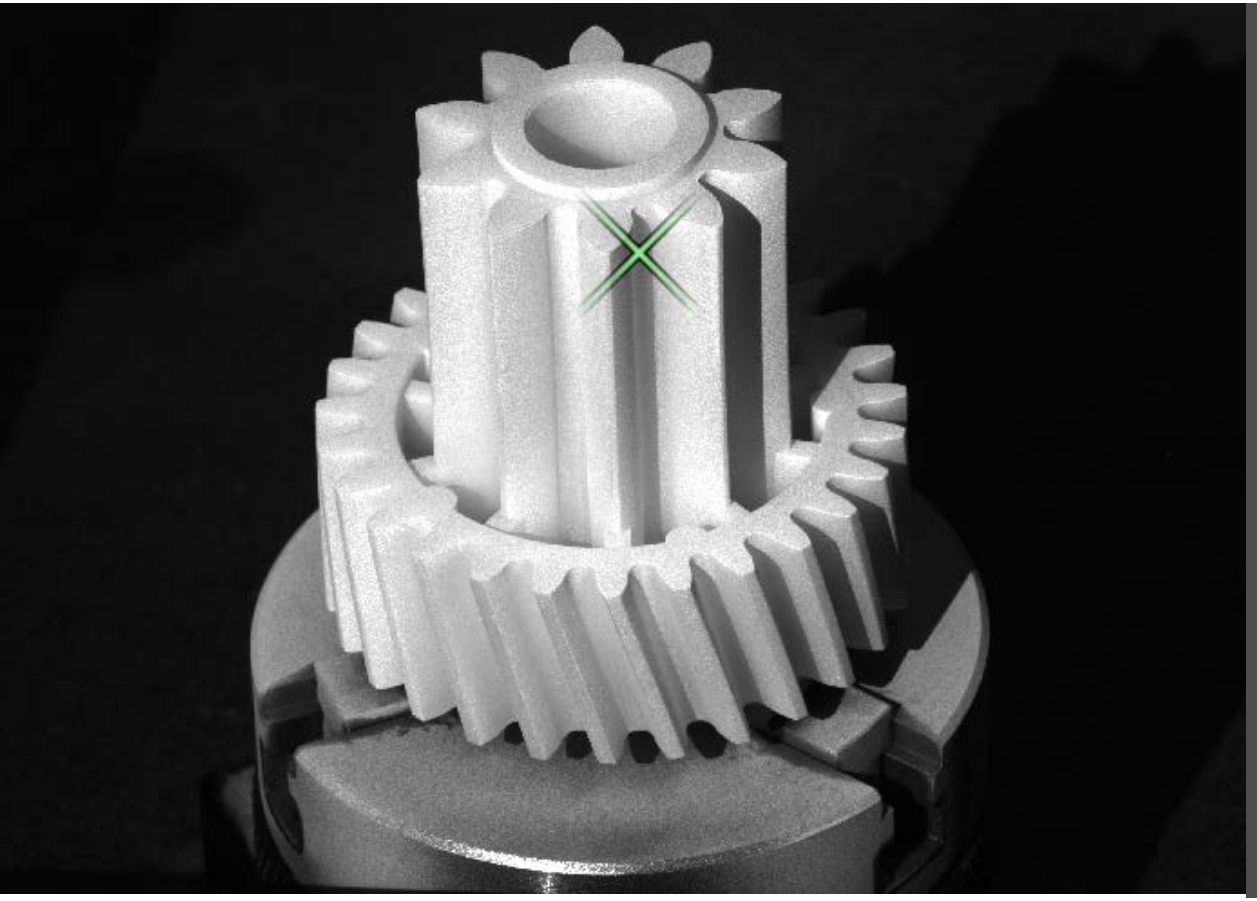
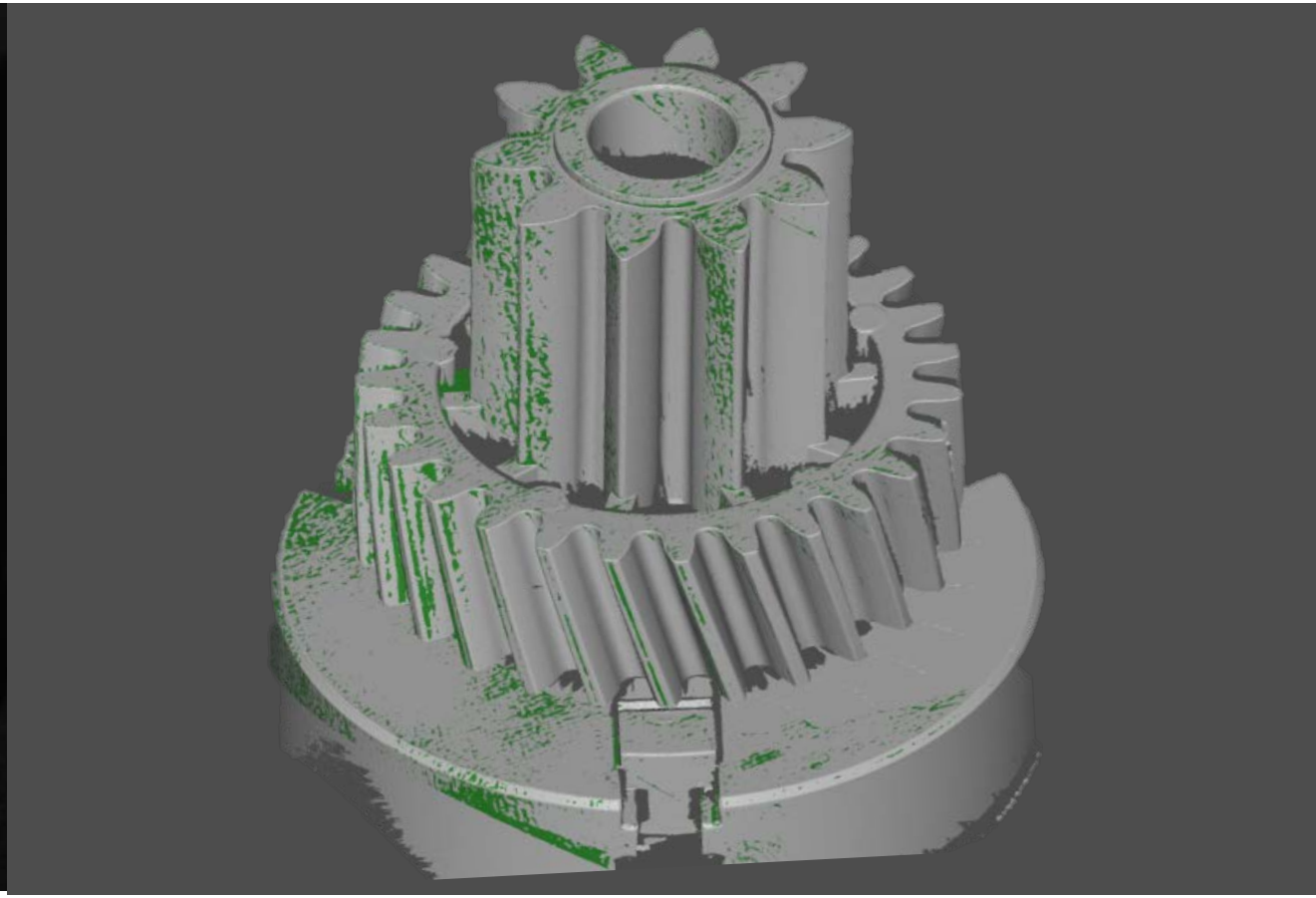
6. VDI Conference Gear Metrology / Verzahnungsmesstechnik 2017

