High precision centerless grinding of transmission shafts
Karsten Otto – Sales Director China – Schaudt Mikrosa GmbH
Feng Qi – Sales Director - United Grinding China
Agenda

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Process characterization
Roundness in centerless grinding
Application examples, quality influences and solved problems
Summary
UNITED GRINDING Group

Fact & Figures

- Over 2,300 employees, more than 130 apprentices
- 24 locations worldwide
- Over 145,000 machines have been produced and delivered – worldwide
- UNITED GRINDING is one of the twenty biggest machine tool manufacturers worldwide (*Metalworking Insider Report*)
- UNITED GRINDING is one of the ten biggest machine tool manufacturers in Europe (*VDW*)

16.05.2018  Transmission Seminar - Baoding
You will find us where our customers are

145,000 machines have been produced and delivered worldwide
Our brands

Technology groups

Surface and Profile
Cylindrical
Tool
Our company
The big world of small tolerances
Machine competence across the board

Schaudt Mikrosa GmbH

- Over 100 years of experience in the development of precision grinding machines
- Fine grinding at the limit of the measurable range
- Individual, workpiece-oriented machine applications
- Over 50 branches and agencies across the world
- Worldwide service network
For everything that really needs to fit

Core competence

- Camshafts, transmission shafts and turbo shafts
- Precision parts for injection, pump and hydraulic systems
- Rolling elements and bearing rings
- High-precision shafts for the printing industry and machines of all kinds
Overview centerless grinding machines

- **KRONOS S**
  - KRONOS S 125
  - KRONOS S 250

- **KRONOS M**
  - KRONOS M 250
  - KRONOS M 400
  - KRONOS K

- **KRONOS L**
  - KRONOS L 550
  - KRONOS L 660
  - KRONOS dual
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Process characterization

Stable workpiece position

Support of the workpiece with the regulating wheel and workrest blade across the whole or a major length of the workpiece

→ No bending of the workpiece

→ Workpieces with a unfavorable diameter length ratio can be processed with a high removing rate in perfect quality
Process characterization

High base accuracy

In centerless grinding process:

→ The infeed is in relation to the diameter (between centers in relation to radius)

→ Wheel wear and dislocation (cause temperature change), leads only to half error compared to grinding between centers

Stable workpiece support
Process characterization

Example – high base accuracy / stable workpiece position

<table>
<thead>
<tr>
<th>Machine</th>
<th>KRONOS S 125</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workpiece</td>
<td>needle (injection system)</td>
</tr>
<tr>
<td>Abmessung</td>
<td>Ø 4,0 x 40 mm</td>
</tr>
<tr>
<td>Material</td>
<td>S 6-5-2</td>
</tr>
<tr>
<td>Stock removal</td>
<td>0,05 ±0,005 mm</td>
</tr>
<tr>
<td>Grinding time</td>
<td>5,9 s</td>
</tr>
<tr>
<td>Diameter</td>
<td>± 0,5 µm</td>
</tr>
<tr>
<td>Roundness</td>
<td>0,7 µm</td>
</tr>
<tr>
<td>Surface Rz</td>
<td>1,2 µm</td>
</tr>
<tr>
<td>Straightness</td>
<td>0,7 µm</td>
</tr>
</tbody>
</table>

(1) average
Process characterization

Polygon effect

Geometric Reason
- Grinding gap geometry

Dynamic reasons
- Self-excitat vibrations
- External-excitat vibrations
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Roundness in centerless grinding

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Summary
The geometric roundness error formation

Infeed of the grinding wheel
The geometric roundness error formation

Infeed of the grinding wheel

This creates new lateral surface on the workpiece (dark green)
The geometric roundness error formation

Infeed of the grinding wheel

This creates new lateral surface on the workpiece (dark green)

If this new surface has contact with work rest blade the workpiece is moving down (in direction work rest blade). The infeed is changing.
The geometric roundness error formation

Infeed of the grinding wheel

This creates new lateral surface on the workpiece (dark green)

If this new surface has contact with work rest blade the workpiece is moving down (in direction work rest blade). The infeed is changing.

This creates a second new lateral surface (light green).

If this surface come in contact with work rest blade, the effect come again. If the first new surface has contact with the regulating wheel the infeed change again. In total three new roundness errors at a half revolution of the workpiece created. This effect is called regenerative effect.
The geometric roundness error formation

- Machining and support of workpiece are effected on the same lateral surface.
- Errors at regulating wheel or work-rest blade as well as at the workpiece itself cause cutting depth changes at the grinding wheel.
- The roundness error regenerates itself.
- The roundness error represents the interaction of harmonic polygon shapes.
- Each grinding zone geometry has its typical roundness scenario.
- The amplitude of the roundness error depends on the wheel penetration depth e.
- Polygon shapes with lower lobes have a bigger roundness error.
The geometric roundness error formation

Determining is the dimension of the angle ratios of the contact points between workpiece and grinding wheel, workpiece and work-rest blade as well as workpiece and regulating wheel. This is described by means of the angles $\varepsilon$ and $\delta$. Using these angles, the stability index can be calculated for every polygon shape for every setting.

