Portable Rotary-angle Detector for Industrial Motor Inspection

Tsung-Han Hsieh¹, Jr-Rung Chen¹, Po-Er Hsu¹ and Bing-Lin Ho¹

¹Center for Measurement Standards, Industrial Technology Research Institute, Taiwan

Email: JrRungChen@itri.org.tw

Abstract. Several types of precision equipment, such as machines and robot arms, rely on precision rotary motion. In this study, we developed a portable rotary-angle detector (PRAD) comprising five optical sensors and one angle ring with a 57-mm diameter to measure the positioning and radial errors of rotary motions. The five optical sensors were installed at equally divided intervals around the angle ring according to the equal division averaged method (EDA-Method) implementation. The grating of the angle ring has 9000 lines, and the signal interpolation of the angle detector system has 4000-fold subdivision. Therefore, the PRAD resolution can be achieved at 0.036 arcsec. Furthermore, a 12-face polygon and an autocollimator with 0.05-arcsec resolution and 0.25-arcsec accuracy were used to check the PRAD performance. The experimental results showed that the structure of the PRAD is simple. However, the difference over 360° is only 0.7 arcsec, indicating that PRAD is suitable for motor inspection in machine tools or robot arms.

1. Introduction

With the advance of industry development, robotic arms are widely used. Applications such as robotic machining, welding, and pick-and-place demand good accuracy of these robots. Another important application is in machine tools. This has been a challenge because the tool at the end must be positioned with extreme precision, especially in a five-axis machine tool. Rotary table have geometric errors in six degrees of freedom as described in ISO230-1 [1]. Some sensors are already preinstalled in the machine tool or mounted in the robot arm to capture the position of every joint. In the machine tool industry, this makes them ideal for monitoring spindle rotations per minute (RPM). The most commonly used sensors are angle encoders and rotary encoders [2]. Angle encoders detect the rotational relationship between two parts with high precision, typically with accuracy better than ±10″. Owing to such extreme levels of precision, angle encoders are important in the development of multi-axis centers. Regardless of simultaneous or independent movements, the designs of components such as the rotary table and swivel head often employ this type of encoder. Rotary encoders are similar to angle encoders, and measure rotation. However, they are not as precise as angle encoders. For angular calibration of a rotary encoder, this study aims to develop a convenient tool to quickly measure and evaluate angular positioning accuracy.

2. PRAD Development

For industrial application, a detector should be portable and convenient for engineers to use in assembly or production lines. Fast installation is a major consideration. Multi-read heads can be built as the comparative angle measurement equipment to calibrate the angle position error of two rotary
encoders whose graduation position deviation are unknown by the equal division averaged (EDA) method [3–6]. Figure 1 shows the conceptual model of comparative angle-measurement equipment, which we call a portable rotary-angle detector (PRAD) system. As shown in Figure 2, the PRAD developed in this paper consists of five read heads to implement EDA. Angle $\alpha$ of the PRAD and angle $\beta$ of the rotary angle of the actuator (to be measured or tested) are connected with the same shaft and rotate at constant speed. $\alpha(\theta)$ can be obtained by equation (1). $A_0(\theta)$ to $A_4(\theta)$ are the readout angles from the optical read heads. The number of residual errors was small because the eccentric error was eliminated by the EDA method. Therefore, the residual errors could be ignored in this study. The difference between the PRAD and motor can be obtained by equation (2) and is indicated as $\delta(\theta)$, which is also called the positioning error of the actuator in the PRAD system.

$$\alpha(\theta) = \frac{A_0(\theta)+A_1(\theta)+A_2(\theta)+A_3(\theta)+A_4(\theta)}{5} + \text{residual errors} (\theta)$$  \hspace{1cm} (1) \\
$$\delta(\theta) = \beta(\theta) - \alpha(\theta)$$  \hspace{1cm} (2)

3. Experimental setup and result
A Renishaw TONiC head is used as the optical read head, and the REXM ring scale has a 57-mm diameter. For the installation, the read heads were adjusted so that the signal strength around the full-axis rotation would achieve five green LEDs and not red flashing. Therefore, the installation is very easy and should only take a few minutes. The experimental result was compared the traditional calibration method. The used instruments of traditional calibration method for measuring the rotary angle were a polygon and autocollimator. A 12-face polygon was employed in this study. The comparison experiment setup is shown in Figure 3. For autocollimator specifications, the measuring
range was from −2000″ to +2000″ and the maximum permission error was less than ±0.1″. For the polygon specifications, the angle accuracy was less than ±1″. We adjusted the tilt angle (y-axis direction) to less than 10″ at approximately 360° rotation and then start to calibrated angle of rotary angle of the actuator. The traditional method had high resolution and accuracy but there were some disadvantages. One, the optical alignment may be inconvenient for an engineer, and second, the data point is limited by the number of faces of the polygon.

The tested motor of actuator was an FHA-mini rotary actuator, which consists of a motor, harmonic gear, and encoder. The motor is a pancake brushless servo. The reduction ratio of the harmonic gear is 50:1. The encoder resolution is 6,553,600 count/rev in the absolute mode, such that a driven resolution of 0.197″ can be achieved. During testing, the motor rotation was set to 15 rpm to reduce the dynamic error influence. The resolution of PRAD is 0.036 arcsec. Finally, the comparison result for the motor one-way position error in the PRAD and autocollimator is shown in Figure 4.

Through equation (1), we analyzed residual errors for two tolerances of the shaft couplings. For the tolerance check, we used a dial indicator with 2-µm resolution to measure the runout. As shown in Figure 5, the difference in the two results of the runout is approximately a factor of 10. However, the two analyzed residual errors are close to each other. Hence, we know that the tolerance will not affect the measurement accuracy of PRAD.

![Autocollimator](image1.png)

**Figure 3.** Experimental setup

![Comparison graph](image2.png)

**Figure 4.** Comparison for motor one-way position error in PRAD and autocollimator
4. Discussion and conclusions
In this paper, PRAD was successfully developed to measure the angular position errors in the rotary actuator quickly. A traditional method including a 12-face polygon and an autocollimator are used to check and compare the PRAD performance. The experimental results showed that the structure of the PRAD is simple. However, the difference beyond 360° is only 0.7 arcsec. This small difference may arise from polygon specification tolerance and it is suitable for industry applications. Future work includes attempts to find more rotary geometric errors from the PRAD measuring results.

5. Reference
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