High precision centerless grinding of transmission shafts

Karsten Otto – Sales Director China – Schaudt Mikrosa GmbH
Feng Qi – Sales Director - United Grinding China

Agenda

Company

Process characterization

Roundness in centerless grinding

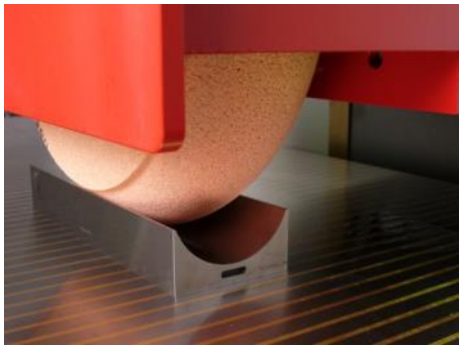
Application examples, quality influences and solved problems

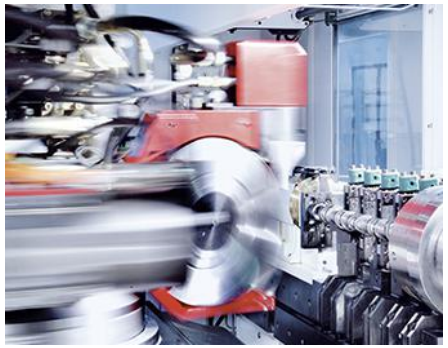
Summary

UNITED GRINDING Group

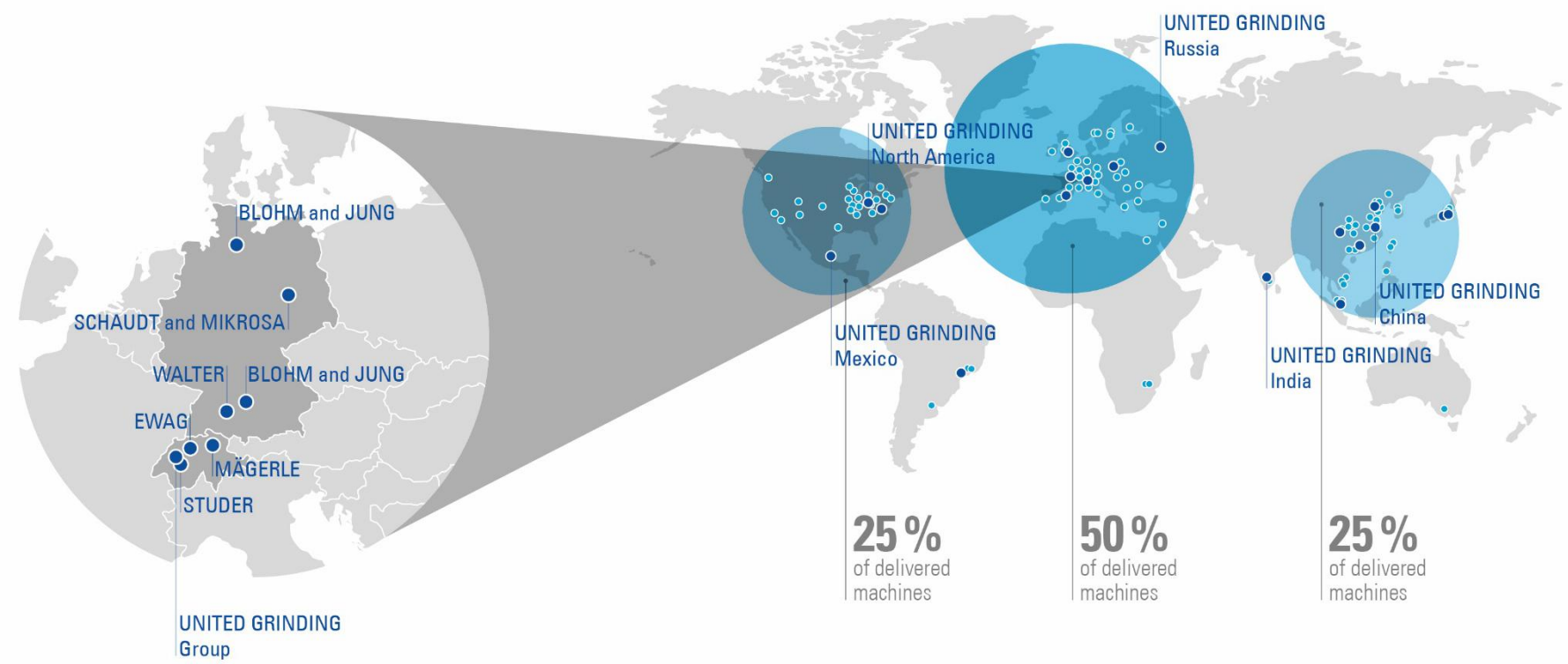
Fact & Figures

- 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*)