$$SI(\varepsilon, \delta, p) = 1 + \frac{\sin(\varepsilon) \cdot \cos(p \cdot \delta) - \sin(\delta) \cdot \cos(p \cdot \varepsilon)}{\sin(\delta - \varepsilon)}$$
Roundness

Polygon effect – geometric reason

HEUREEKA - Software solution for optimization of grinding zone geometry

- Software for calculation of optimal machine / grinding zone geometry, e.g. optimization of roundness and cylindricity
- Useful tool for the analysis and planning of the grinding process
- HEUREEKA can be integrated into the KRONOS machine control
The geometric roundness error formation

Stability index

The **stability index** (SI) indicates, if a polygon of certain order is reduced or not. The aim is to find a machine setting, which has a **positive stability index for all polygons** from 2 ... 30 (50)
Roundness

Polygon effect – dynamic reasons

Good results require high machine stiffness and high dampening

- Generous dimensioning of the machine components
- Symmetric design

Scraping of the contact surfaces by hand

Optimization of the dynamic machine behavior

Usage of mineral casting - Granitan
Process vibrations

Process vibrations overlay the nominal movement between the grinding wheel and the workpiece in a periodical motion.

**Effects:**

- Reduction of workpiece quality (dimensional accuracy, shape- and position tolerances and surface quality)
- Reduce the tool life
- Reduction in productivity
- Shortening the life time of the machine
- Increase the noise exposure of employees
Vibrations on centerless grinders

Externally created vibrations
- Impulse excitation
  - Machine vibrates with natural frequency
    - e.g. vibrations through the foundation

Self-excited vibrations
- Periodic excitation
  - Machine vibrates with excitation frequency
    - e.g. Unbalance, Bearing faults, Interrupted cut (Caused by the workpiece)
- Machine vibrates with natural frequency
  - e.g. Regenerative effect, Background noise of the cutting forces

16.05.2018 Transmission Seminar - Baoding
Interrupted cut
Interrupted cut

- 12 interruptions
- 12 other interruptions are offset by 15 °
- → 24 interruptions
- Problem: bad roundness
- Roundness = 6.2 microns

- Workpiece: Ø 40 x 80
- z = 0.25 mm in 2 grinding operations
- Roundness <1.0 micron at filter 1 ... 150
- Ra <0.25 microns
Interrupted cut

- Removing the cause is not possible
- Reducing the impact
- Geometric stability analysis with "Heureeka"
Interrupted cut

- Changing workpieces height
- \( H_w = 9.8 \text{ mm} \Rightarrow H_w = 17 \text{ mm} \)
Interrupted cut

- Result: improvement of roundness from 6.2 microns to 0.9 microns

Further optimization resulted in a roundness in average of 0.6 microns.
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Roundness in centerless grinding

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Summary
Application Example 1 – long transmission shaft

**KRONOS L660**

<table>
<thead>
<tr>
<th>Workpiece</th>
<th>transmission shaft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>34MnB5</td>
</tr>
<tr>
<td><strong>Dimensions</strong></td>
<td>Ø 50 × 605 mm</td>
</tr>
<tr>
<td>Stock removal Ø</td>
<td>0.25 mm</td>
</tr>
<tr>
<td><strong>Accuracy</strong></td>
<td></td>
</tr>
<tr>
<td>Surface finish (Rz)</td>
<td>6.3 µm</td>
</tr>
<tr>
<td>Diameter tolerance</td>
<td>11.0µm</td>
</tr>
<tr>
<td>Roundness</td>
<td>4.0 µm</td>
</tr>
<tr>
<td><strong>Cycle time</strong></td>
<td></td>
</tr>
<tr>
<td>Grinding time</td>
<td>24.0 s</td>
</tr>
<tr>
<td>Loading / Unloading</td>
<td>12.0 s</td>
</tr>
<tr>
<td>Cycle time (without dressing)</td>
<td>36.0 s</td>
</tr>
</tbody>
</table>

**Features**

- Infeed grinding of a long transmission shaft
- Grinding of the splines (no contact of splines to reg. wheel and workrest blade)
- Post-process measuring system
## Application Example 2 – Solving roundness problems

### KRONOS M400

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workpiece</td>
<td>transmission shaft</td>
</tr>
<tr>
<td>Material</td>
<td>16MnCr5</td>
</tr>
<tr>
<td>Hardness</td>
<td>60±2HRC</td>
</tr>
<tr>
<td>Dimensions</td>
<td>Ø 40 × 357 mm</td>
</tr>
<tr>
<td>Stock removal Ø</td>
<td>0.35 mm</td>
</tr>
<tr>
<td>Accuracy</td>
<td>target</td>
</tr>
<tr>
<td>Surface finish (Ra)</td>
<td>0.3 µm</td>
</tr>
<tr>
<td>Diameter tolerance</td>
<td>±6.0 µm</td>
</tr>
<tr>
<td>Roundness</td>
<td>4.0 µm</td>
</tr>
<tr>
<td>Cycle time</td>
<td></td>
</tr>
<tr>
<td>Grinding time</td>
<td>13.5 s</td>
</tr>
<tr>
<td>Loading / Unloading</td>
<td>6.0 s</td>
</tr>
<tr>
<td>Cycle time (wo dressing)</td>
<td>19.5 s</td>
</tr>
</tbody>
</table>

