Runout of Rotational Positioners

Definition and measurement of radial error motions

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Effectively managing error motion is essential for achieving success in high precision engineering applications. This TechNote outlines attocube's definition of radial runout, identifying it as a primary type of error motion in rotational positioners. Additionally, it describes the methodology employed for measuring radial runout and provides typical values for two positioners: the ECR4040 and the ECR5050hs from the ambient and vacuum positioner EC-series.

Definition: Motion Error

The lateral motion error of a rotational positioner is superimposed from two independent errors: radial runout and wobble. Because of its relevance for the application and measurement limitations, the radial runout is often measured and interpreted as the combined movement of radial runout and wobble effects (see Measurement Procedure). Yet, the following definitions should help to maintain clarity regarding the fundamental nature of the two contributing radial errors:

Radial runout [µm] is defined as the position-dependent lateral error motion of a rotary stage perpendicular to the axis of rotation (see a in Figure 1).

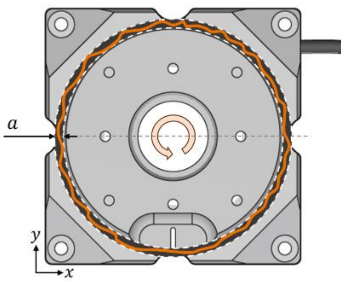

Figure 1: Illustration of the radial runout error motion

Wobble [µ°] is the position-dependent angular misalignment of the real axis of motion relative to its ideal axis. It effects a radial runout that scales with height (see $a(z)$ Figure 2).

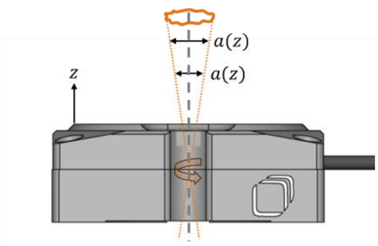

Figure 2: Illustration of the wobble error motion

Radial runout and wobble are often cyclic in nature and are caused by the imperfect nature of mechanical components. They are defined for one full rotation (360°) and do not include a static offset (eccentricity or tilt) or surface errors of the rotating table.

Measurement Procedure: Radial Runout

To determine the radial runout of a rotator attocube has developed a setup based on the error separation method (ESM) as described in [1] and a test setup similar to [2]. The setup uses four measuring axes of attocube's IDS3010 displacement interferometer that are perpendicular to the rotation axis from different angles at same height. The height is adjustable to meet customer requirements. To offer an interferometric readout over the rotary movement a reflective cylinder is mounted onto the rotator. An illustration of a comparable setup is shown in Figure 3. By processing the measurement data with the ESM following information is obtained: A radial runout split into an x- and y-direction (see Figure 4), that is free from static offsets (eccentricity or tilt) and the error of the cylinders shape. With the serial repetition of the testing routine average values can be calculated.

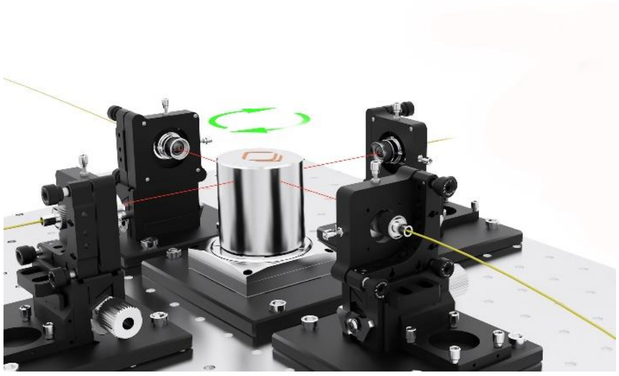

Figure 3: Illustration of the measurement setup

For most customers a user-friendly description of the relevant error within their application is desirable. Therefore, the measurement setup detects the superimposition of the radial runout and the height-dependent lateral component of the wobble as experienced by the user.

Measurement Interpretation

Figure 4 shows the radial runout that has been separated in an x-y-directional error motion over a rotation of 360°. We define the maximum radial runout as the magnitude of the radial

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vector at the angular position where the sum of the absolute x- and y-directional runouts is at its peak.