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

MÄGERLE KÖRBER SOLUTIONS
BLOHM KÖRBER SOLUTIONS
JUNG KÖRBER SOLUTIONS

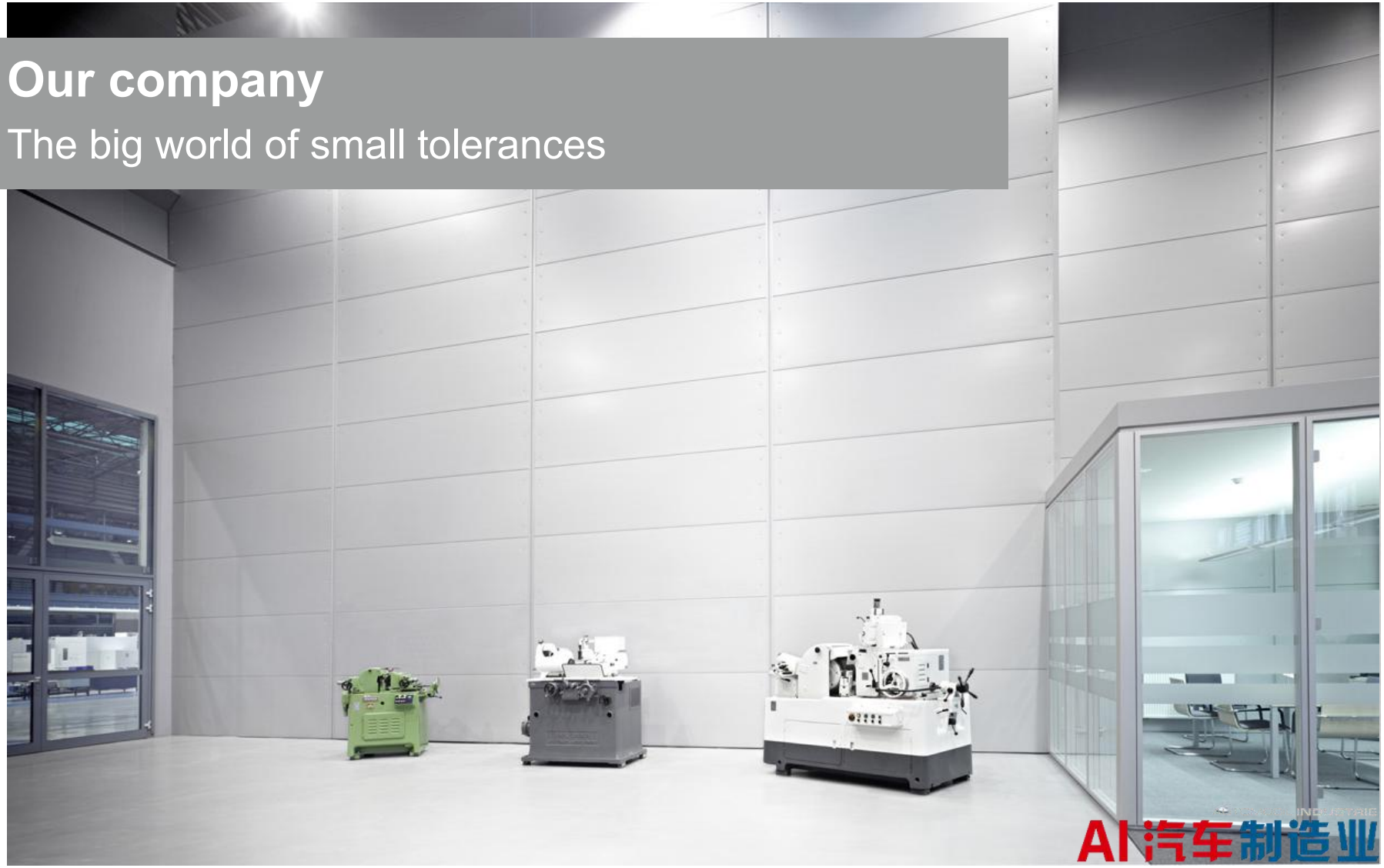
STUDER KÖRBER SOLUTIONS
SCHAUDT KÖRBER SOLUTIONS
MIKROSA KÖRBER SOLUTIONS

WALTER KÖRBER SOLUTIONS
EWAG KÖRBER SOLUTIONS

AUTOMOBIL INDUSTRIE
AI 汽车制造业

Our company

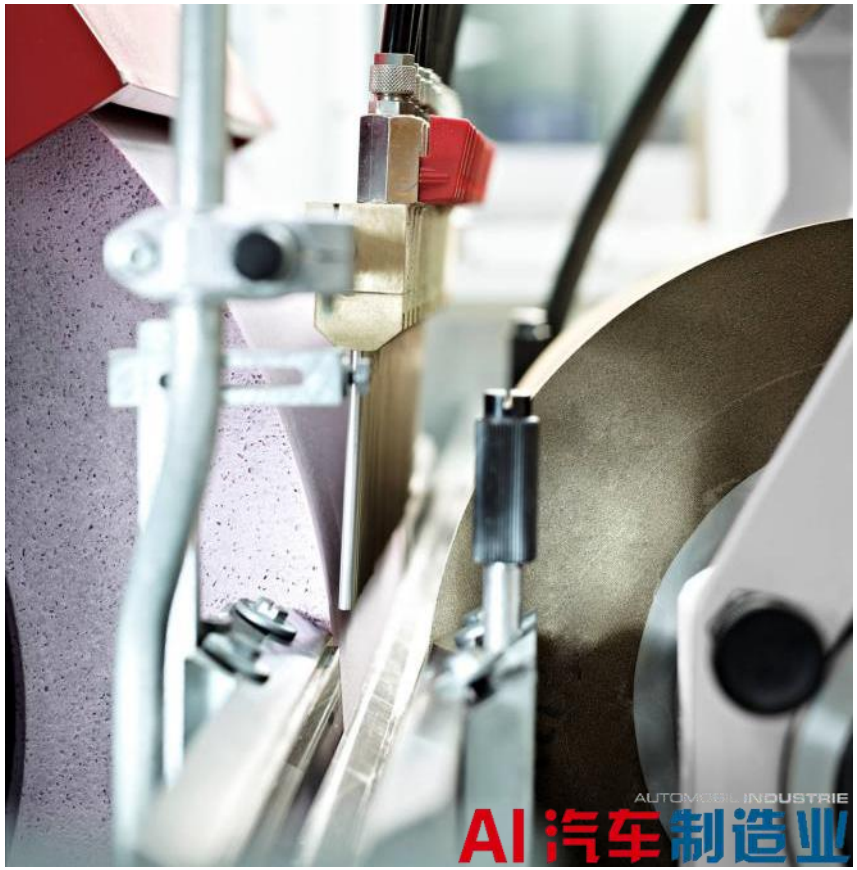
The big world of small tolerances



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

SCHAUDT KÖRBER SOLUTIONS

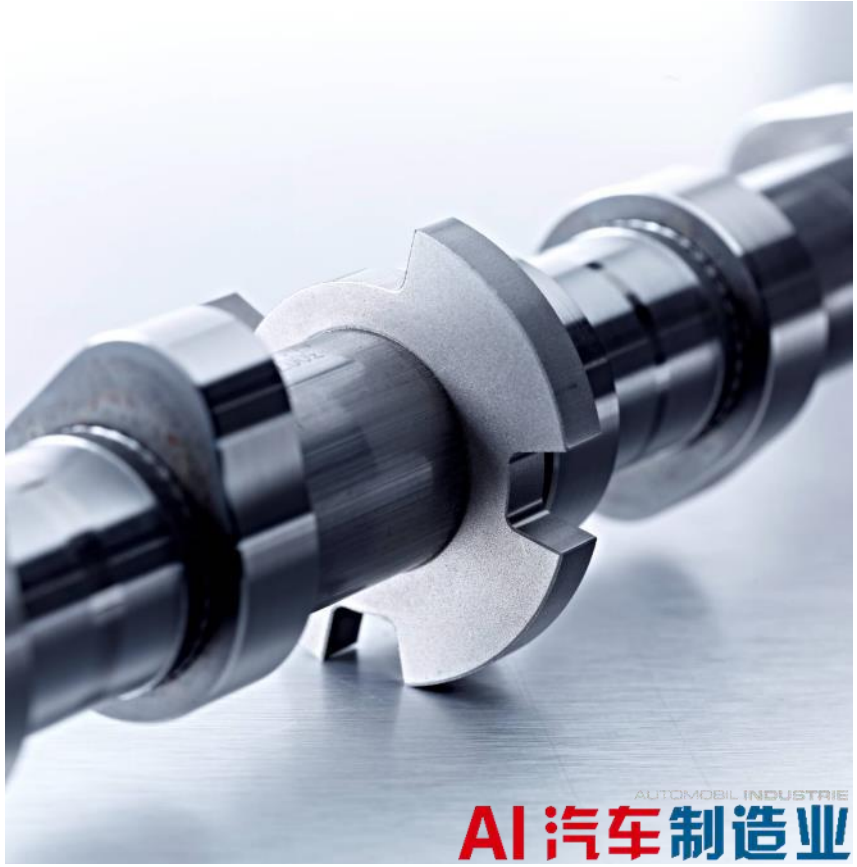
Cylindrical and non-cylindrical grinding

Universal grinding

MIKROSA KÖRBER SOLUTIONS

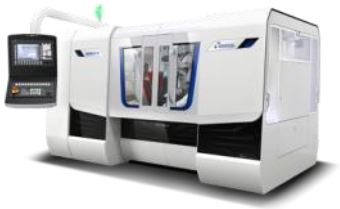
Centerless cylindrical grinding

- 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 griniding 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

Roundness in centerless grinding

Application examples

Summary

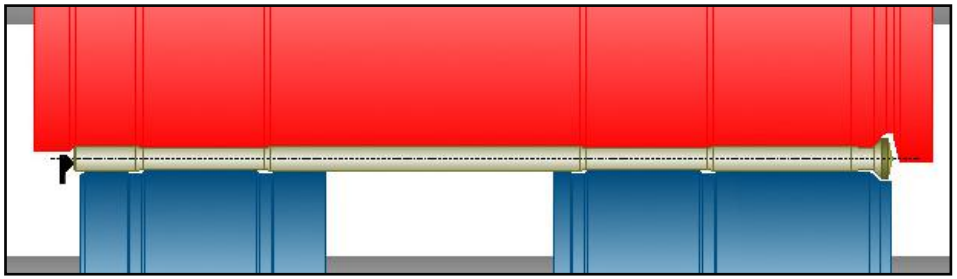
Process characterization

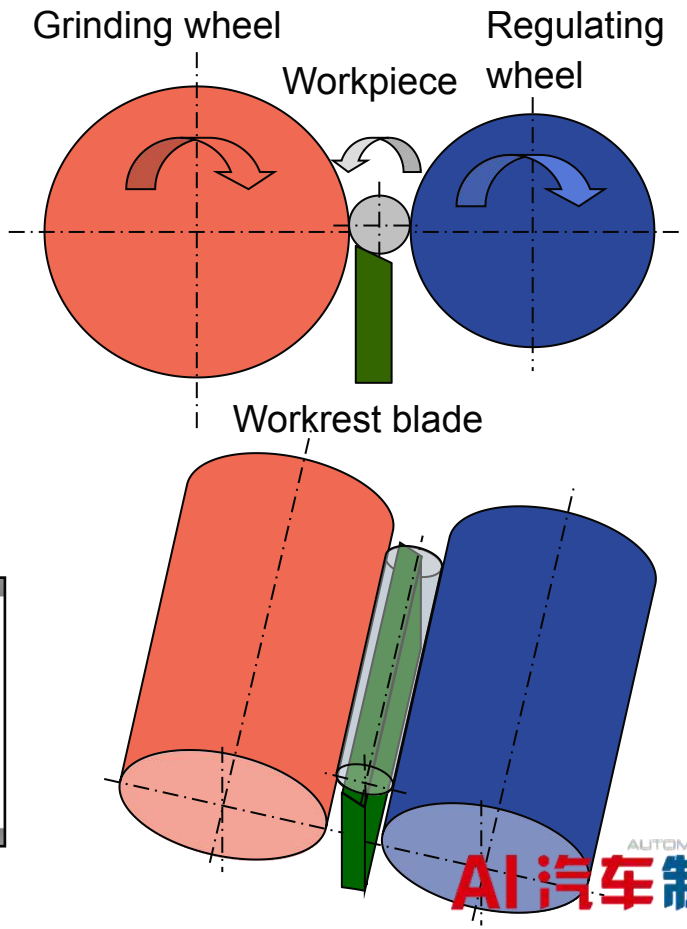
Stable workpiece position

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

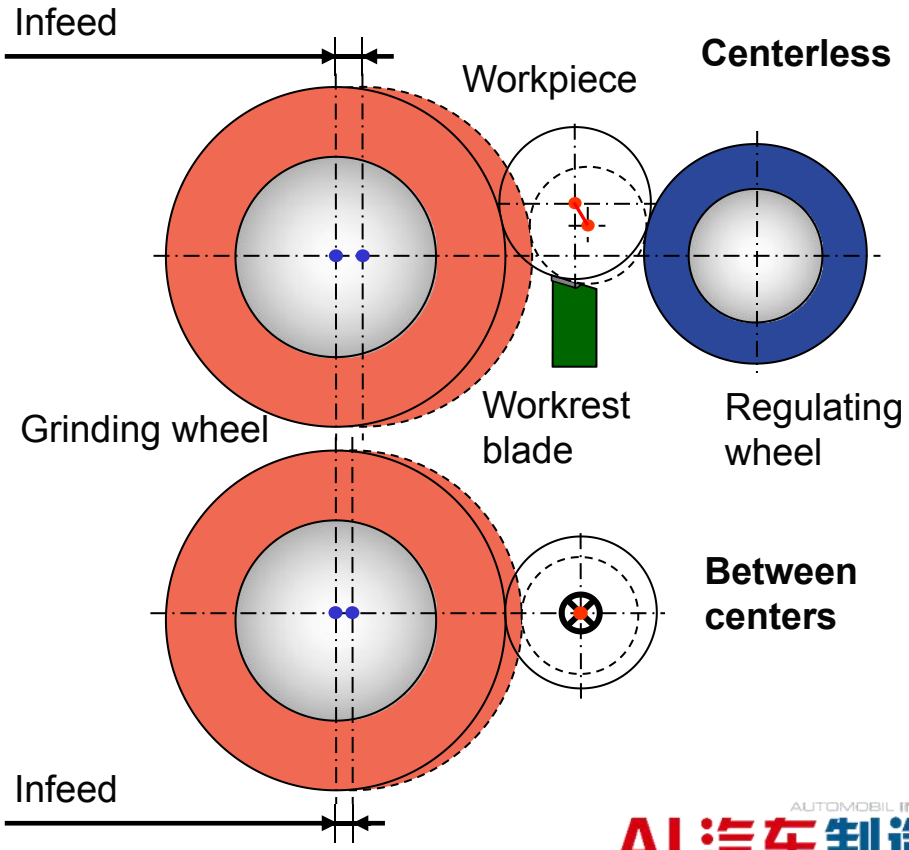
High base accuracy

In centerless grinding process:

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

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

Stable workpiece support



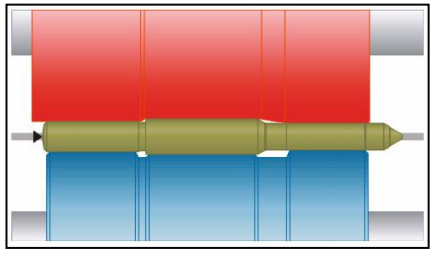
Process characterization

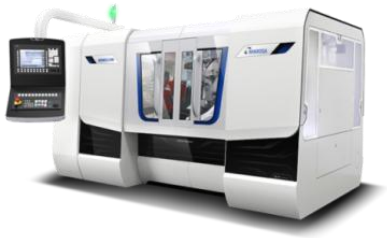
Example – high base accuracy / stable workpiece position

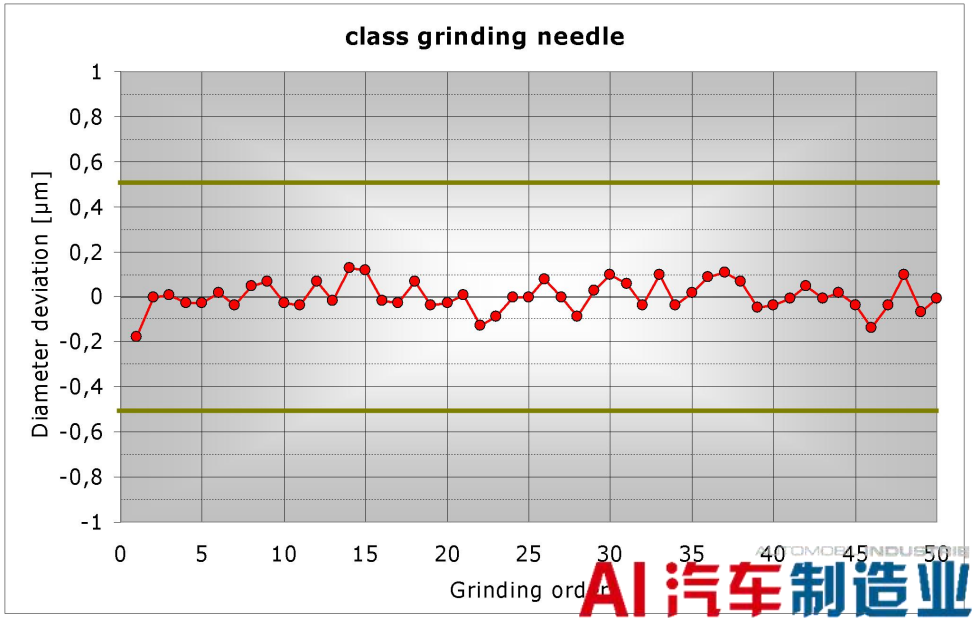
Machine	KRONOS S 125
Workpiece	needle (injection system)
Abmessung	∅ 4,0 x 40 mm
Material	S 6-5-2
Stock removal	0,05 ±0,005 mm
Grinding time	5,9 s

	target	result
Diameter	± 0,5 µm	cmk 2,40
Roundness	0,7µm	0,22 µm (1)
Surface Rz	1,2 µm	0,72 µm (1)
Straightness	0,7 µm	0,19 µm (1)