**Features**
- Infeed grinding of a transmission shaft
- Post-process measuring system
Application Example 2 – Solving roundness problems

Roundness problem

Possible influences:
- Grinding gap geometry

Stability index 3…30-eck  Stability index 9-eck
Application Example 2 – Solving roundness problems

Roundness problem

Before optimization

Possible influences:

- Grinding gap geometry
- Regulation wheel specification with higher damping
- Workpiece speed
- Direction of coolant nozzle
- Contact conditions of workpiece to grinding wheel, axial stop and regulating wheel

Reason: Contact of this area to reg. wheel and workrest blade
Application Example 2 – Solving roundness problems

Solved roundness problems – contact conditions

Before optimization

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0</td>
<td>0,52</td>
<td>0,0030</td>
<td>MZC</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>0,69</td>
<td>0,0030</td>
<td>MZC</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>0,19</td>
<td>0,0030</td>
<td>MZC</td>
</tr>
<tr>
<td>13</td>
<td>0</td>
<td>2,38</td>
<td>0,0030</td>
<td>MZC</td>
</tr>
<tr>
<td>14</td>
<td>0</td>
<td>2,54</td>
<td>0,0030</td>
<td>MZC</td>
</tr>
</tbody>
</table>

After optimization

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0</td>
<td>0,59</td>
<td>0,0030</td>
<td>MZC</td>
</tr>
<tr>
<td>7</td>
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<td>0,52</td>
<td>0,0030</td>
<td>MZC</td>
</tr>
<tr>
<td>10</td>
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<td>0,55</td>
<td>0,0030</td>
<td>MZC</td>
</tr>
<tr>
<td>13</td>
<td>0</td>
<td>0,98</td>
<td>0,0030</td>
<td>MZC</td>
</tr>
<tr>
<td>14</td>
<td>0</td>
<td>2,54</td>
<td>0,0030</td>
<td>MZC</td>
</tr>
</tbody>
</table>
Application sample 3 - Simultaneous pre and finish grinding

**KRONOS L 660**

**Workpiece**
- transmission shaft

**Material**
- TL4220

**Dimension**
- Ø 35 × 280 mm
- Stock Removal Ø 0.3 mm

**Precision**
- Surface (Rz) 3.5 µm
- Diameter tolerance 9.0 µm
- Roundness 2.0 µm

**Processing time**
- Grinding time 16.0 s
- Loading / unloading 6.0 s
- Cycle time 22.0 s

**Special features**
- OP 1 grinding diameter and splines
- OP 2 finish grinding diameter
- No risk to copy the splineform on the diamenter
# Application sample 4 – Multiple production

## KRONOS L 660

<table>
<thead>
<tr>
<th>Workpiece</th>
<th>transmission shaft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>16MnCr5</td>
</tr>
<tr>
<td><strong>Dimension</strong></td>
<td>Ø 43 × 150 (180)mm</td>
</tr>
<tr>
<td>Stock Removal Ø</td>
<td>0.3 mm</td>
</tr>
<tr>
<td><strong>Precision</strong></td>
<td></td>
</tr>
<tr>
<td>Surface (Rz)</td>
<td>2.5 / 6.3 µm</td>
</tr>
<tr>
<td>Diameter tolerance</td>
<td>11.0 / 13.0 µm</td>
</tr>
<tr>
<td>Roundness</td>
<td>3.0 µm</td>
</tr>
</tbody>
</table>

## Processing time

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Grinding time</td>
<td>24.5 s</td>
</tr>
<tr>
<td>Loading / unloading</td>
<td>7.0 s</td>
</tr>
<tr>
<td>Dressing time per infeed</td>
<td>7.0 s</td>
</tr>
<tr>
<td>Cycle time</td>
<td>38.5 s</td>
</tr>
<tr>
<td>Cycle time per part</td>
<td>13.0s</td>
</tr>
</tbody>
</table>

**Special features**

- High productive solution
Application sample 5 – Mixed Production

KRONOS M400

**Workpiece**
- Transmission shaft

**Material**
- 16MnCr5

**Dimension**
- Ø 43 × 150 (180)mm
- Stock Removal Ø 0.3 mm

**Precision**
- Surface (Rz) 2.5 / 6.3 µm
- Diameter tolerance 11.0 / 13.0 µm
- Roundness 3.0 µm

**Processing time**
- Grinding time 24.5 s
- Workpiece change time 6.0 s
- Dressing time per infeed 4.0 s
- Cycle time 34.5 s
- Cycle time per part 17.5 s

**Special features**
- Solution for smaller production volumes
- Nearly no time for change over necessary
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Summary

Requirements

Machine with high static, dynamic and thermic stiffness

Optimized grinding and dressing tools

Grinding technology

Qualified employees for machine set up

Analyzing tools and process understanding

Effective coolant
Thank you!