Comparison of different metrology systems for gear metrology.

Plastic gears on Coordinate Measuring Machines und non-contact metrology systems





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Roman Groß // Product Manager Gear Metrology
Dr.-Ing. Dietrich Imkamp // Director Visual Systems

Agenda

1. Introduction and presentation of the compared workpieces
2. Overview of the compared measuring principles
3. Overview of the compared metrology systems
4. Measurement comparison
5. Analysis
6. Summary

Comparison of different metrology systems for gear metrology.

Introduction and presentation of the compared workpieces.

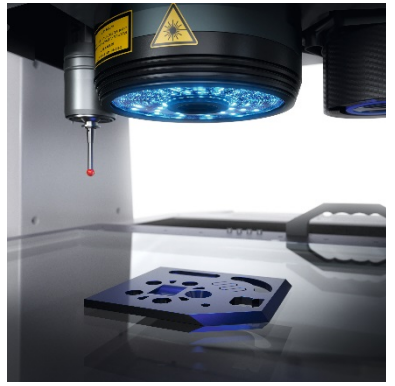
1

Comparison of different metrology systems for gear metrology

Introduction and presentation of the compared workpieces.

Non-contact metrology systems are established in a wide range of application fields






- Which possibilities arise for the application field gears regarding accuracy / comparability / measurement time reduction / totally captured surface?
- Measurement comparison with focus on numerical gear specific parameters acc. to ISO 1328-1:2013-09

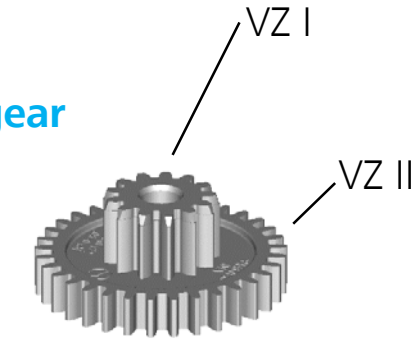
Comparison of different metrology systems for gear metrology

Introduction and presentation of the compared workpieces.

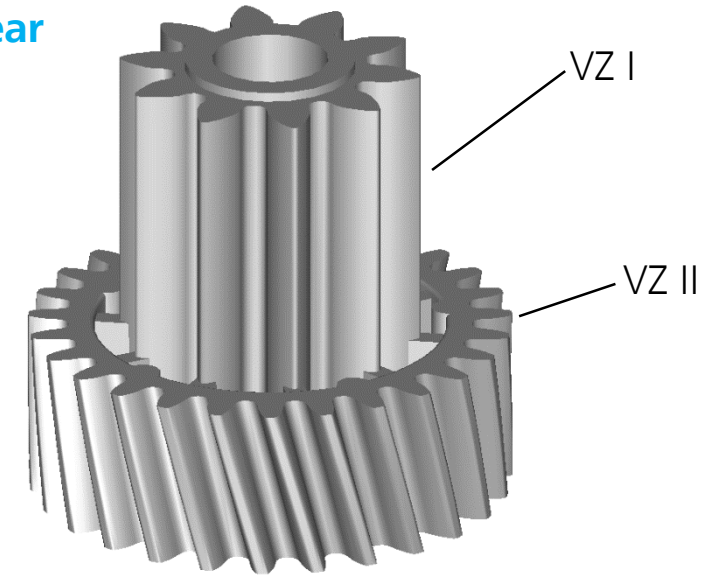
Requirements for an practically orientated measurement comparison

- Gears instead of splines
- Spur and helical gears
- Pressure angle α ≤ 30°
- Plastic due to good radiolucency properties (suitable for CT systems)
- Different workpiece surface properties (challenge for non-contact systems)

B-gear



W-gear



Gear	W-gear		B-gear	
Gearing	VZ I	VZ II	VZ I	VZ II
Label	W-gear_ z10_m2.5 _β0	W-gear_ z27_m1.75 _ β15	B-gear_ z13_ m0.75 _β0	B-gear_ z33_m0.75 _ β0
No. of teeth z	10	27	13	33
Module m_n	2.5 mm	1.75 mm	0.75 mm	0.75 mm
Pressure angle α	20°	20°	20°	20°
Helix angle β	0°	15° L	0°	0°
Tip diameter d_a	32 mm	50.95 mm	11.85 mm	25.25 mm
Face width b	28 mm	18 mm	6 mm	4 mm

Comparison of different metrology systems for gear metrology.