(1) average





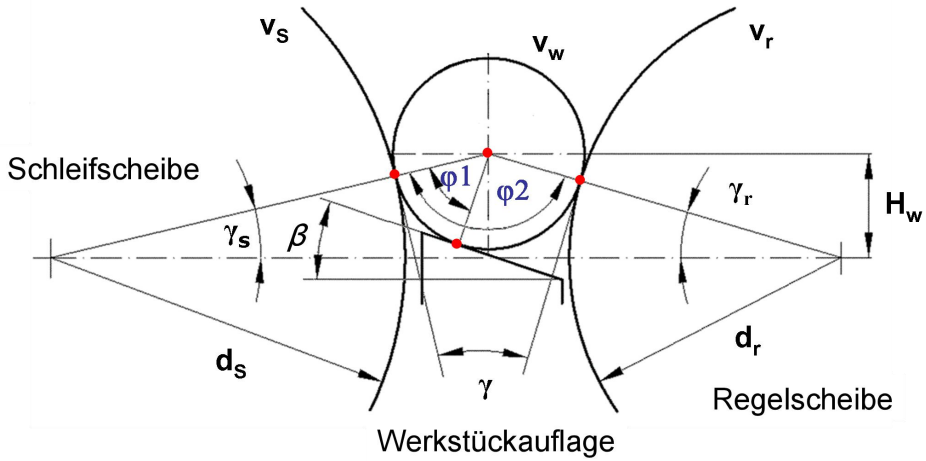


Process characterization

Polygon effect

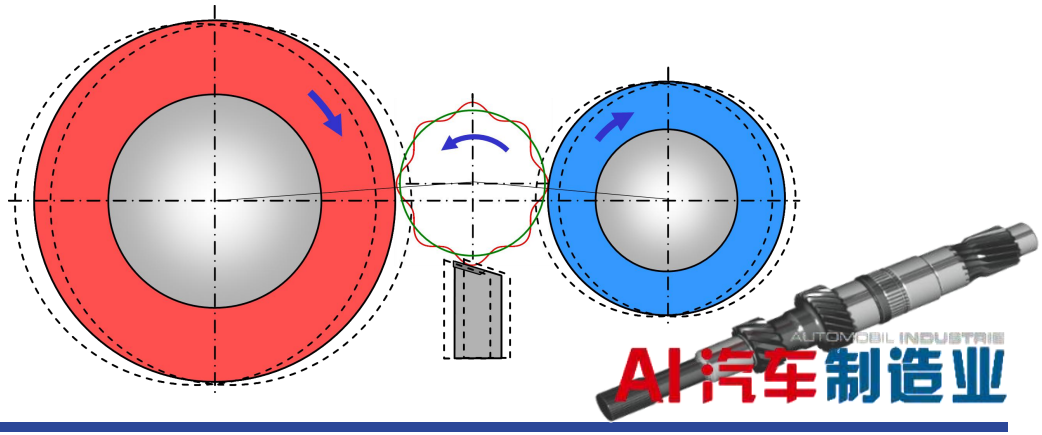
Geometric Reason

- Grinding gap geometry



Dynamic reasons

- Self-excitat vibrations
- External-excitat vibrations



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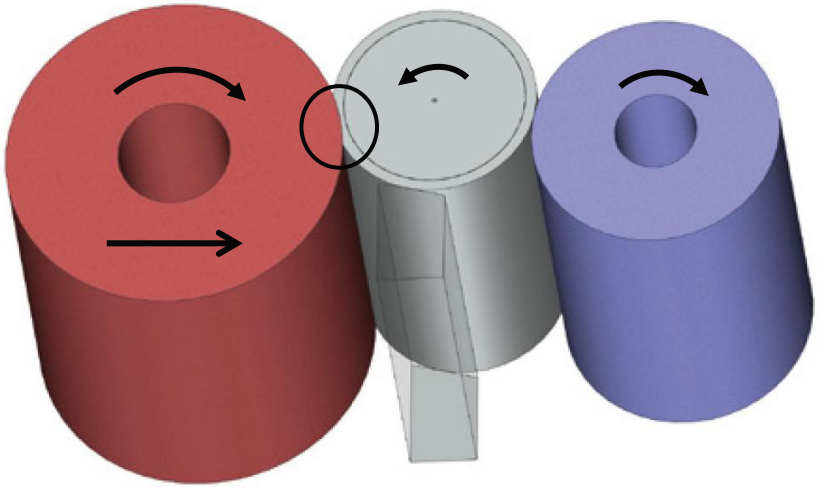
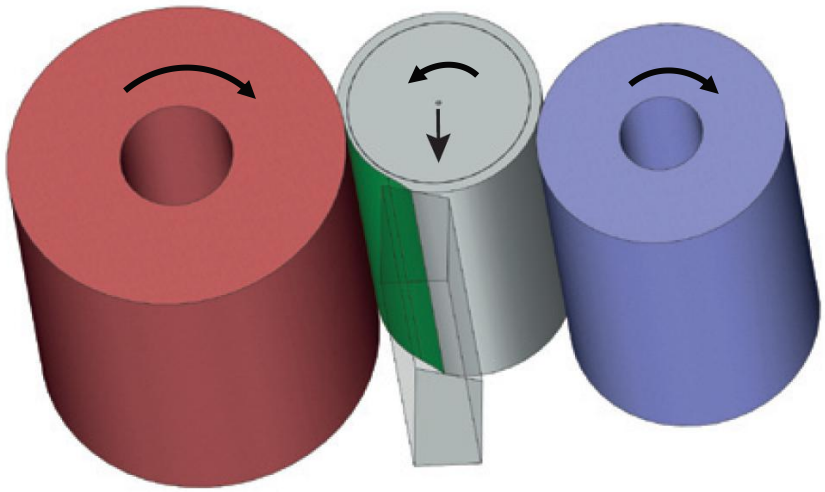
The geometric roundness error formation

Infeed of the grinding wheel



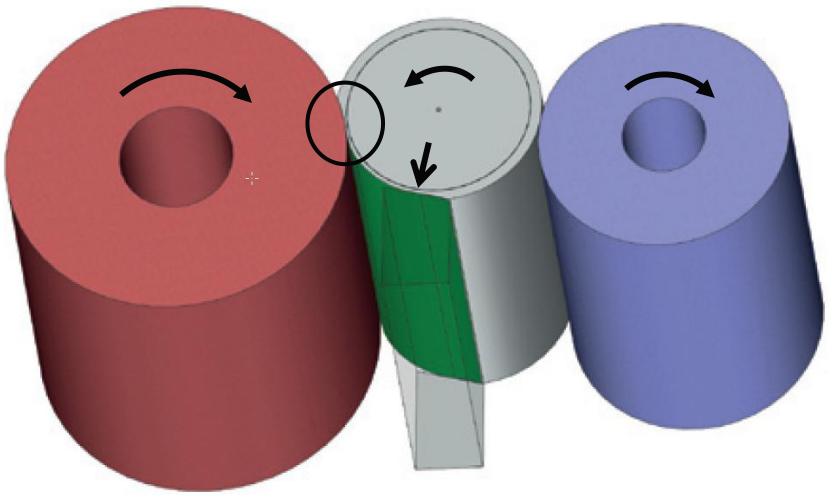
The geometric roundness error formation



Infeed of the grinding wheel

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

The geometric roundness error formation

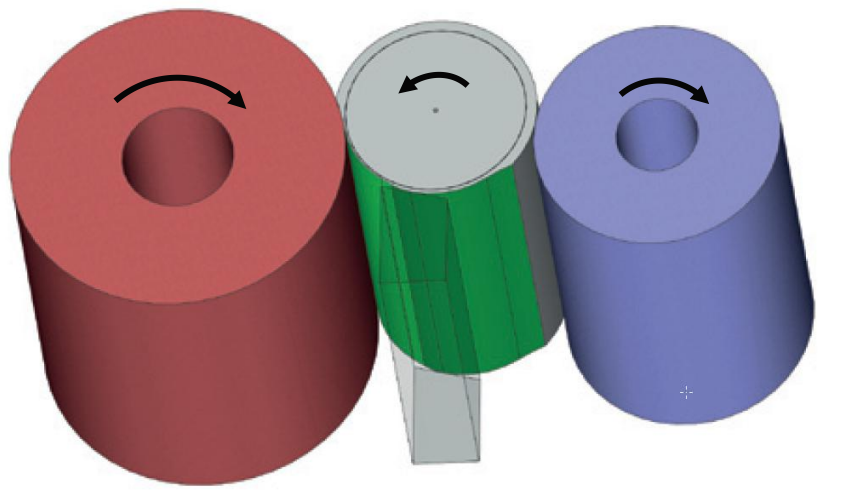


Infeed of the grinding wheel

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)

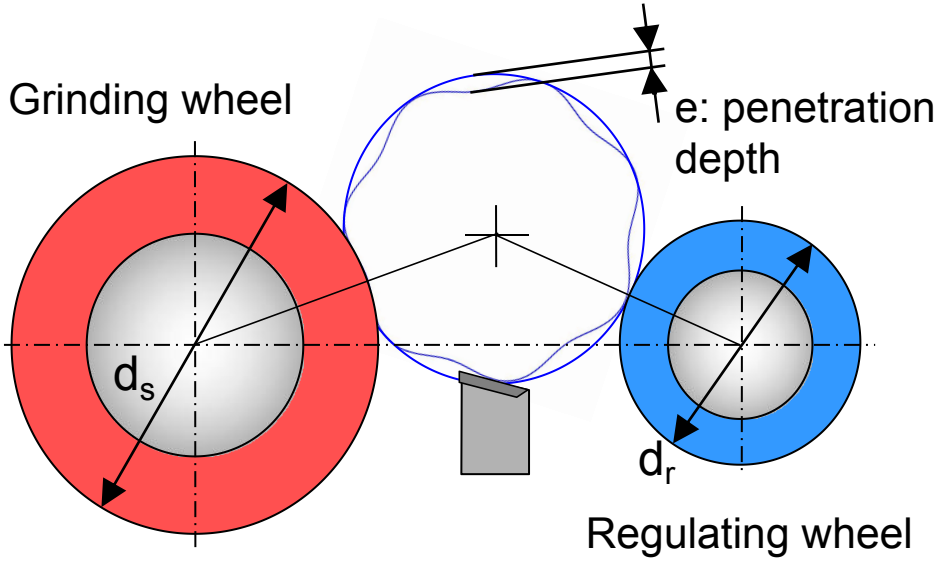
If this new surface has contact with work rest blade the workpiece is moving down (in direction work rest blade). The infeed is changing.

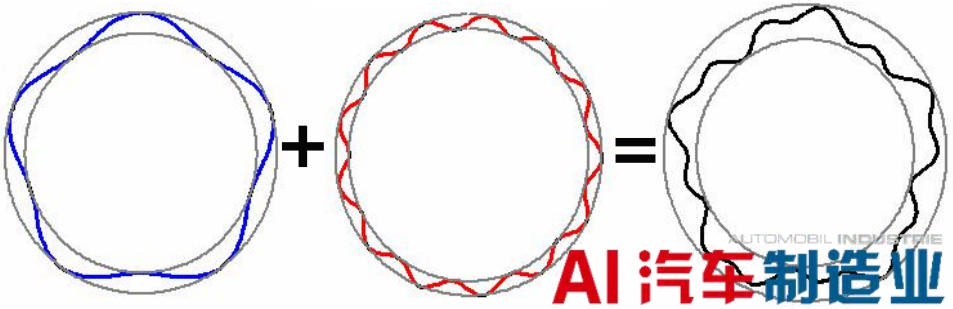
This creates a second new lateral surface (light green).