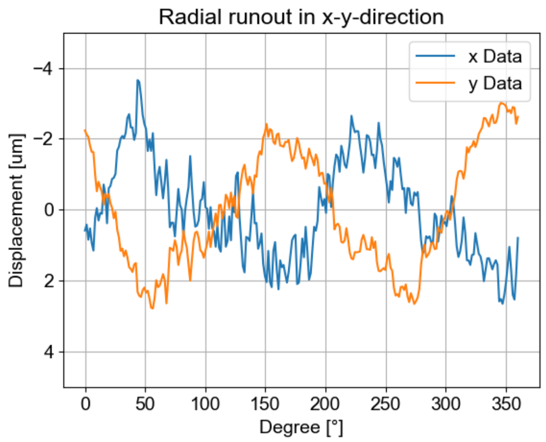

Figure 4: x-y-directional runout of an ECR4040

To visualize the maximum radial runout a radial-directional plot is helpful (see Figure 5). For a better graphical representation, an arbitrary radius of 40 µm has been added to the error. In this example the maximum radial runout is about 6.8 µm peak-to-peak (p2p) deviation from an ideal movement.

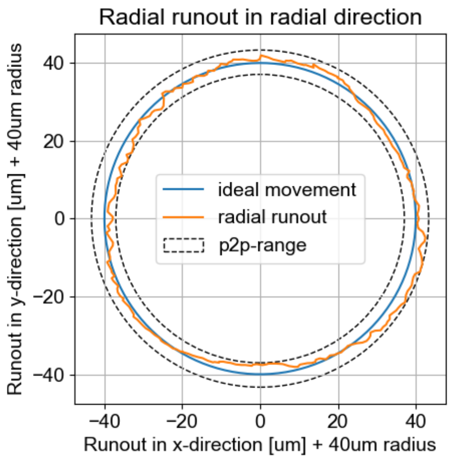

Figure 5: radial runout presentation of an ECR4040

Measurement Results

Two types of the ambient and vacuum positioner EC-series were tested. Averaged values for the maximum radial runout are shown in Table 1. The testing routine for these measurements involved serial repetitions of one rotation at room temperature. Testing the repeatability between continuous rotations has revealed that these positioners exhibit a non-systematic error motion.

The results of the ECR5050hs are the average values of ECR5050hs/Al and ECR5050hs/StSt positioners. The ECR3030 of the EC series has not been tested. Additional measurements can be requested.

Table 1: results for standard rotators, z = 15 mm

	ECR4040	ECR5050hs
Max. radial runout typical value	4.9 µm	8.2 µm
Number of tested positioners	10	6

Conclusion

We have defined two of the most relevant cyclic error motions as radial runout and wobble. attocube has developed a measurement setup that allows an application-oriented measurement of the overall radial error motion that is freed from static offsets (eccentricity or tilt) and target surface errors. We specified typical values for the maximum radial runout of attocube´s standard ambient rotators which supports our customers in achieving their precision engineering goals.

Additional Information

Systematic runout errors can be compensated in a feedforward approach by reversing the x-y-directional runout with linear positioners. To enable a feedforward runout compensation, attocube developed a customized version of the ECR4040 with an optimized radial runout (see Table 2) that is repeatable over multiple rotations[1]. For applications that require runouts down to 100 nm, a feature to automatically apply the feedforward error compensation is available on request [3].

Table 2: results for the ECR4040/cust., z = 15 mm

	ECR4040/cust.
Max. radial runout typical value	0.4 µm*
Number of tested positioners	5

*Can further be reduced with the rotation compensation feature [3].

Sources

[1] M. Jansen and P. H. J. Schellekens, “Advanced spindle runout-roundness separation method,” Jan. 2001, doi: 10.1142/9789812811684_0024.

[2] T. Stankevič *et al.*, “Interferometric characterization of rotation stages for X-ray nanotomography,” *Rev. Sci. Instrum.*, vol. 88, no. 5, p. 053703, May 2017, doi: 10.1063/1.4983405.

[3] attocube systems AG, “Customized Nanopositioning Solutions.” 2024. [Online]. Available: Customized Nanopositioning Solutions (attocube.com)

1 Currently available as customization (03/2024)