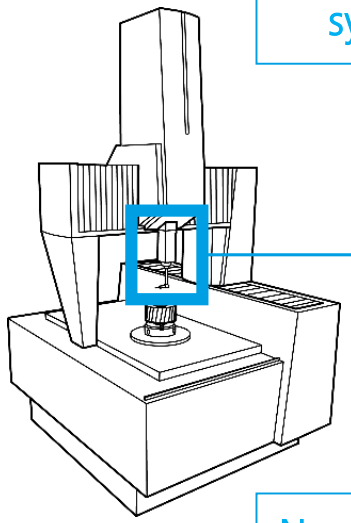
Overview of the compared measuring principles.

2

Comparison of different metrology systems for gear metrology

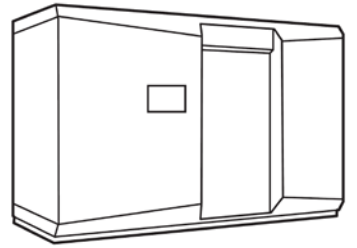
Overview of the compared measuring principles.

Coordinate Measuring Machine



- Tactile probing system
  - Touch-trigger → ZEISS RST-P
  - Scanning
    - Passive → ZEISS VAST XXT
    - Active → ZEISS VAST gold
- Non-contact probing system
  - Distance
    - Triangulation → ZEISS LineScan
    - Chromatic confocal → ZEISS DotScan
  - Lateral (Distance) → Image processing / Camera → ZEISS ViScan

Computed Tomography System



ZEISS METROTOM

Triangulation / Fringe projection

ZEISS COMET

Comparison of different metrology systems for gear metrology.

Overview of the compared metrology systems.

3

Comparison of different metrology systems for gear metrology

Overview of the compared metrology systems.

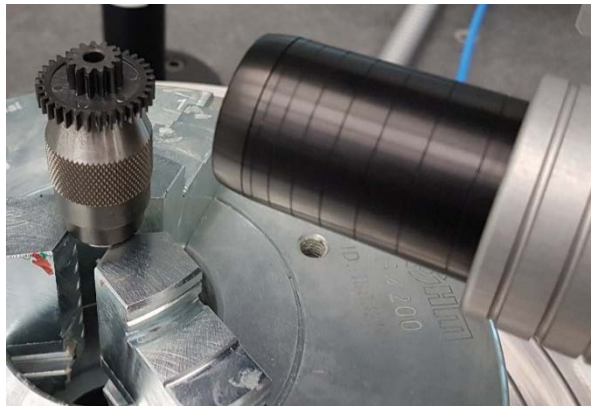
Tactile – ZEISS PRISMO ultra with VAST gold

W-gear with VAST gold and RT-AB

Triangulation / fringe projection – ZEISS COMET

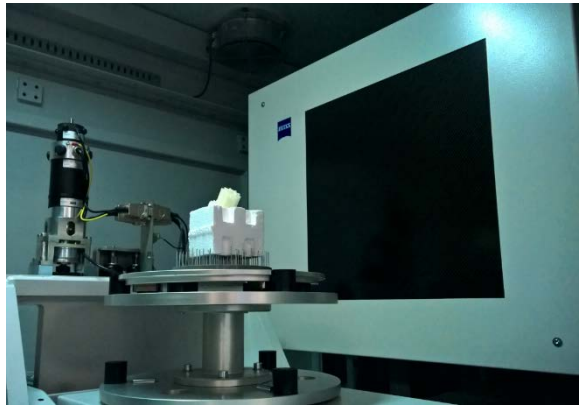
W-gear with COMET L3D 8M

Chromatic confocal – ZEISS PRISMO ultra with DotScan



B-gear with DotScan 3 mm

Computed tomography – ZEISS METROTOM



W-gear with METROTOM 1500

Comparison of different metrology systems for gear metrology.