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.

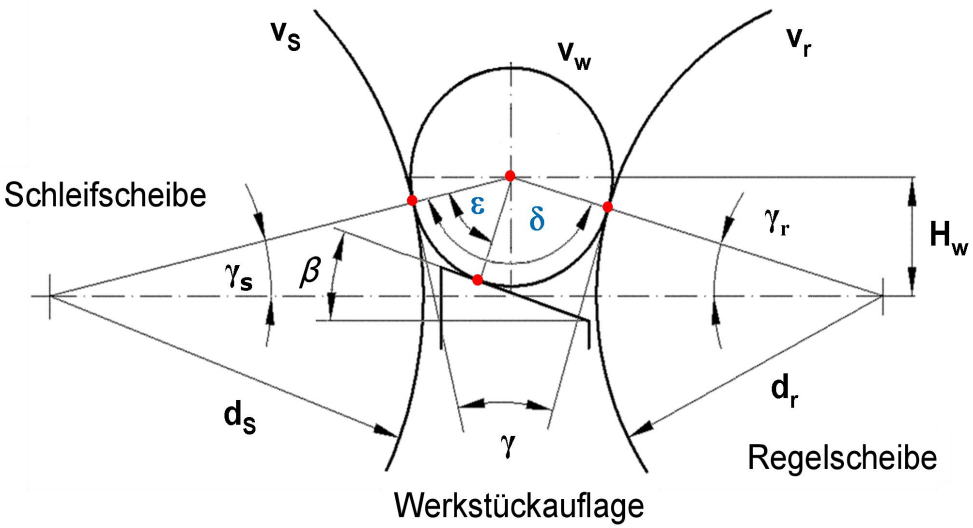
The geometric roundness error formation

- 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



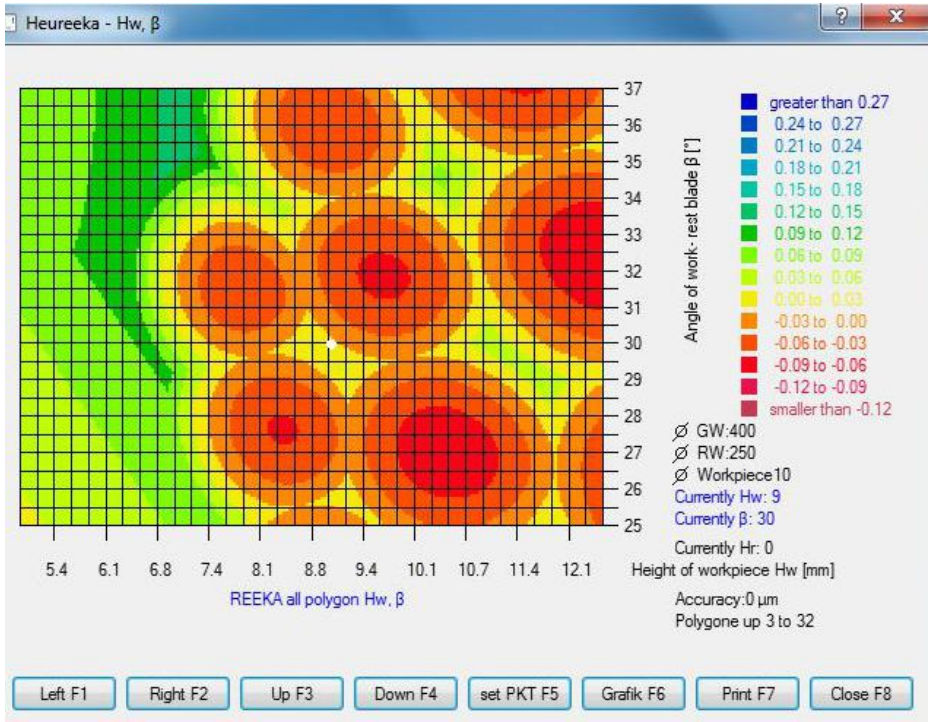
Determining is the dimension of the angle ratios of the contact points between workpiece and grinding wheel, workpiece and work-rest blade as well as workpiece and regulating wheel. This is described by means of the angles ε and δ . Using these angles, the stability index can be calculated for every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

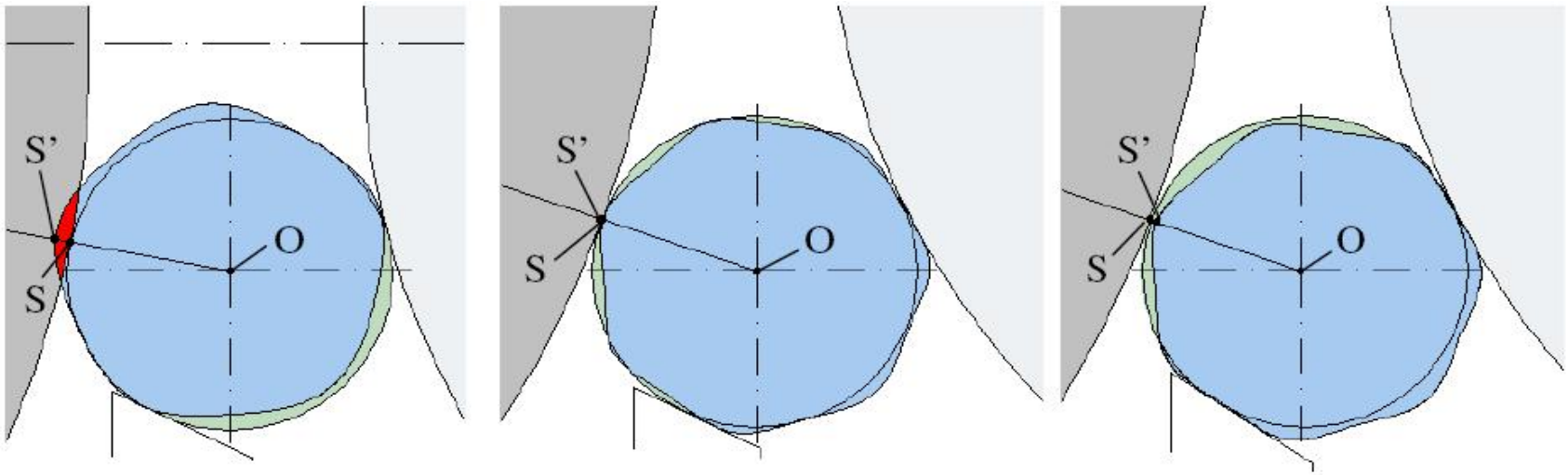
HEUREEKA - Software solution for optimization of grinding zone geometry



- 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



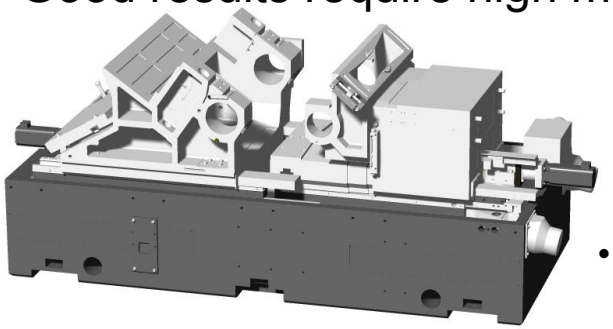
stability index (SI) > 0 | stability index (SI) = 0 | stability index (SI)< 0

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

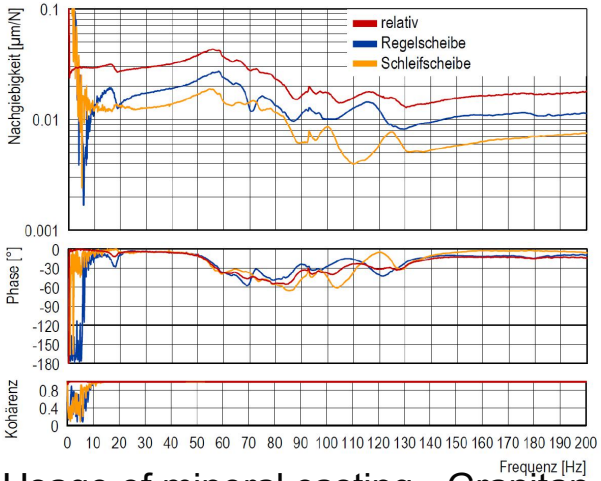
Polygon effect – dynamic reasons

Good results require high machine stiffness and high dampening

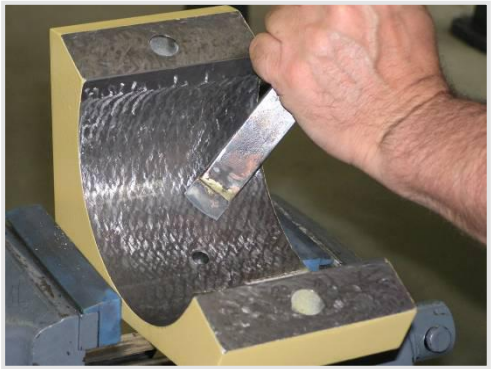


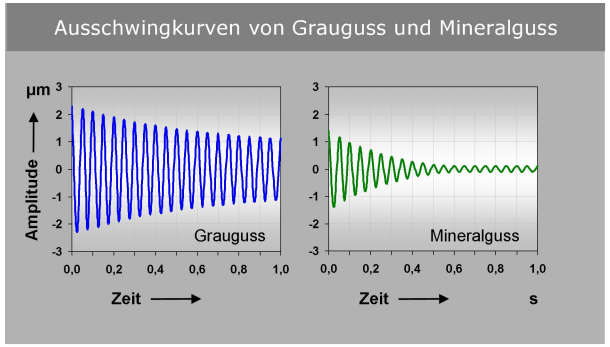
Optimization of the dynamic machine behavior

