Measurement of roundness errors on roller machines and determination of their uncertainties

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Measurement of roundness errors on roller machines and determination of their uncertainties

- What is roundness, how it is measured
- Roundness for rollers
- Traceability
- Uncertainty evaluation
ISO 1101 – Geometrical tolerances

Roundness

5 Symbols

See Tables 1 and 2.

### Table 1 — Symbols for geometrical characteristics

<table>
<thead>
<tr>
<th>Tolerances</th>
<th>Characteristics</th>
<th>Symbol</th>
<th>Datum needed</th>
<th>Subclause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Form</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Straightness</td>
<td></td>
<td>—</td>
<td>no</td>
<td>18.1</td>
</tr>
<tr>
<td>Flatness</td>
<td></td>
<td>□</td>
<td>no</td>
<td>18.2</td>
</tr>
<tr>
<td>Roundness</td>
<td></td>
<td>○</td>
<td>no</td>
<td>18.3</td>
</tr>
<tr>
<td>Cylindricity</td>
<td></td>
<td>—</td>
<td>no</td>
<td>18.4</td>
</tr>
<tr>
<td>Profile any line</td>
<td></td>
<td>◇</td>
<td>no</td>
<td>18.5</td>
</tr>
<tr>
<td>Profile any surface</td>
<td></td>
<td>◊</td>
<td>no</td>
<td>18.7</td>
</tr>
<tr>
<td>Parallelism</td>
<td></td>
<td>//</td>
<td>yes</td>
<td>18.9</td>
</tr>
</tbody>
</table>
Measurement of roundness

Roundness instrument, best
Uncertainty U = 0,1 µm

CMM, reasonable
Uncertainty U = 5 µm
You also get diameter
Number of points affect result

Dial gauge and rotation of part is cheap and easy
Uncertainty U = 10 µm
Difficult to see shape of your part

Source: H Dagnall. Let’s talk roundness. Rank Taylor Hobson Ltd Leicester 1976
Roundness material standards for laboratory

Cylinder with a flat part, Flick standards
- Calibration of gauge
Almost perfectly round sphere
- Calibration of rotation
Roundness in roller measurements

Roundness is an important feature when thickness and flatness of the end product is needed, such as paper machines, rolling mills for steel strips or sheets, printing machines.

Uncertainty of roundness is roughly 0.5 µm to 50 µm.

Three R-MS developed in WP2.
Roundness measurement with 4-point instrument
In-process measurement Roll Geometry & Machining

Modernised roll grinding machine at a Paper Mill. The control system includes 3D grinding control technology. The fully-automatic 3D measuring device is based on the fourpoint measuring method.

Multi point systems and the Ozono method

Using Ozono algorithm transducer readings are combined to exclude the errors in rotation

The method is commonly used, but often the traceability and measurement uncertainty are not known

Harmonic amplitudes in roundness

Examples of run-out profiles and their harmonic amplitudes
## Roundness standards

<table>
<thead>
<tr>
<th>Name</th>
<th>Nominal Form</th>
<th>Deviation from nominal form / µm</th>
<th>Surface texture /µm</th>
<th>Diameter /mm</th>
<th>Thickness /mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A</td>
<td>round</td>
<td>2 µm filtered 1-500 UPR</td>
<td>Ra 0.2</td>
<td>503</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Rz 0.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type B</td>
<td>21 UPR with 20 µm amplitude</td>
<td>1 µm</td>
<td>Ra 0.4</td>
<td>503</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Rz 1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type C</td>
<td>asymmetric multi-wave, 2 to 30 UPR, 10 µm / undulation</td>
<td>2 µm</td>
<td>Ra 0.4</td>
<td>503 +/-1</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Rz 1.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Function of each standard

The type A standard is almost perfectly round. With a roundness error below 2 µm this standard helps to reveal errors like noise and thermal drift.

Type B has characteristic form of a 21 UPR wave. The hypothesis is that the characterisation of a single probe of a multi-point measurement system is straightforward with a disc with single harmonic content.

The harmonic amplitude from the calibration certificate of the disc will be compared with the harmonic measured by a single sensor.
The type C, asymmetric multi wave, consists of several waves.

Are expected to work as overall test standard.

Previously only type C discs have been used in the calibration.
Calibration of the roundness standards

Disc is centered on a rotary table

Readings from an inductive sensor gives run-out
Roundness analysis is done by software (centering, FFT)

Traceability
Sensor is calibrated against laser interferometer
Radial run-out of rotary table is checked using a very round glass hemisphere (calibrated using error-separation on a separate roundness instrument)
Roundness measurement with modernized roundness instrument

VTT-MIKES Roundness analysis

Roundness Analysis

Configuration:
- Instrument: C.E. Johansson
- Author: All
- Object: B
- Signal number: B 274m
- Averaging: 40 Round
- Reference circle: Least squares
- Filtering: Gaussian 500UPR
- Dall correction: No

Results:

<table>
<thead>
<tr>
<th>Roundness axis</th>
<th>R100</th>
<th>R50</th>
<th>R25</th>
</tr>
</thead>
<tbody>
<tr>
<td>R100</td>
<td>52.6243 mm</td>
<td>18.9188 μm</td>
<td>18.9188 μm</td>
</tr>
<tr>
<td>R50</td>
<td>18.9188 μm</td>
<td>18.9188 μm</td>
<td>18.9188 μm</td>
</tr>
<tr>
<td>R25</td>
<td>18.9188 μm</td>
<td>18.9188 μm</td>
<td>18.9188 μm</td>
</tr>
</tbody>
</table>

Eccentricity
- Ecc. x = 0.475 μm
- Ecc. y = 0.475 μm
- Ecc. z = 0.475 μm
- Ecc. phi = 47.3°
- Meridional Error = 37.93 μm

Spectral content:
Verification of roundness with a CMM
Measurements of the R-MS comparison to CMM

- Disc A
- Disc B
- Disc C
Measurements of the R-MS

Disc B also measured at Metrosert
Measurements of the R-MS comparison to two CMM’s

- Disc B
- Also measured at Metrosert
- Variation of results within +/- 0.5 µm

Conclusion
- Disc B is a robust material standard
R-MS, type C

Measurements at MIKES, Aalto and industrial partner (IP)
Task specific uncertainty for harmonic amplitudes

A script written in Python and generates a large number of input data files (synthetic data representing a roundness measurement, distorted with suitable distributions for error contributions),

The Ozono algorithm doing the calculations for the four point method was acquired from Rollresearch as a executable program.

Output file is read by a Python script and after many runs the standard deviation and other statistical properties are evaluated.
Task-specific uncertainties for measurements of rollers, preliminary uncertainty contributions

- The assumed errors are alignment error of one degree for length transducers.

- Scale error of +/- 0.5 µm for length transducers

- Temperature change of 0.5 °C are assumed

- Note: it is impossible to do a single uncertainty estimate that works for all conditions, situations and users around the world
Output from Monte Carlo simulation (N = 10 000) where standard uncertainties are shown as error bars.

Mean values noted as ball deviates from the true value of 10 µm mainly because of limitations in the four point algorithm.
Conclusion

- New traceable material standards
- Procedure developed for task specific uncertainties
- Values for uncertainty components show reasonable agreement with measurements of R-MS
- No knowledge of previous published work on uncertainty evaluation for industrial roller measurements