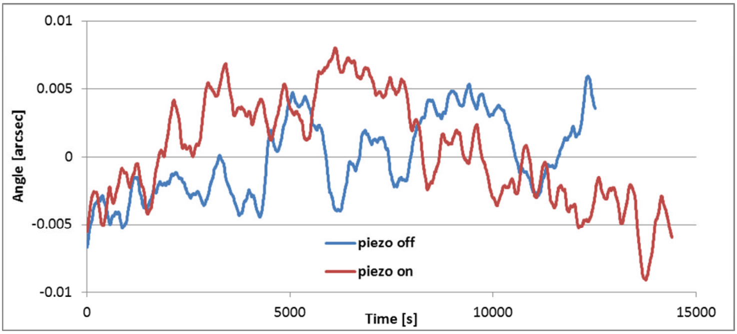

Figure 5: typical drift over 3-4 hours period. The two curves are respectively with the piezo-actuator switched off and switched on.

In the second test we have driven the piezo-capacitive actuator with a square signal having 100 s period. The step height is 12 nm corresponding to a 0.02 arcsec peak to peak rotation. In figure 6 ten consecutive 400 s records are plotted. The vertical dispersion is compliant with the above reported 0.01 arcsec per hour drift.

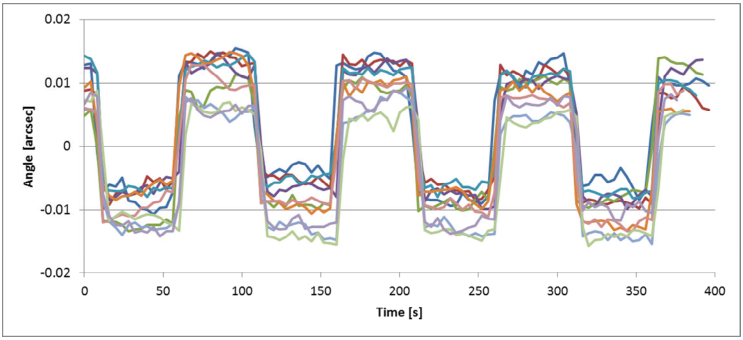

Figure 6: response to a 0.02 arcsec p.p. step. Full acquisition time is 4000 s.

5 Conclusions

A demonstrator for the development of the electronics and the software of the new INRIM angle comparator have been presented. The preliminary results are compliant to the expected accuracy of the system. On the basis of the results above the angle comparator, which will be based on a double air bearing structure, will be designed and built.

References:

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[3] E.W. Palmer, Goniometer with continuously rotating gratings for use as an angle standard, Precision Engineering 6359(88)90033-5