- Generous dimensioning of the machine components
- Symmetric design

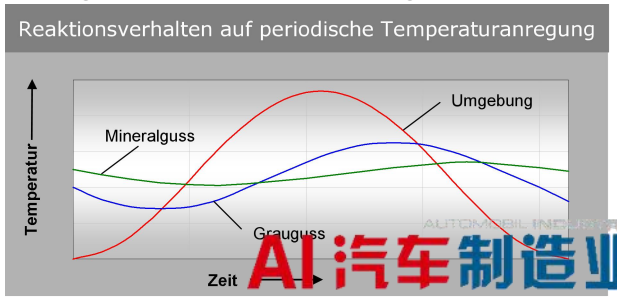


Scraping of the contact surfaces by hand



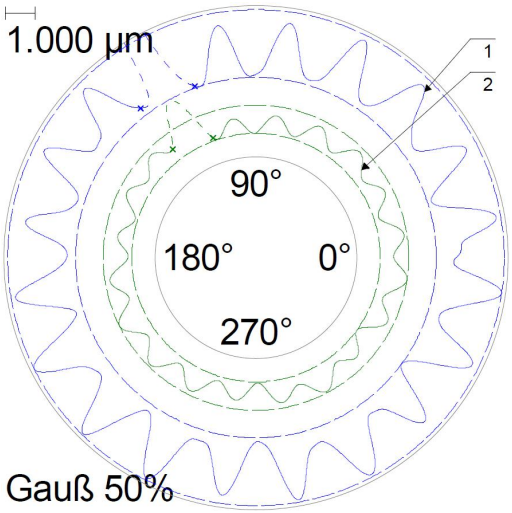


Usage of mineral casting - Granitan



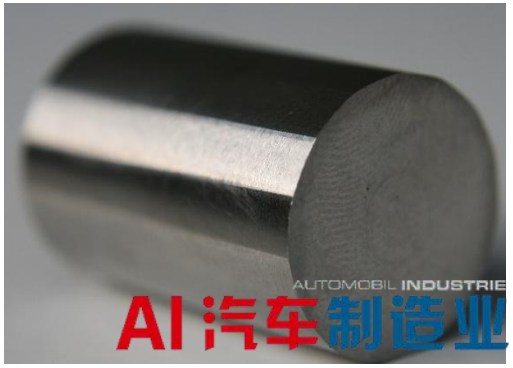
Process vibrations

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



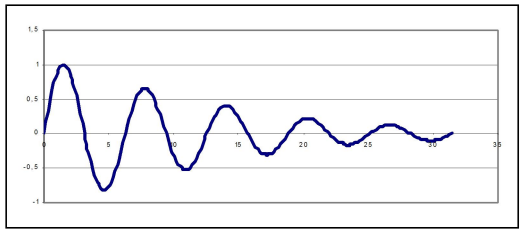
Effects:

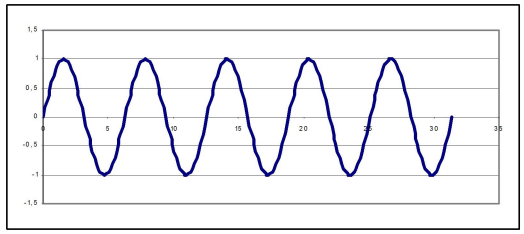
- Reduction of workpiece quality (dimensional accuracy, shape- and position tolerances and surface quality)
- Reduce the tool life
- Reduction in productivity
- Shortening the life time of the machine
- Increase the noise exposure of employees

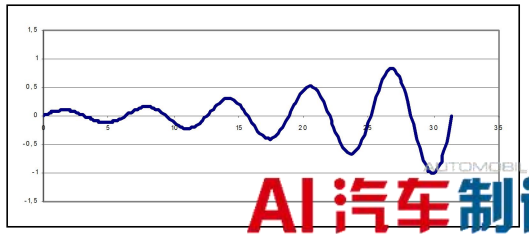


Vibrations on centerless grinders

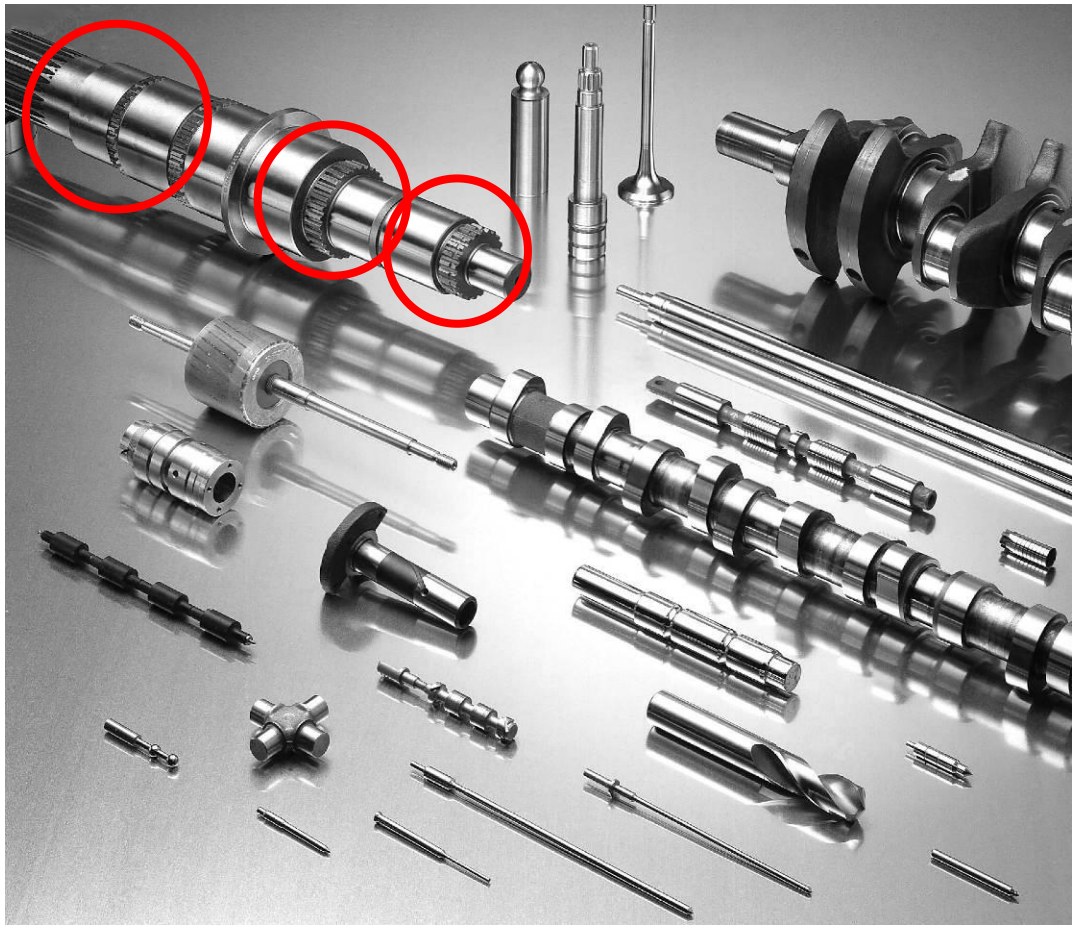
- Vibrations on centerless grinders
  - Externally created vibrations
    - Impulse excitation
      - Machine vibrates with natural frequency
        - e.g. vibrations through the foundation
    - Periodic excitation
      - Machine vibrates with excitation frequency
        - e.g. Unbalance, Bearing faults, Interrupted cut (Caused by the workpiece)
  - Self-excited vibrations
    - Machine vibrates with natural frequency
      - e.g. Regenerative effect, Background noise of the cutting forces







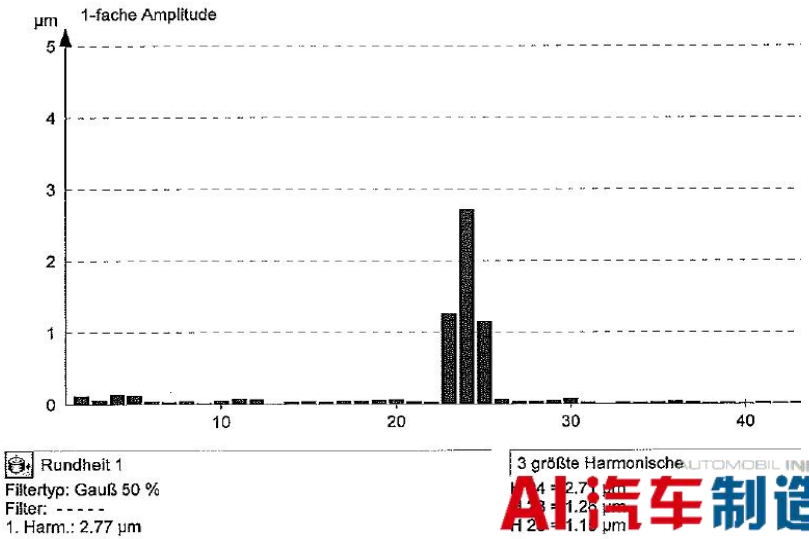
Interrupted cut



Interrupted cut

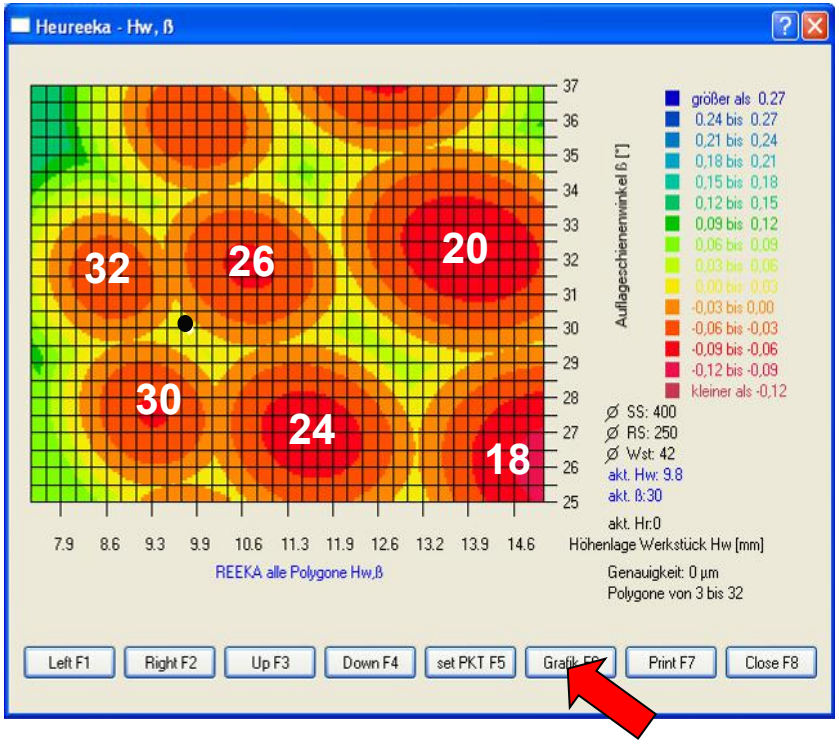
- 12 interruptions
- 12 other interruptions are offset by 15 °
- → 24 interruptions
- Problem: bad roundness
- Roundness = 6.2 microns

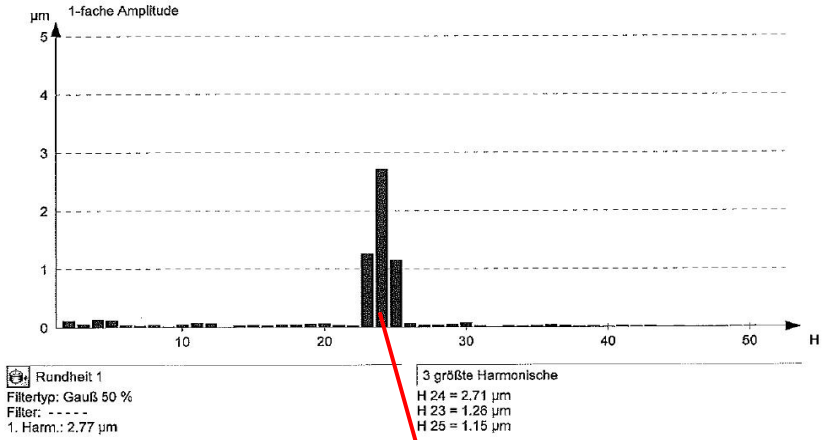
- Workpiece: Ø 40 x 80
- z = 0.25 mm in 2 grinding operations
- Roundness <1.0 micron at filter 1 ... 150
- Ra <0.25 microns