Measurement comparison.

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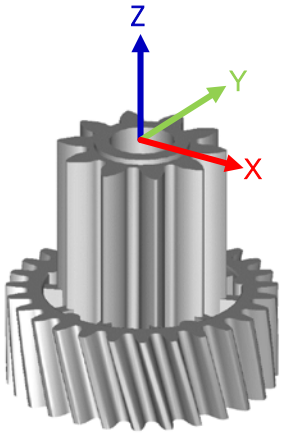
Comparison of different metrology systems for gear metrology

Measurement comparison.

Measurement strategy

- Measuring scope and workpiece alignment is identical for all measuring systems
- Workpiece alignment is determined in the bore of the gear
- Evaluation of profile and helix on all teeth on both gearings
- Pitch, runout and tooth thickness are calculated from the profile measurement
- 5 repeatability runs for each measuring system



Workpiece properties

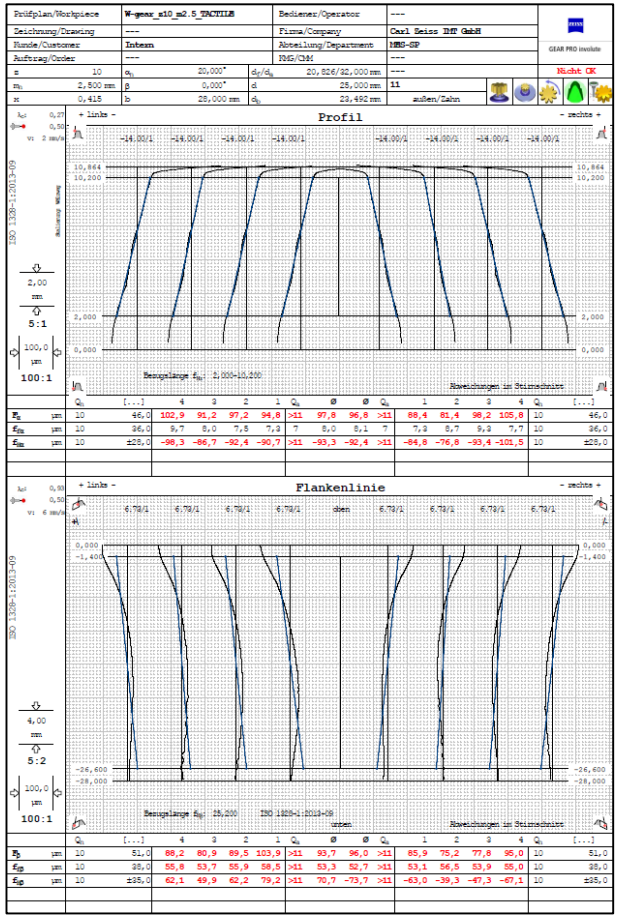
- W-gear: white plastic with volume scattering semitransparent surface (challenge for non-contact systems)
- B-gear: black plastic (better material properties for optical systems)
- Workpieces with big deviations to the nominal geometry were selected deliberately (pre-production parts)
  - W-gear: profile and helix angle deviation up to 100 µm
    total pitch deviation up to 80 µm / tooth thickness deviation up to 400 µm
  - B-gear: profile and helix angle deviation up to 15 µm
    total pitch deviation up to 150 µm / tooth thickness deviation up to 150 µm

