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Development of a novel high precision Large Range Small Angle Generator

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Abstract
Angle metrology is a key technology for scientific and industrial applications of high value. Industrial applications range from precision engineering, automotive, aircraft to robotics. Scientific applications that require extreme angular measurements can be found in synchrotron facilities, measurement of physical constants and space missions.
The angle measuring devices in recent years have evolved and are able to provide measurements in larger ranges whereas the resolutions and accuracy have been maintained or even improved. These new measurement devices require new calibration solutions. The Angle Metrology project has been granted funding under the European Metrology Research Program (EMRP) with the project number and acronym of SIB58 ANGLES to work on this subject.
Small Angle Generators (SAGs) are used to provide traceability for angle measurement devices and thus enable their calibration. While former SAGs provided ranges of few arc seconds, new devices are under development to cope with the requirements of the new instruments focusing on portable use and aiming at ranges of ±3600 arc seconds and nanoradian uncertainty values.
The device presented in this paper relies on a novel symmetrical angle generation mechanism which enables a compact design, high eigenfrequencies and high stiffness, important for its stability and repeatability. Moreover, a measuring system has been integrated in order to enable the use of the angle generator without the need of external means. This system consists on a novel absolute diferential in plane displacement solution that directly measures the three in plane DOF of the moving platform.
The device is already manufactured and it is under performance characterization by the CEM (Centro Español de Metrología).

Keywords: Angle, angle metrology, small angle generator, SAG, autocollimator, calibration, Robert´s mechanism

1. Introduction

Angle metrology is a key technology for scientific and industrial applications of high value, enabling countries to be globally competitive. Precise angle measuring devices – such as angle encoders, angle interferometers, small angle generators and autocollimators – are extensively used in various applications where high precision is demanded. In precision engineering, for instance, the performance of ultra-precise machines in terms of straightness, flatness, and parallelism is commonly measured by autocollimators which enable the precise non-contact measurement of angles. Application of autocollimators also includes the ultra-precise form measurement of optical surfaces [1] like beam guiding and shaping optics for beam lines at synchrotron storage rings [2] and Free Electron Lasers (FEL) or flatness standards for interferometer calibration. Further industrial applications for precise angle measuring devices exist in the area of automobiles, aircraft industry and robotics as well as in several scientific applications (e.g. the measurement of the gravitational constant G and the angular stabilization of X-ray optical components). Traceability for high precision angle metrology is demanded in all these areas and is increasing continuously with ever more stringent demands.

Small Angle Generators (SAGs) are used to provide traceability for angle measurement devices. For instance, the calibration of autocollimators is conveniently carried out by SAGs and expanded uncertainties of 0.01 arc seconds are achieved for small ranges such as 10-20 arc seconds. Besides, SAGs are also used for precise calibration of other angle measurement devices such as electronic levels for larger ranges.

Besides classical metrology needs, such as calibration of precision autocollimators, there are other fields of science that require extremely high accuracy and sensitivity at very small angles, as for instance the calibration of gamma spectrometers or the calibration of accelerometers used in missions to explore other planets.

Hybrid angle comparators consist of a combination of SAGs and angle encoders in one system and benefit from the advantages of both angle measurements systems. Larger angular ranges (up to 360 degrees) can be achieved with hybrids to calibrate angle measuring devices.

2. Development of the large range SAG

2.1 Angle generation mechanism

Usually SAGs have been desgined around a cantilever arm and lever mechanism concept [3, 4] so that the angle has been materialized as the ratio of two lengths, the lever displacement and the arm length.

In this development a novel mechanism is introduced with the aim of improving several mechanical and operational characteristic of the SAG. Linear stages are still considered as the primary actuator, due to the wide offer of large stroke and high resolution solutions commercially available that rely on piezomotors [5].

Figure 1 shows the core of the mechanism, which consists on a double Robert's mechanism that suspends the moving platform at four distant points and thus enables larger stiffness and eigenvalues compared to simple cantilever arm solution. Moreover, this design allows a considerable reduction of the size of the whole device still keeping a similar kinematical behaviour to a long cantilever arm design.

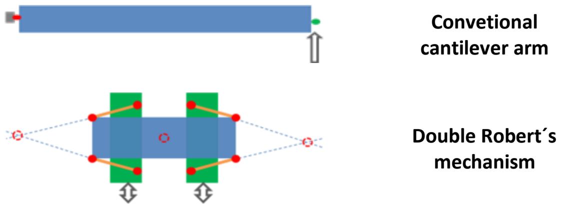

Figure 1. Angle generation mechanisms: (a) cantilever arm concept; (b) double Robert's concept.