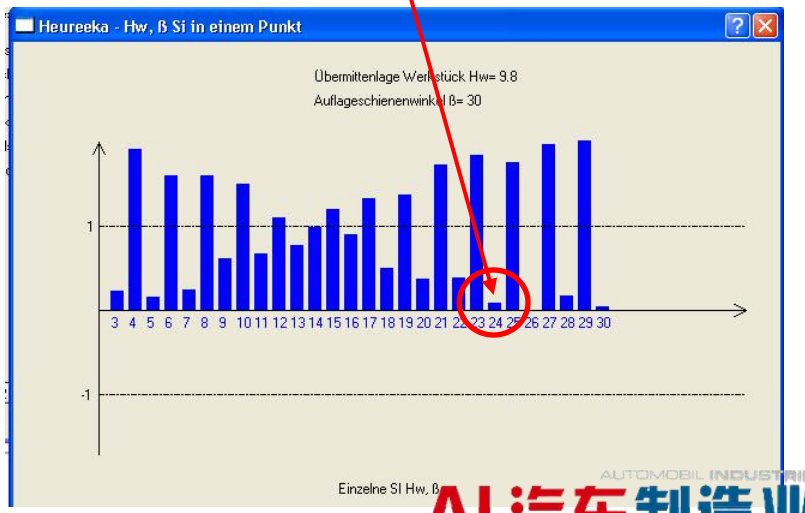


Interrupted cut

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

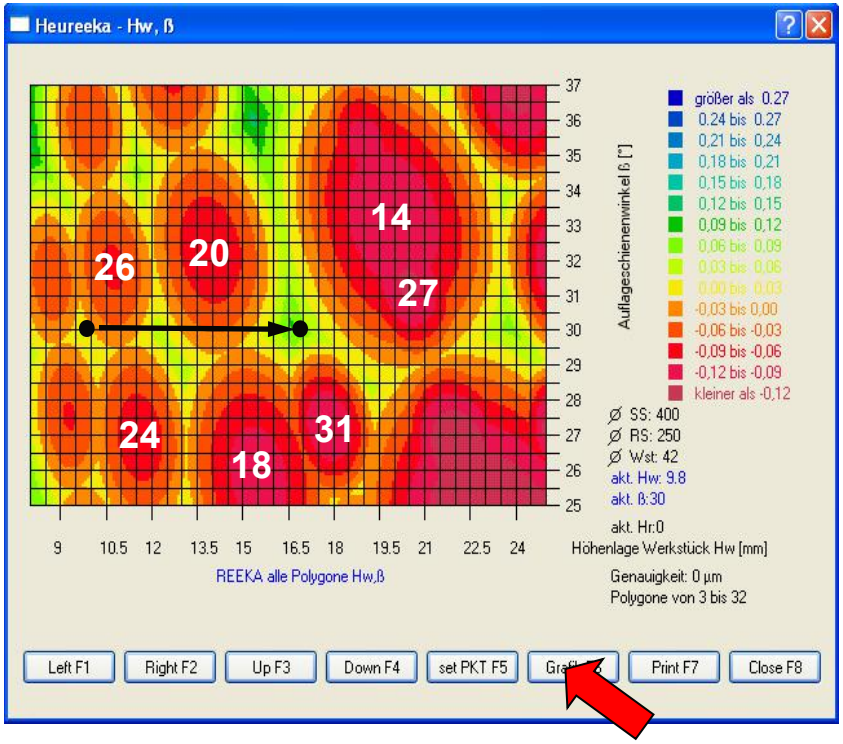


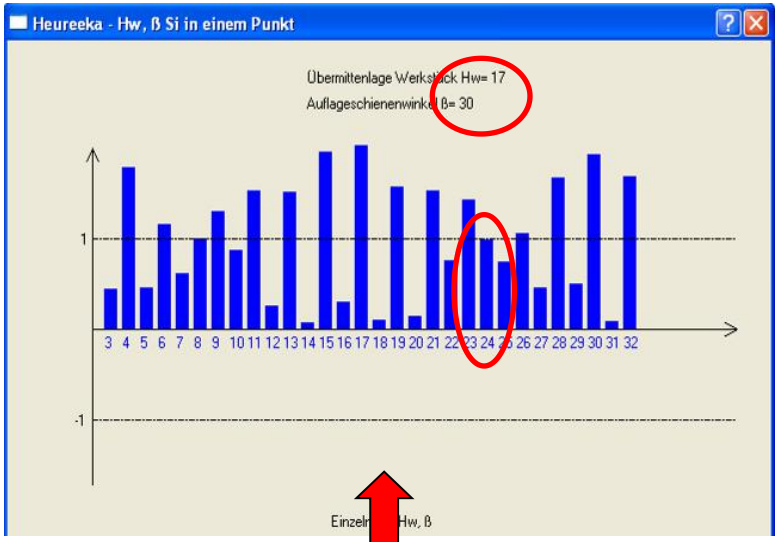


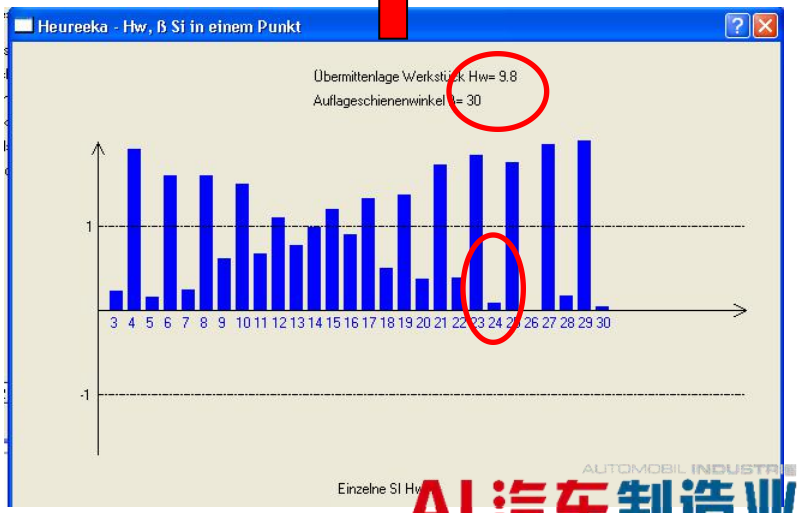


Interrupted cut

- Changing workpieces height
- Hw = 9.8 mm ⇒ Hw = 17 mm

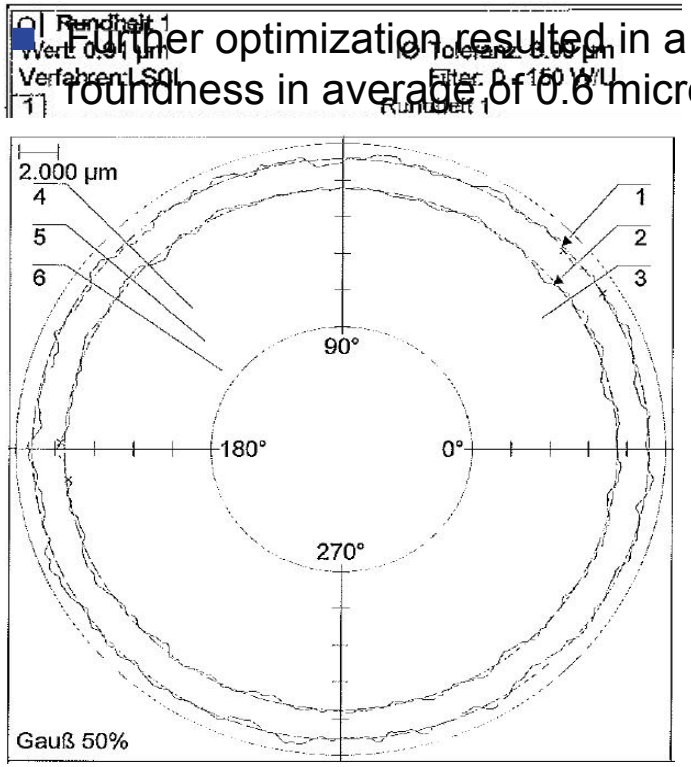


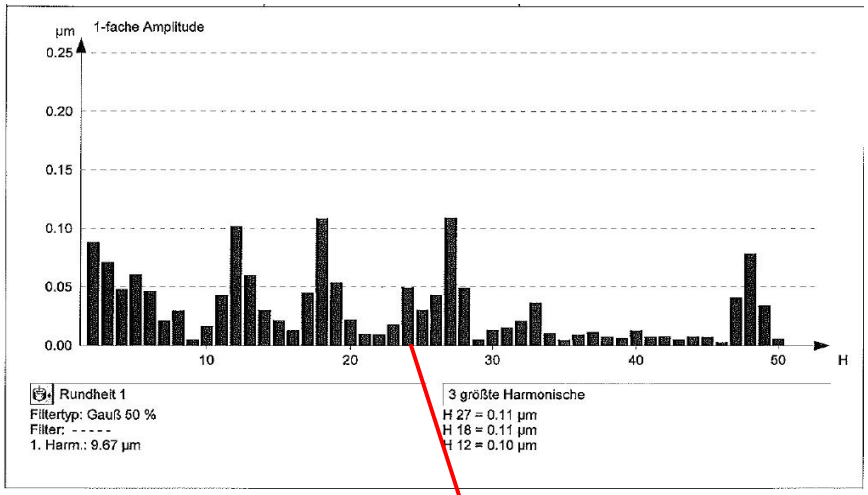


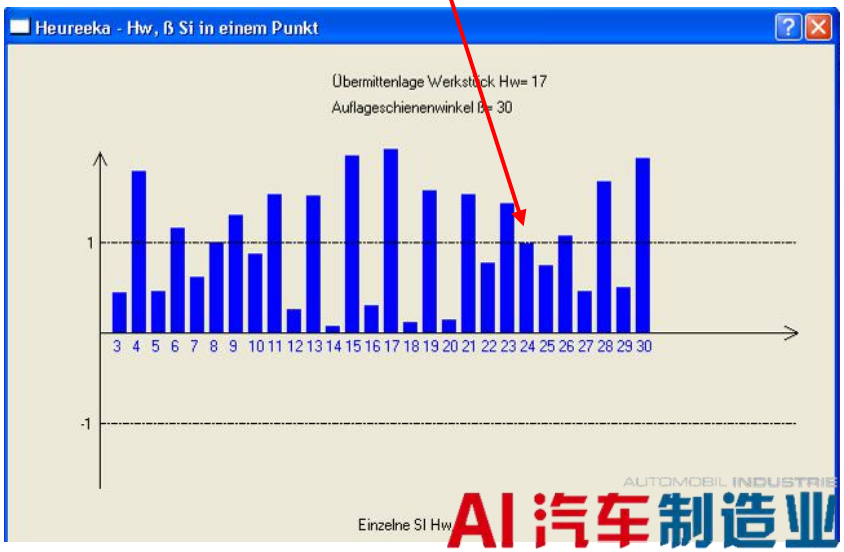


Interrupted cut

- 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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Summary

