

Development of a laser-guided deep small-sized hole-measurement system: measurement accuracy

Akio Katsuki¹, Takao Sajima¹, Hiroshi Murakami², Ali Md Hazrat³, Osamu Ohnishi⁴, Kouji Akashi⁵

¹Kyushu University, ²The University of Kitakyushu, ³Nazarbayev University, ⁴Miyazaki University of Miyazaki, ⁵Ariake National College of Technology

kaetsuki@gmail.com

Abstract

A measurement system for measuring a small-sized hole with a 17 to 21 mm diameter and 1 000 mm length was constructed. The constructed system consists of a measurement probe, a laser interferometer for detecting the roundness of a hole, and an optical system for detecting the probe position and inclination. The probe consists of a rotatable measurement unit with a pentaprism and corner cube prism, a DC motor for rotating the measurement unit, and a laser diode to radiate a laser beam toward the optical system. In this study, the measurement accuracy of the system is examined through a comparison with other measurement instruments. Further, factors causing measurement errors are analyzed and discussed. As a result, it is clear that a deviation of the probe from the center of the hole and the fabrication error of the probe adversely affect measurement accuracy. Further, small deviations lead to a decrease in measurement errors and a simplification of the measurement system.

Keywords: Deep hole, Measurement, Laser, Accuracy, Roundness, Hole deviation

1. Introduction

Holes with normal 10-millimeter-level diameters and lengths of several hundred millimeters are used for the main spindles of machines, the small cylinder in plastic injection molding, the tube sheet for heat exchanger, and gun barrels.

Accurate measurements of the diameter, roundness, cylindricity, and straightness of a deep hole are essential for improving the performance of such products. However, existing systems have drawbacks in precisely measuring holes with large length-to-diameter ratios, which require multiple measurement devices.

In a previous study [1], a guided system was applied to holes with typical 10 mm diameters and lengths of several hundred millimeters. A measurement system that can measure a small-sized hole with a 17 to 21 mm diameter and 1 000 mm length was constructed. Further, a performance test showed that this system can be used to measure the accuracy of a hole.

In this study, the measurement accuracy of the system is examined through a comparison with other measurement instruments.

2. Measurement system for a small-sized hole

2.1. Experimental apparatus

Figure 1 shows the measurement system for a small sized hole. A deep-hole boring machine is used. A laser diode (8) is located

1 Measurement unit 2 Workpiece 3 Measurement bar
4 Laser interferometer 5 CCDδ 6 CCDi 7 Gear motor 8 Laser diode
9 Flange shaft 10 Skid 11 Pentaprism 12 Corner cube prism

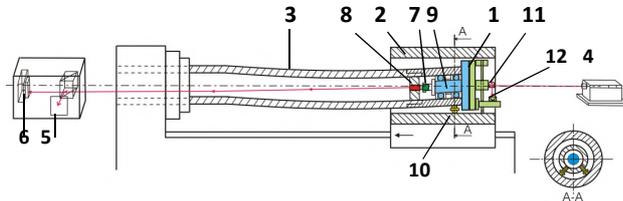


Figure 1. Laser-guided deep-hole measurement system.

at the back end of the probe. Optical devices CCDδ (5) and CCDi (6) are to detect position and inclination of the probe. A laser interferometer (4) is placed in front of the measurement unit (1). Figure 2 shows a workpiece on a fixing jig of another apparatus. A probe stuck out from the workpiece shows the measurement unit with a flange shaft (9).

2.2. Working principle

The up and down movements of the stylus are detected using the pentaprism (11) and corner cube prism (12) by the laser interferometer. The hole shape can be detected spirally while the measurement unit (1) rotates and the workpiece (2) is fed. Hole deviation is calculated geometrically as the probe position from data acquired from the CCDδ (5) and CCDi (6) [1].

