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HIGH-RESOLUTION AUTOCOLLIMATOR CALIBRATION SYSYTEM

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Abstract: This paper describes high-resolution autocollimator calibration system in NMIJ. A goniometer system with nano-radian resolution provides precision rotation angles of a mirror attached on the rotation axis and rotation angles read by an autocollimator are compared to the set angles. The rotation angle is detected by a high-precision angle interferometer that observes motions of corner reflectors attached to the axis. The interferometer is calibrated to output absolute angles by a 24-sided optical polygon that is attached to the rotation axis. The performance of the system is verified by comparing the calibration curves of same autocollimator taken by this system and those taken by the national standard of NMIJ.

Keywords: Autocollimator, Angle Interferometer, X-ray diffraction, Optical Polygon.

1. INTRODUCTION

Autocollimators are very important instruments to measure angular direction of surfaces with very high resolution down to nano-radian order.

One of the application that requires wide angular measurement range with high resolution measurement capability is the optical deflectometry. The surface profile is derived by line integral of the local gradient of the surface that is equivalent to the local direction of the surface. For example, a mirror sized 100 mm diameter with radius of curvature of 10 m has about from -1000" to 1000" surface direction variation. On the contrary if we want to know 1 nm over 100 mm, 10 nrad resolution is required[1].

Autocollimators are calibrated by the higher angular reference. It is realized by comparing the reading of the autocollimator with the angle set by the angle generator while rotating the mirror attached on the axis of rotation.

To fulfill the requirements, the angle generator is equipped with an angle interferometer to provide graduation free set angle with less than nano-radian resolution with an ability of self-calibration of the interferometer.

2. APPARATUS

Figure 1 shows a schematic diagram of the precision goniometer system as an angle generator. The system consists of a precise rotation axis and an angle interferometer with the polygon calibration system. Rotation of the axis causes relative displacement D between the two retro-reflectors attached symmetrically to the axis with an arm length, L. Then, D measured by the interferometer is converted to the rotation angle, θ, using the relationship $D=L\sin\theta$. Using the polygon calibration system, the arm length, L, is predetermined.

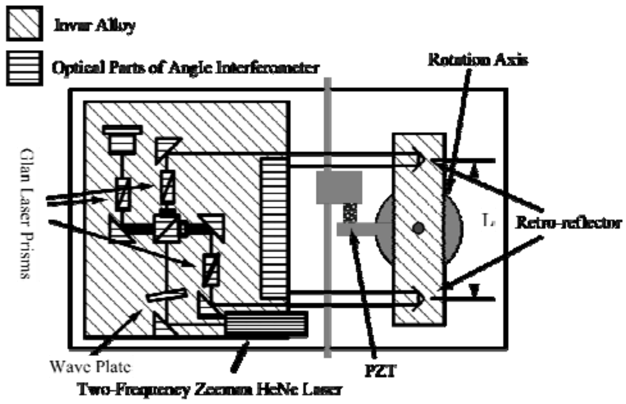

Fig. 1 Schematic diagram of the goniometer system

The Michelson geometry polarization-sensitive heterodyne method is used in the angle interferometer because of the potential high resolution over a wide angular range. A two-frequency Zeeman laser (MOC Quartz Zeeman Laser Type QQD, Japan Micro-Optics Co., Ltd.), whose beat frequency is 260kHz and optical power is more than 1.5mW, is used as a light source for the interferometer.

The retro-reflectors realize the application of only the $D=L\sin\theta$ relation without any need for compensation such as that due to the refractive index of glass in the case of a solid-type retro-reflector. They are attached to the rotation axis using an invar plate. Thus, the arm length, L, becomes less sensitive to thermal condition change. The change is estimated to be 0.2ppm when the temperature changes by 0.1K.

Surface quality is one of the most important origins of nonlinearity. These retro-reflectors have a surface quality of $\lambda/20$ at the wavelength of 633nm, according to the manufacturer's specifications, and because the laser beams move in a small area in the reflector, the error is small. The error due to the imperfection of the reflection angle from the reflector has a cosine nature and thus is not so serious.

Invar alloy, which has a thermal expansion coefficient ten times smaller than conventional steel, is used as a base plate and the adjustment mechanisms of the optical parts to reduce thermal drift due to temperature change and temperature nonuniformity in the apparatus.

In figure 2, a block diagram of the electric circuits to control the rotation angle using an interference signal is shown.

