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QC20 ballbar error budget and uncertainty calculations

Introduction

This document summarises the system measurement uncertainty calculations for a Renishaw QC20 ballbar and ballbar calibrator. These calculations are used to derive the published specifications:

- The QC20 ballbar is specified to measure radial variation to ± [0.7+0.3%*L] µm at 20 ±5 °C. Where L is the absolute value of radial variation (range).
- The ballbar calibrator is specified to have a length uncertainty of ±1 µm.

General information on the methodology used

The derivation of error budgets is a standard part of Renishaw's new product development process which is covered by the group's ISO 9001:2015 compliant quality management system. ISO 9001:2015 is the internationally recognised standard for quality management systems and is verified at Renishaw by BSI management systems (UKAS accredited).

Error budgets are calculated following the guidance as outlined in EA-4/02 'Expression of the Uncertainty of Measurement in Calibration' and NIST technical note 1297. The contributory elements to the budget are derived from a combination of the validation of component specifications, experimental evidence of performance and theoretical calculations. The combination of these individual terms results in the system level specification. All specifications are published with 95% (k=2) confidence level. The error budgets are reviewed and signed off by qualified personnel. The sections below show the individual elements of the QC20 ballbar and ballbar calibrator error budgets.

Uncertainty in the measurement of radial variation with a QC20 ballbar

Source of uncertainty	Uncertainty value µm	Probability distribution	Uncertainty (k=1) ± µm
Uncertainty of ballbar calibration	±0.40	Normal (k=2)	0.20
Ballbar acceptance test limit	±0.40	Normal (k=2)	0.20
Ballbar drift over 1 year	±0.30%L*	Normal (k=2)	0.15%L*
Balls sphericity	0.13	Rectangular	0.11
Hysteresis	±0.06	Normal (k=3)	0.02
Ballbar thermal expansion	±0.10	Normal (k=1)	0.10
Centre pivot deflection	±0.15	Normal (k=1)	0.15
Combined uncertainty (k=1)			**0.35 µm + 0.15%L**
Expanded uncertainty (k=2)			**0.70 µm + 0.30%L**
Published specification (k=2)			**0.70 µm + 0.30%L**

** Where L is the absolute value of radial variation*

Application of the specification over different radial variations

Ballbar specification when measuring 10 µm radial variation of the machine:

- ± [0.70 + 0.30%*10] µm = ±0.73 µm

Ballbar specification when measuring 100 µm radial variation of the machine:

- ± [0.70 + 0.30%*100] µm = ±1.00 µm

Uncertainty in the ballbar calibrator length

When measuring the radius of a circle with a QC20 ballbar the additional error of the uncertainty in the calibrator length must be included.

Source of uncertainty	Uncertainty value µm	Probability distribution	Uncertainty (k=1) ± µm
Uncertainty of the master ballbar	±0.40	Normal (k=2)	0.20
Master ballbar non-linearity	±0.40	Normal (k=2)	0.20
Repeatability of calibration	±0.03	Normal (k=1)	0.03
Uncertainty of the master calibrator	±0.30	Normal (k=2)	0.15
Drift in master calibrator	±0.50	Normal (k=2)	0.25
Ballbar scale factor error and length mismatch	0.0004	Normal (k=2)	0.02
Sphericity of ballbar balls	0.13	Rectangular	0.11
Temperature (ballbar)	±1.2°C	Rectangular and normal	0.01
Temperature (calibrator)	±1.2°C	Rectangular and normal	0.03
Combined uncertainty (k=1)			**0.42**
Expanded uncertainty (k=2)			**0.85**
Published specification (k=2)			**1.00**

General notes for all tables:

- The first column lists the sources of the uncertainty errors considered.
- The second column gives the uncertainty value for the source of uncertainty in the appropriate units.
- The third column gives the probability distribution function for the source of the errors and the coverage factor used. This coverage factor is used to convert uncertainty values to k=1. An additional multiplier is applied to account for size of the sample data.
- The fourth column lists the uncertainties for the appropriate source of uncertainty.
- The individual values are combined using a 'root sum square' calculation to produce the total combined uncertainty.

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