3. Deviation of spindle rotation center from hole center

The deviation of the center of the spindle rotation from the hole center can be obtained as follows. For the triangle $O_S O_P A$ shown in Fig. 3, the following formula can be obtained.

$$r_R^2 = \delta^2 + r^2 - 2\delta r \cos(\pi - \beta) \quad (1)$$

From Eq. (1),

$$r = -\delta \cos(\beta) + \sqrt{\delta^2 \cos^2(\beta) - (\delta^2 - r_R^2)} \quad (2)$$

Because $r_R \cong 9$ mm, $\delta \leq 0.05$ mm are managed as,

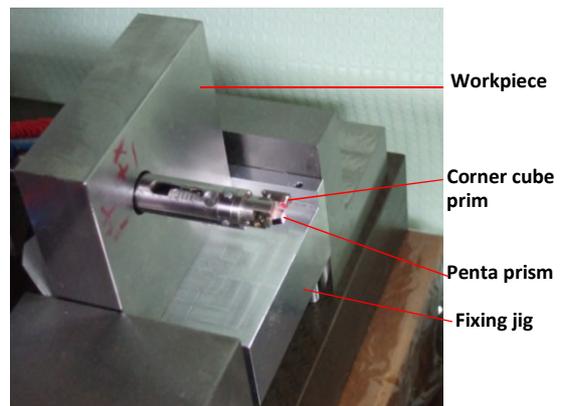


Figure 2. Workpiece on a fixing jig of another apparatus.

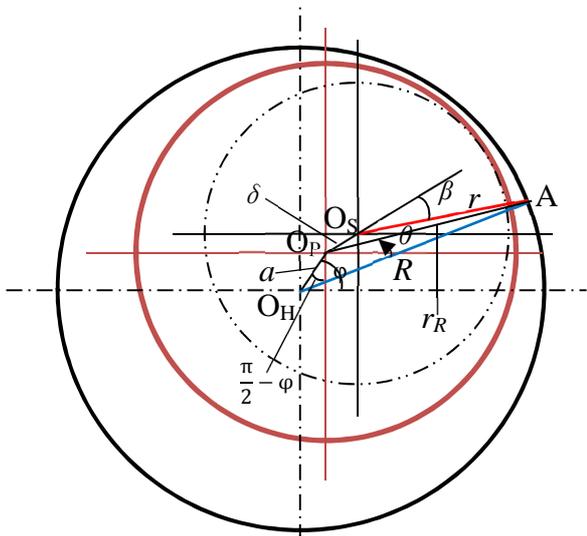


Figure 3. Deviation of spindle rotation center from hole center.

$$(\delta^2/r_R^2)\sin^2(\beta) \ll 1 \quad (3)$$

$$r = r_R - \delta \cos(\beta) \quad (4)$$

For the triangle $O_P O_H A$, the following can be obtained.

$$R^2 = a^2 + r_R^2 - 2ar_R \cos(\pi - \varphi + \theta) \quad (5)$$

From Eq. (5),

$$r_R = -a \cos(\theta - \varphi) + \sqrt{a^2 \cos^2(\theta - \varphi) - (a^2 - R^2)} \quad (6)$$

Here, Eq. (7) is managed as follows:

$$(a^2/R^2)\sin^2(\theta - \varphi) \ll 1 \quad (7)$$

For example, in the case of $R \cong 9\text{mm}$, $a \leq 0.09\text{mm}$,

$$r_R = R - a \cos(\theta - \varphi) \quad (8)$$

From Eqs. (4) and (8),

$$R = r + \delta \cos(\beta) + a \cos(\theta - \varphi) \quad (9)$$

4. Experimental procedure

4.1. First experiment

This experiment was conducted with another apparatus using the probe, a workpiece and an interferometer (4) (Fig. 2).

A measured hole was machined using an end mill. The hole-diameter is 18 mm. The rotational speed of measurement unit (1) is 6 rpm.

4.2. Second experiment

This experiment was conducted using a deep-hole boring machine. The holes of a guide bush and short-length workpiece were measured. The former was machined using internal grinding and the latter through gun drilling. Each hole-diameter is 17.6 mm.

5. Experimental result

5.1. First experiment

The hole-profile measured by the probe is shown in Fig. 4. The influence of the probe deviation is applied using Eq. (9) and is removed. The measured profile is transformed from the profiles measured by the roundness tester and designed for machining.