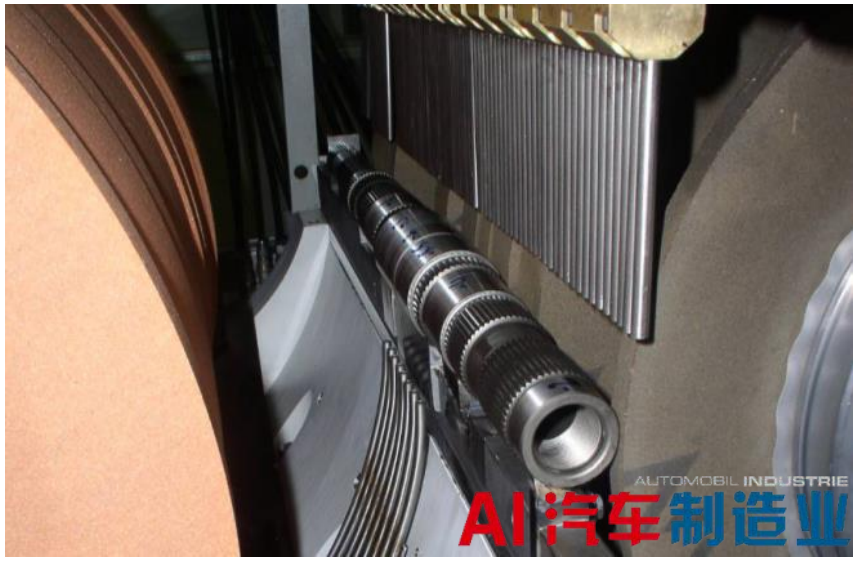
Application Example 1 – long transmission shaft

KRONOS L660

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

Features

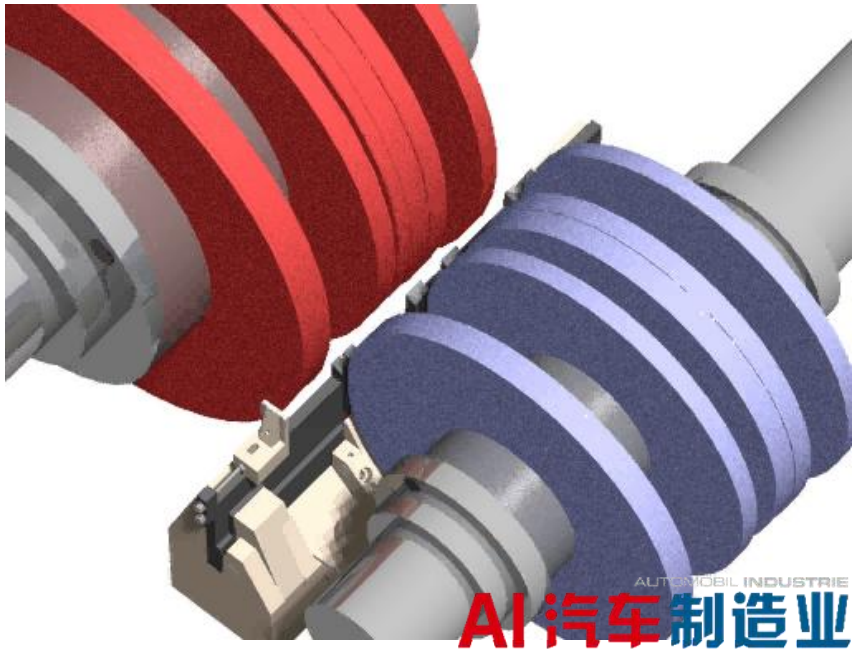
- Infeed grinding of a long transmission shaft
- Grinding of the splines (no contact of splines to reg. wheel and workrest blade)
- Post-process measuring system



Application Example 2 – Solving roundness problems

KRONOS M400

Workpiece	transmission shaft	
Material	16MnCr5	
Hardness	60±2HRC	
Dimensions	Ø 40 × 357 mm	
Stock removal Ø	0.35 mm	
Accuracy	target	result
Surface finish (Ra)	0.3 µm	< 0.3 µm
Diameter tolerance	±6.0 µm	cmk 2,08
Roundness	4.0 µm	< 2.0 µm
Cycle time		
Grinding time	13.5 s	
Loading / Unloading	6.0 s	
Cycle time (wo dressing)	19.5 s	



Features

- Infeed grinding of a transmission shaft
- Post-process measuring system

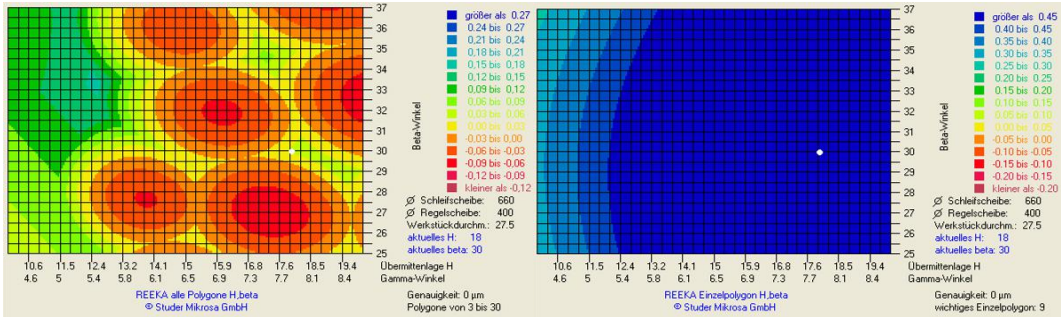
Application Example 2 – Solving roundness problems

Roundness problem

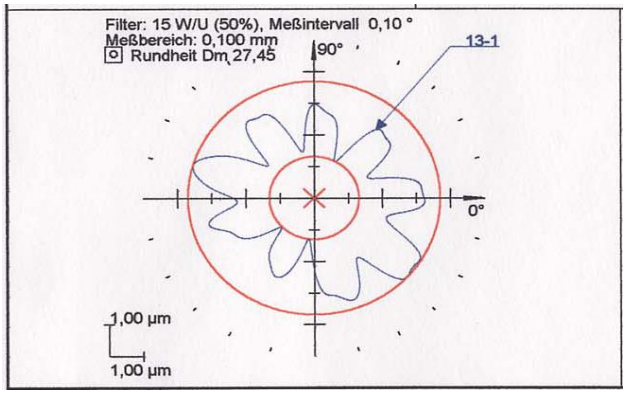
Possible influences:

- Grinding gap geometry

Stability index 3…30-eck Stability index 9-eck



Before optimization



Profil bzw. Aufgabe	Position [mm, °]	Ergebnis [µm] ⌀:[mm]	Toleranz [mm]	Ref.
4		0,52	0,0030	MZC
7		0,69	0,0030	MZC
10		1,19	0,0030	MZC
13		2,38	0,0030	MZC
14		2,54	0,0030	MZC

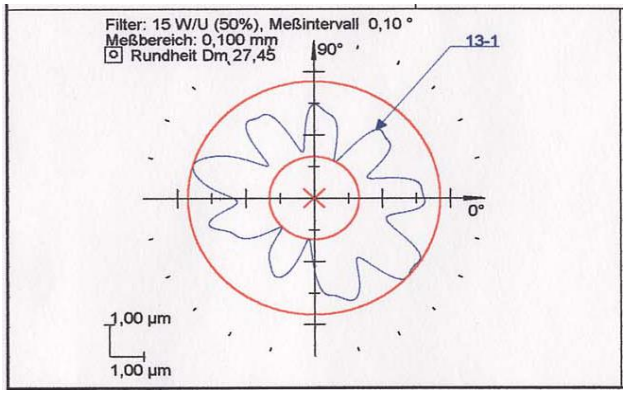
Application Example 2 – Solving roundness problems

Roundness problem

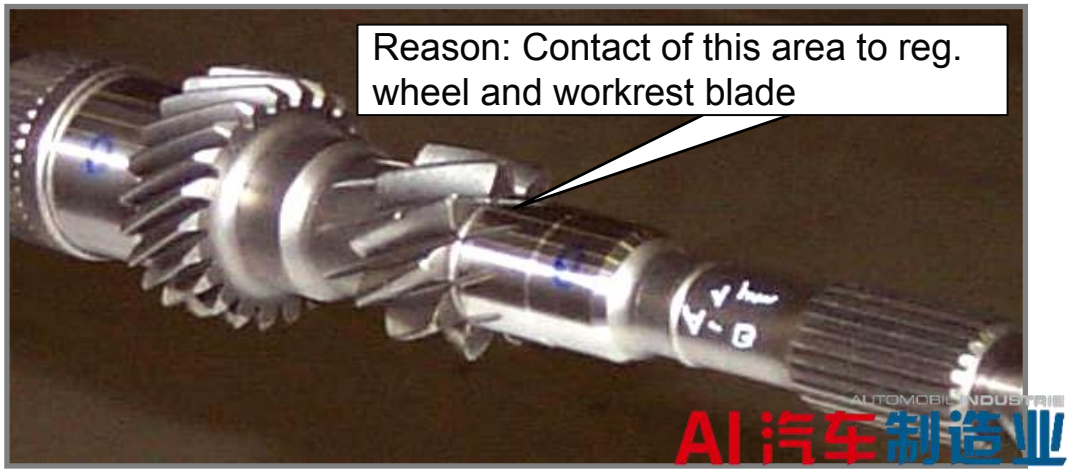
Possible influences:

- 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

Before optimization



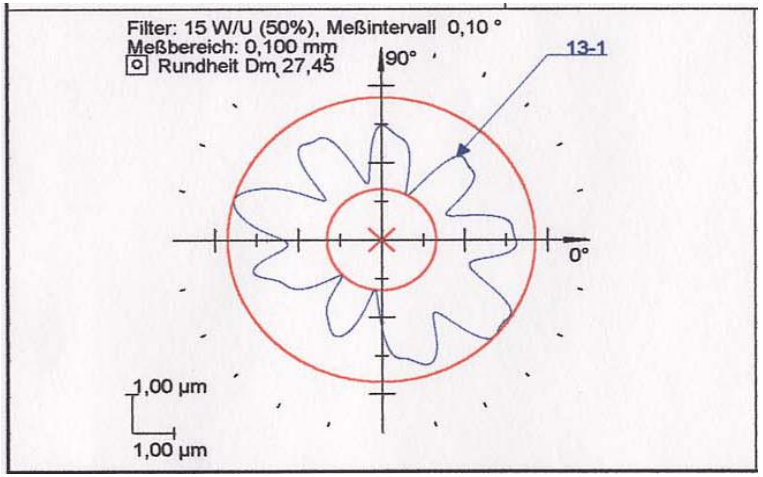
Profil bzw. Aufgabe	Position [mm, °]	Ergebnis [µm] ⌀:[mm]	Toleranz [mm]	Ref.
4		0,52	0,0030	MZC
7		0,69	0,0030	MZC
10		1,19	0,0030	MZC
13		2,38	0,0030	MZC
14		2,54	0,0030	MZC



Application Example 2 – Solving roundness problems

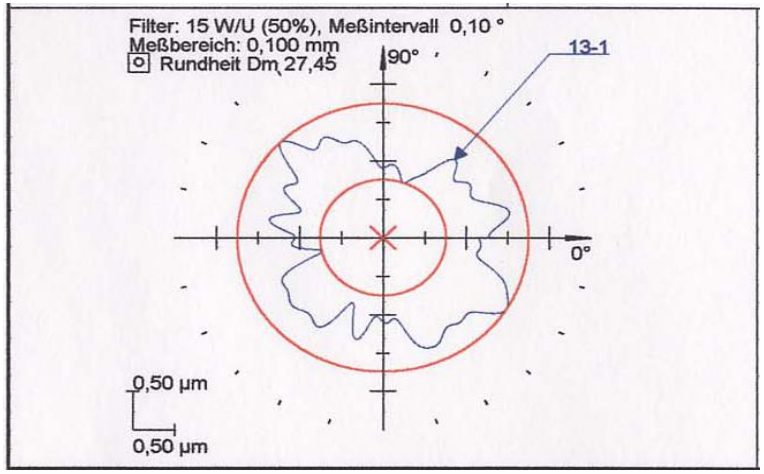
Solved roundness problems – contact conditions