Using two linear stages is possible to implement a completely symmetrical device, which is beneficial in order to keep the center of rotation in the center of the device and improve stability and thermal response behaviour.

The actual device has been designed around two PI LPS65 long stroke linear stages featuring 2 nm close loop resolution. A compliant aluminium part has been designed in order to implement the mechanism. The angle generation mechanism shows a ±3600 arc seconds range, eigenfrecuencies above 100 Hz and an effective arm length of 630 mm.

2.2. Integrated measuring system

Several measuring system has been integrated in the device in order to test the performance of each solution. From simple to complex, we find: (1) two linear encoders of the PI linear stages; (2) two linear optical encoders by Fagor that measure directly the tangential displacement of the moving platform; (3) a novel absolute diferential displacement solution that directly measures two in plane translations and the rotation of the moving platform.

The third solution is aiming at providing angle measurements without disturbances due to parasitic motions of the moving platform and lack of radial position stability of the measuring heads.

Figure 2. Novel integrated measuring system concept: (a) Relative position A; (b) Relative position B.

The solution consist on two gratings of size 65 mm x 150 mm manufactured on glass by Fagor. One grating is fixed to the base platform and the second is solidary to the moving platform. Each grating presents a field of dots and a few absolute referencing features. The fields of dots of the fixed and moving gratings are designed so that they do not interfere during the movement of the mechanism. Two CCD cameras with telecentric lenses of 17 mm diameter field of view are used to image two areas of the gratings that are 140 mm apart from each other. Each image contains about 5500 dots. An affinity transformation is used to compute the relative in plane translations and rotation of the moving grating with respect to the fixed grating. Therefore, about 11000 dot position coordinates are considered in the calculation of the desired relative in plane motion, enabling a huge noise reduction from dot centroiding in images to final angle value.

The actual distribution of dots in the gratings and its behaviour when rotating is under calibration in CEM facilities.

2.3. Detailed design and overall result

One important requirement for the long range SAG under development is portability and ease of use in workshop enviroments. The compactness of the solution relies on the mechanism concept and the integration level of the measuring systems.

Figure 3 (a) shows an exploded view of the detailed design of the development. In Figure 3 (b) the manufactured device can be seen. The device is 310 mm in diameter and 100 mm in heigth, the weigth is just below 13 kg.

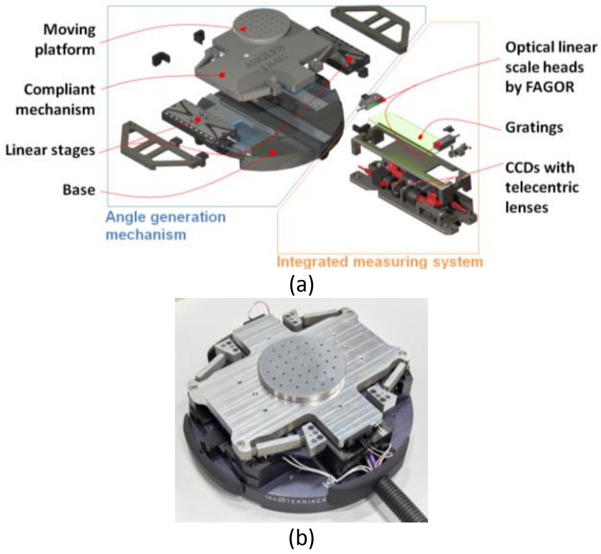

Figure 3. LRSAG: (a) exploded design view; (b) manufactured device.

4. Conclusions and further work

A portable and ease of use large range Small Angle Generator for the calibration of accurate angle measuring instruments in the field has been presented.

The device relies on a novel symmetrical angle generation mechanism which enables a compact desing, high eigenfrequencies and high stiffness, important for maintaining its stability and accuracy. Moreover, measuring solutions have been integrated in order to enable the use of the angle generator without the need of external means.

The characterization of the device performance is under study. This will be carried out by comparing the results based on the relative rotation of the dots gratings against those obtained by using a 200 mm arm prepared by the CMI, the Czech metrology institute, and a laser source calibrated by the CEM.

5. Acknowledments

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