5.2. Second experiment

The hole-profiles of the guide bush and short-length workpiece are shown in Fig. 5. After compensation using Eq. (9), ovals were observed in the horizontal direction. The roundness of each hole was ten-times larger than that of the roundness tester. In the case of a 110 mm diameter probe, no such phenomenon, including the case of experiment 1, occurred [2]. Errors in the fabrication and setting of the probe affected the distortion of the profiles.

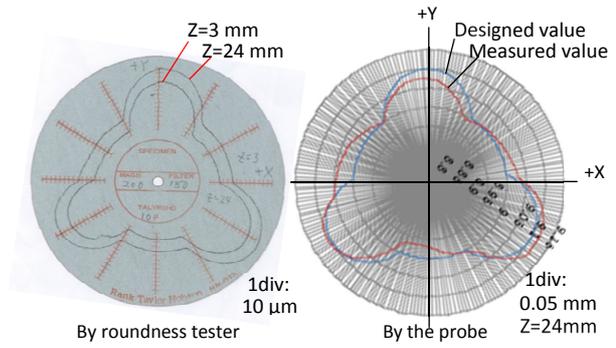
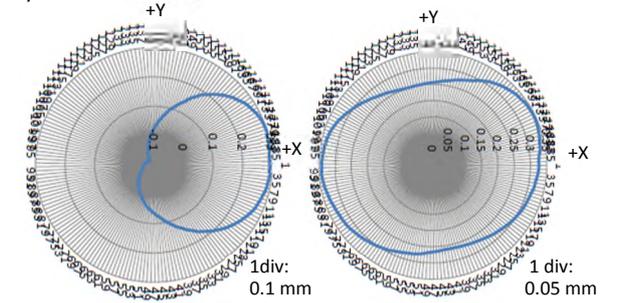


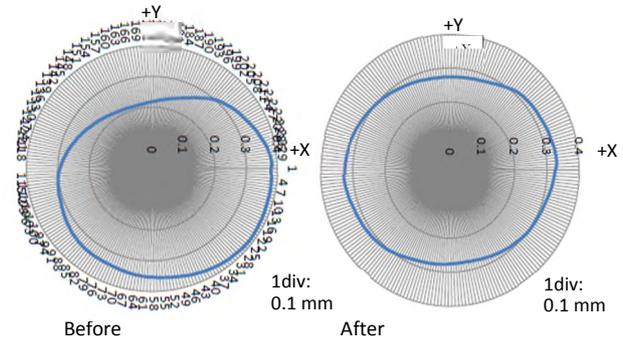
Figure 4. Roundness profiles of machined hole of the workpiece.

6. Conclusion

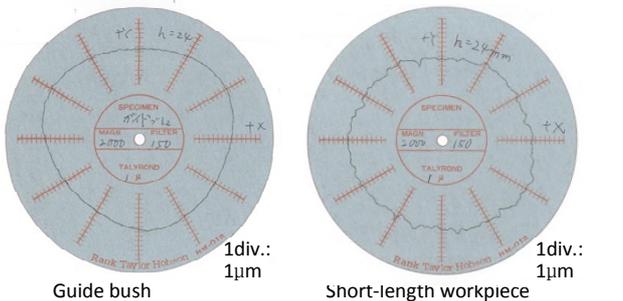
A sufficient measurement accuracy of the developed probe has yet to be obtained.



(a) Before and after compensation of roundness profile of guide bush ($Z = 24\text{ mm}$, by the probe)



(b) Before and after compensation of roundness profile of short length workpiece ($Z = 24\text{ mm}$, by the probe)



(c) Roundness profiles of guide bush and short length workpiece ($Z = 24\text{ mm}$, by roundness tester)

Figure 5. Comparison of the roundness profiles of the guide bush and short-length workpiece measured by the probe and a roundness tester.

However, improvement will be possible through continuing studies. Furthermore, measurements of hole deviation without a backward optical system are possible using a and φ of Eq. (9).

References

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