Before optimization



Profil bzw. Aufgabe	Position [mm, °]	Ergebnis [µm] ⌀:[mm]	Toleranz [mm]	Ref.
4		○ 0,52	0,0030	MZC
7		○ 0,69	0,0030	MZC
10		○ 1,19	0,0030	MZC
13		○ 2,38	0,0030	MZC
14		○ 2,54	0,0030	MZC

After optimization

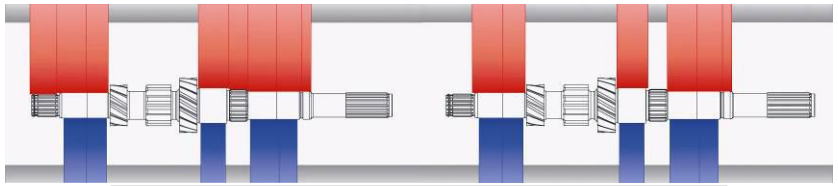


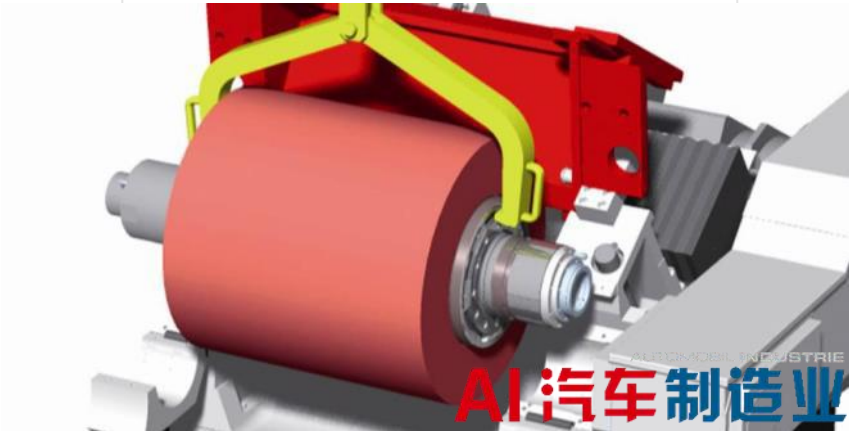
Profil bzw. Aufgabe	Position [mm, °]	Ergebnis [µm] ⌀:[mm]	Toleranz [mm]	Ref.
4		○ 0,59	0,0030	MZC
7		○ 0,52	0,0030	MZC
10		○ 0,55	0,0030	MZC
13		○ 0,99	0,0030	MZC
14		○ 1,89	0,0030	MZC

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





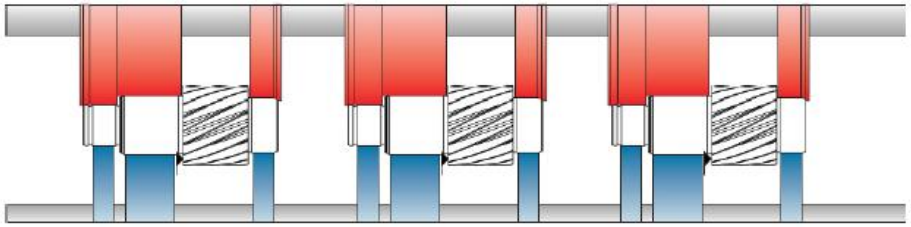
Special features

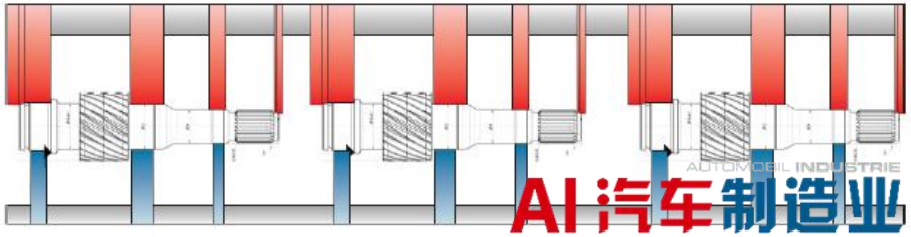
- OP 1 grinding diameter and splines
- OP 2 finish grinding diameter
- No risk to copy the splineform on the diamenter

Application sample 4 – Multiple production

KRONOS L 660

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
Loading / unloading	7.0 s
Dressing time per infeed	7.0 s
Cycle time	38.5 s
Cycle time per part	13.0s





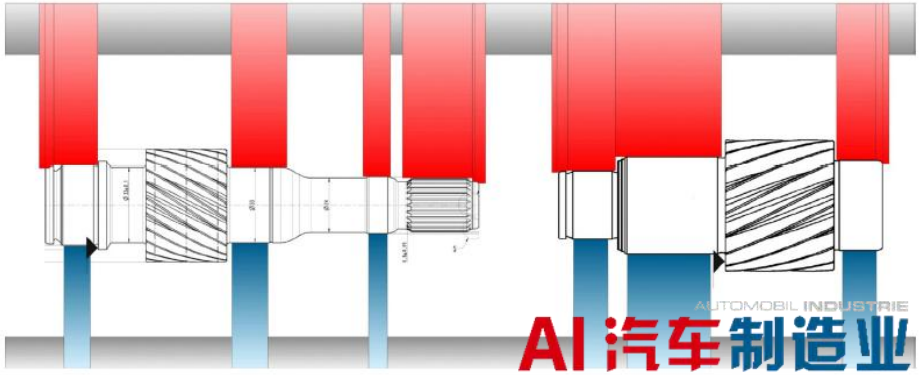
Special features

- 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

Agenda

Company

Process characterization

Roundness in centerless grinding

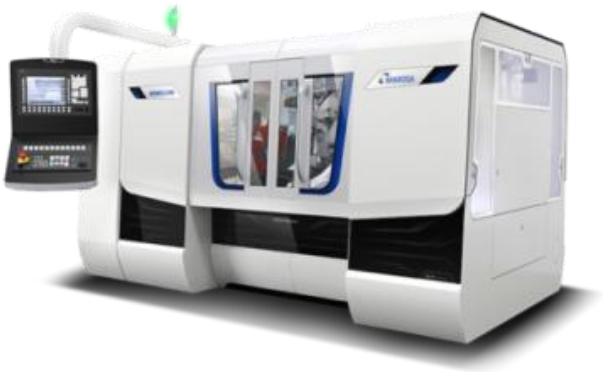
Application examples

Summary

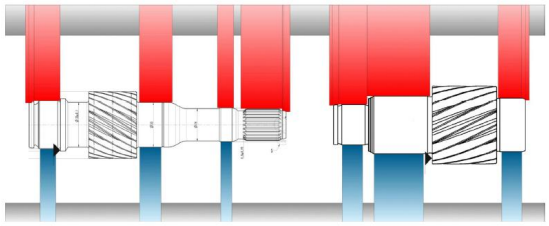
Summary

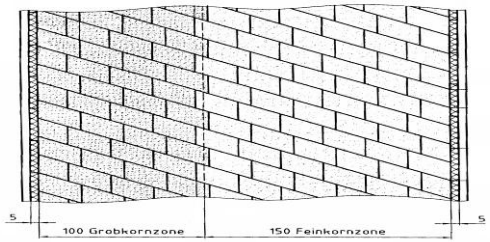
Requirements

Machine with high static, dynamic and thermic stiffness



Grinding technology

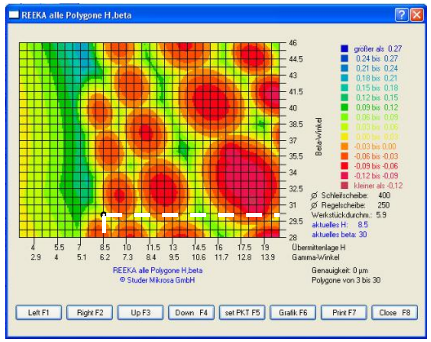




Optimized grinding and dressing tools

Qualified employees for machine set up

Analyzing tools and process understanding



Effective coolant

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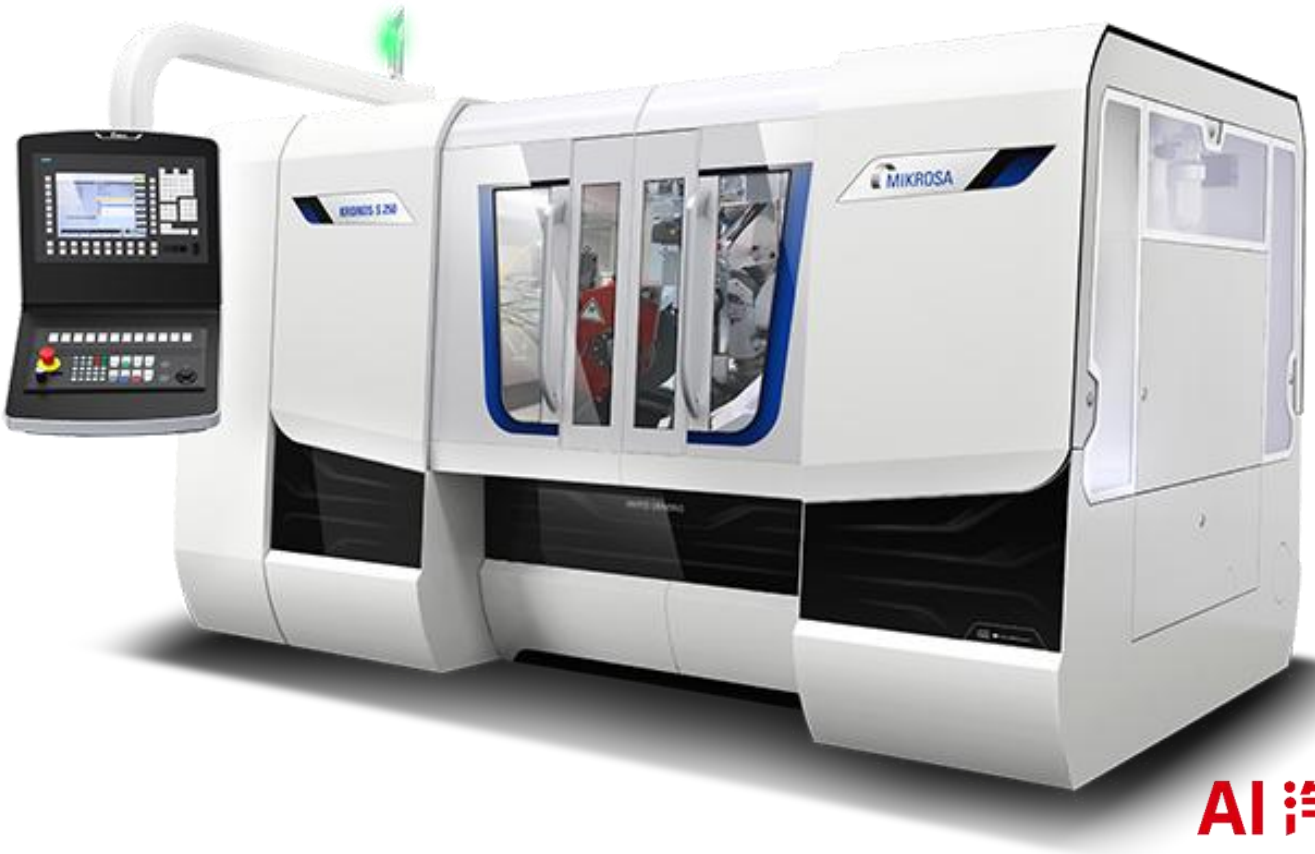
Thank you!



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