MEASUREMENT OF SURFACE ROUNDNESS USING A MULTI-BEAM ANGLE SENSOR

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Abstract:
This paper analyses existing techniques and proposes a newly technology named Multi-Beam Angle Sensor (MBAS) for measuring the roundness errors. Comparing with other methods, MBAS has just used one sensor and independence on the rotary stage, and can be used as a simple and convenient one in factory-level. Stability can also be improved by using the MBAS. In this paper, the optical probe is based on the principle of autocollimator and has a stability of 0.3arcsec. Unlike multi-probe methods, the MBAS is constructed to realize the roundness measurement by using only one probe, which is less susceptible to instrumental errors. The experimental results confirming the feasibility of the MBAS for roundness measurement are also presented.

Keywords: Roundness, Measurement, MBAS, Metrology, Stage-independence

1. INTRODUCTION

In recent years, it has been critical to develop both high roundness measurement accuracy and range for various applications, including fields such as optical metrology instruments, semiconductor industry, artificial satellite, and so on [1-3].

To measure roundness errors of cylindrical workpieces and spindle errors of machine tools in on-machine conditions, it is important to separate the roundness error and spindle error from each other. Basically there are two kinds of error separation method. One is known as the multi-orientation method, and the other is the multi-probe method.

Multi-orientation method can separate the spindle error and the roundness error effectively, if the spindle error has good repeatability. Compared with multi-orientation methods, multi-probe methods are more suitable for on-machine measurements, because the repeatability of the spindle error is not necessary [4-6].

To eliminate the systematic errors of a spindle, reversal methods can be used, but they are very time consuming and still demand good repeatability of the spindle motion. This has led us to the solution of using the measured object itself as a reference by employing the three-point method. But too many sensors make it difficult to attach or remove the measured object, and it is not easy to adjust the direction of sensor’s radius [7-8].

In this study, the MBAS based on the autocollimator is proposed for roundness measure. Compared to other system methods, the MBAS system has just used one sensor and independence on the rotary stage, which can be used as a simple and convenient one in factory-level [9].

2. MULTI-BEAM ANGLE SENSOR (MBAS)

2.1 Construction of MBAS

Figure 1 illustrates the construction of MBAS. The MBAS is based on multi-autocollimator system using micro-lens array. The reflected angles at several points on the cylindrical workpiece can be measured by MBAS. Therefore, the curvature of the workpiece can be calculated by difference of two reflected angles.

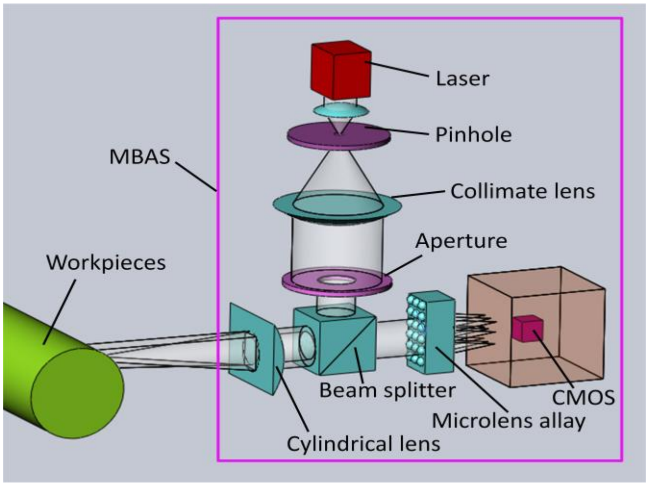


Fig. 1: Construction of the Multi-Beam Angle Sensor

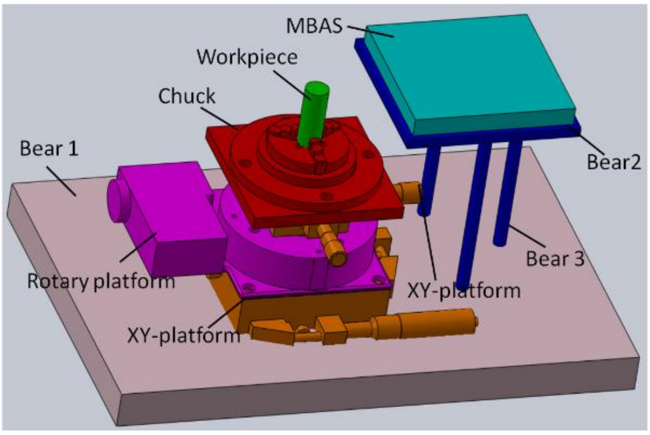


Fig. 2: Schematic of MBAS system

Using MBAS, we made an experimental system shown in figure 2. A cylindrical workpiece is mounted on the chuck, and the rotary platform is mounted between two XY-platforms. The cylindrical workpiece is rotated by the rotary platform of the headstock for the round measurement by MBAS.