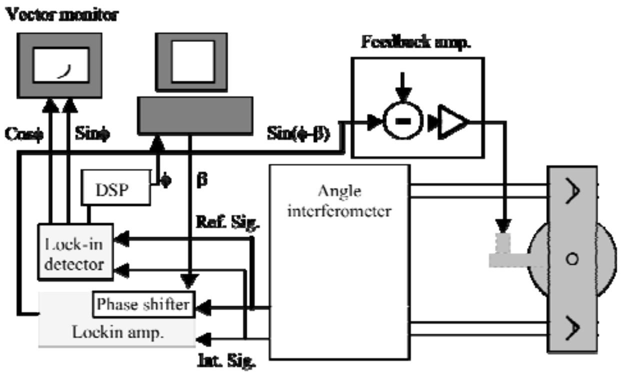

Fig. 2 Block diagram of electric circuits

A lock-in phase detector module is used to convert the phase shift ϕ of the interference RF signal with respect to the reference RF signal extracted from the laser light source into sin ϕ and cos ϕ voltage output. Here, the period of ϕ corresponds to the displacement of the interferometer by one wavelength of the laser light. Then sin ϕ and cos ϕ output signals are fed to a DSP–based CPU board and the shift angle ϕ is calculated. The uncertainty of this phase detection estimated using the standard oscillator is not less than 100 prad.

A lock-in amplifier is used for precise angle steering. The same RF signals are fed to the amplifier. In the lock-in amplifier, the phase shifter shifts a phase of the external reference RF signal by an amount β and produces an internal reference signal. Therefore, the phase shift α, the phase difference between the interference signal and the internal reference signal, makes $\phi - \beta$. If the α signal is fed through the error amplifier to the piezo-actuator PZT, the closed loop functions so that the α signal becomes zero. If the phase of the internal reference signal is manipulated while the closed loop is activated, the rotation axis follows the shifted amount of β. In this way, the rotation axis is continuously steered with the resolution of the lock-in phase shifter.

For the self-calibration of the interferometer, a 24 sided optical polygon, i.e. mirrors with 15˚ intervals, is used. It is attached coaxially to the rotation axis through a serrated table so that it can be displaced rotationally with respect to the axis, e.g., the angle interferometer. The rotational resolution of this serrated table is 1˚. Within the maximum rotational span, a little bit more than 30˚, of the axis, surface normal of three face of the polygon can be detected by a null angular position sensor attached beside of the axis. On these three position, outputs of the angle interferometer are recorded. Twenty four pairs of interferometer outputs are used to correlate the angle to the interferometer readout using the closure principle of angle.

After this self-calibration procedure, the autocollimator under test is calibrated by comparison measurement.

3. PERFORMANCE

The system is evaluated by comparing the calibration data of the autocollimator, ELCOMT 3000, with the calibration data of same autocollimator taken by using the national standard of angle[2] as an angle generator.

Figure 3(a),(b) show the result. Very good agreement is observed.

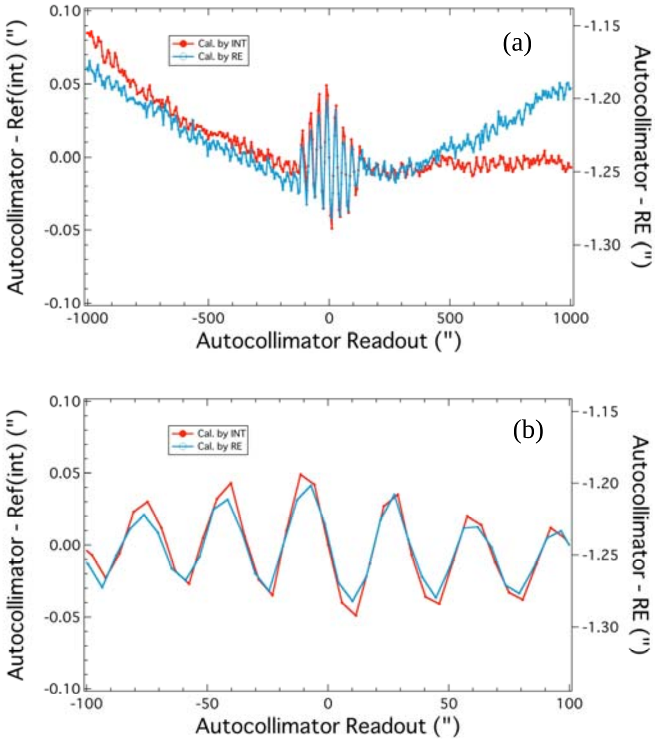

Figure 3, INT means this system and RE means the national standard of angle. (a) measurement for wide angular range and (b) for narrow range.

5. REFERENCES

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