2.2 Measurement principle

Figure 3 shows simulation of the reflected beam from cylindrical workpiece surface. An optical probe is used to scan a cylindrical workpiece while the workpiece is rotating. Assume that the center of the cylinder (eccentricity) is at (o_x, o_y), the cylinder radius is R, then can get the two measured angles c_a and c_b by MBAS. The difference angle Δc ($c_a - c_b$) is influenced by the eccentricity of the workpiece as equation (1). From this relation, the effect of eccentricity is very small in the practical measurement using MBAS.

$$\Delta c = c_a - c_b \approx \frac{-2o_x \sin t}{R} \tag{1}$$

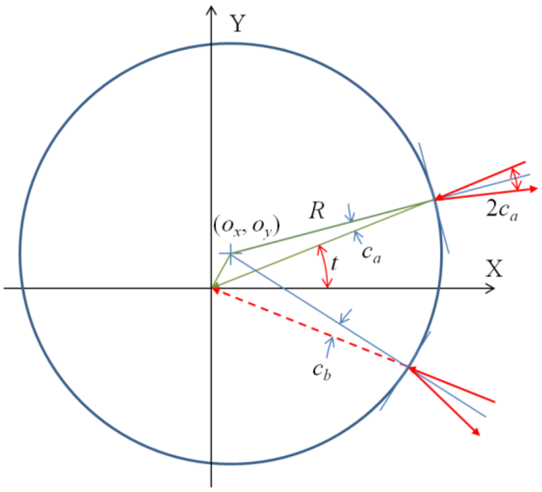


Fig. 3: Relation between eccentricity and reflected beam: o_x, o_y: center of cylinder (eccentricity), R: radius of cylinder, c_a, c_b: measured angles by MBAS, t: converging angle

2.3 Data Processing

Figure 4 shows algorithm chart of the measurement. First, we can calculate profile data (P) in the position t which is deformed by the Fourier series as Eq. (2). Here n is the maximum iterations of Fourier series. Then the angle difference value (Δc) can be expressed by the second order differential of the profile data(P), as shown in Eq. (3). From Eq. (4), we note that Fourier series of the profile data (P) can be denoted by the Fourier transform of the angle difference (curvature).

$$P(t) = a_0 + \sum_{i=1}^{n}(a_i \cos ti + b_i \sin ti) \tag{2}$$

$$\Delta c(t_j) = P''(t_j) = -\sum_{i=1}^{n} i^2 (a_i \cos t_j i + b_i \sin t_j i) \tag{3}$$

$$c_j = \sum_{i=1}^{n}(d_i \cos t_j i + e_i \sin t_j i) = P''(t_j) \tag{4}$$

$$a_i = -\frac{d_i}{i^2}, b_i = -\frac{e_i}{i^2} \tag{5}$$

The angle difference value Δc can be denoted as the Eq. (3), by using the Fourier transform of the angle difference value Δc, we can get the Fourier series d_i and e_i of the profile value. Then the a_i and b_i is obtained from the Eq. (5). Through the use of inverse Fourier transform, we get the profile value P in every measurement point.

Get the angle difference data Δc by the CMOS

⇩

Calculate the Fourier series of the profile data P by the Fourier transform of the angle difference data Δc

⇩

Express the angle difference data Δc by the second order differential of the profile data P

⇩

Calculate the profile data P by the Fourier series

Fig. 4: Algorithm chart of the measurement

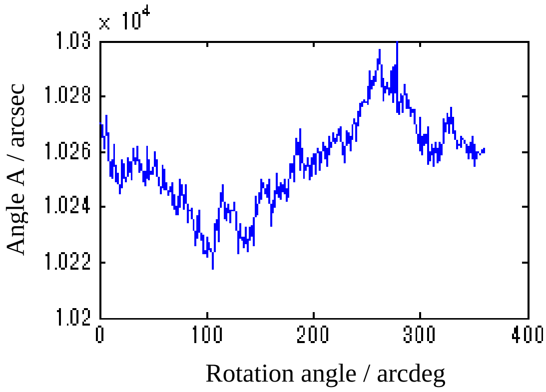
3. EXPERIMENT AND RESULTS

Table 1 shows the experimental conditions. Figure 5 shows the angle data c_a and c_b by MBAS system. The horizontal axis is rotation angle (0 - 360 arcdeg) and the vertical axis is angle data. The angle data has eccentricity of 70 arcsec. According to equation (1), we can evaluate the eccentricity is about 3.4 μm. Therefore, the eccentricity of the rotary stage of MBAS system is not good of some μm level.

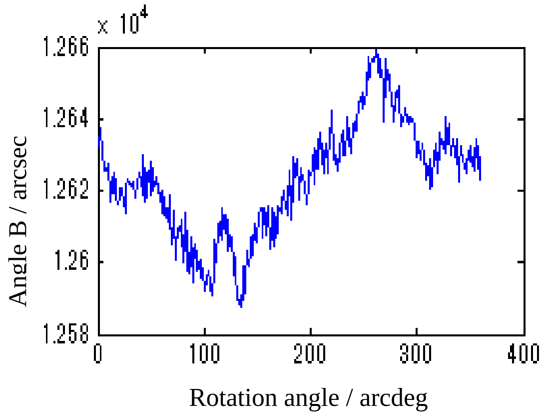
By the Fourier series, we can calculate the measured roundness of the cylinder is 307.1 nm (in the figure 6) with a repeatability of 8.7 nm. Results are presented that prove the high repeatability and accuracy of the instrument.

Table 1 Experimental conditions

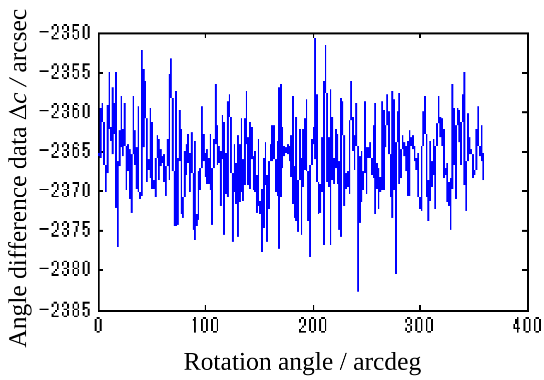
Parameters	Values
Diameter of cylinder	20 mm
Measured roundness	< 800 nm
Sample points	360
Rotation angle of one point	1 arcdeg



(a) Angle data c_a at Point A

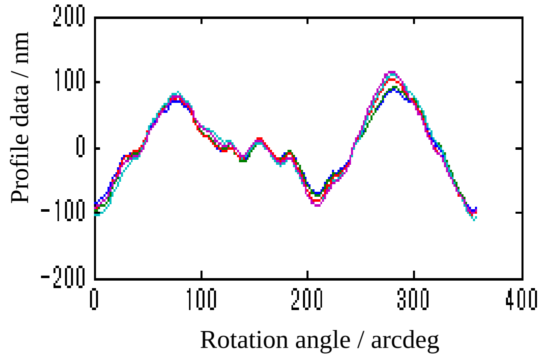


(b) Angle data c_b at Point B

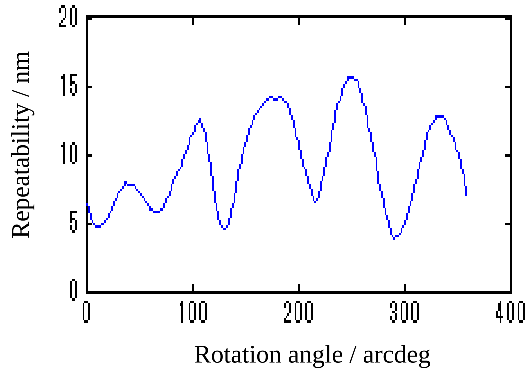


(c) Angle difference data Δc between Point A and B

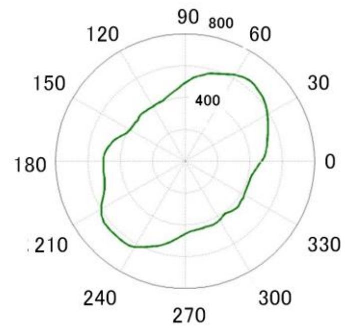
Fig. 5: Measured angle data in point A and B



(a) Profile data



(b) Repeatability



(c) Roundness chart (nm)

Fig. 6: Profile, repeatability and roundness figure of cylinder measured by MBAS

4. SUBMISSION

Based on construction principle of system, we propose a newly roundness measuring sensor (MBAS), which has just used one sensor and independence on the rotary stage. Then we construct full-scale platform for cylinder measurement, the size of the MBAS is about 125 × 130 × 90 mm, the resolution of MBAS is 0.01 arcsec and the stability of MBAS is 0.3 arcsec. At last, we measure roundness of a cylinder and the radius is 20 mm, the repeatability of the measurement is under 10 nm.

In the future, we will calibrate the autocollimator: analyze factors influencing measurement accuracy or find measures adopted for evaluating and calibrating.

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