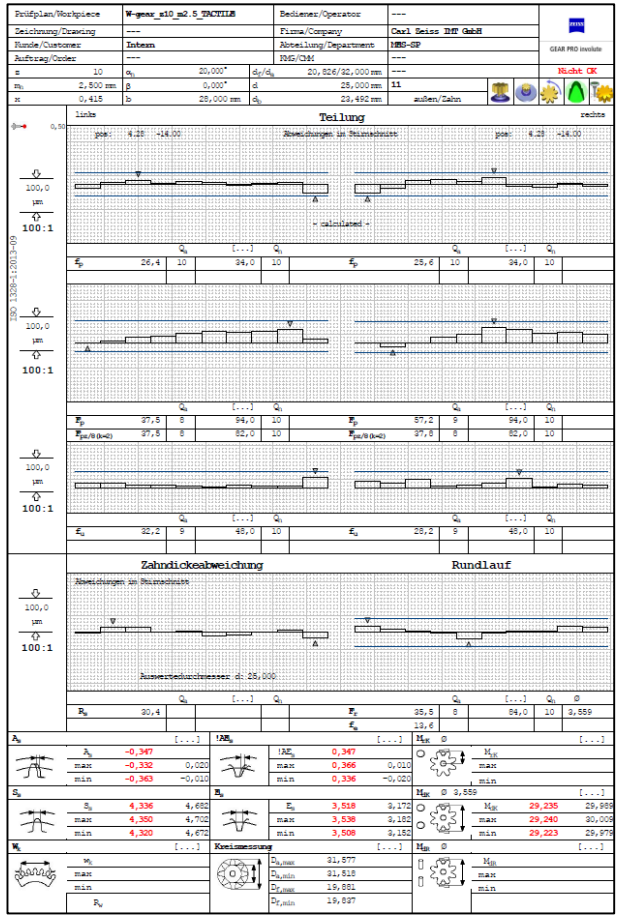
Comparison of different metrology systems for gear metrology

Measurement comparison.

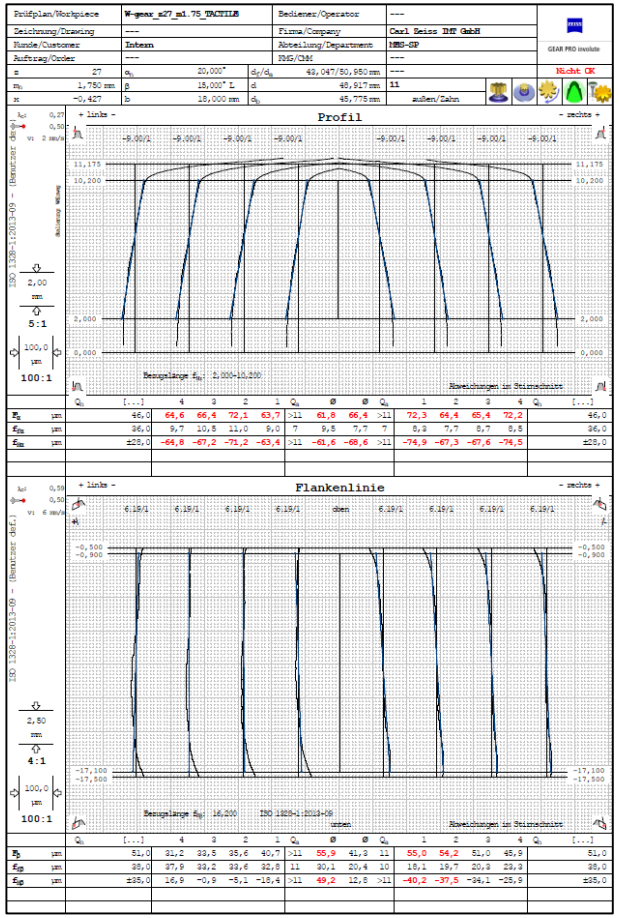
Example printout tactile W-gear

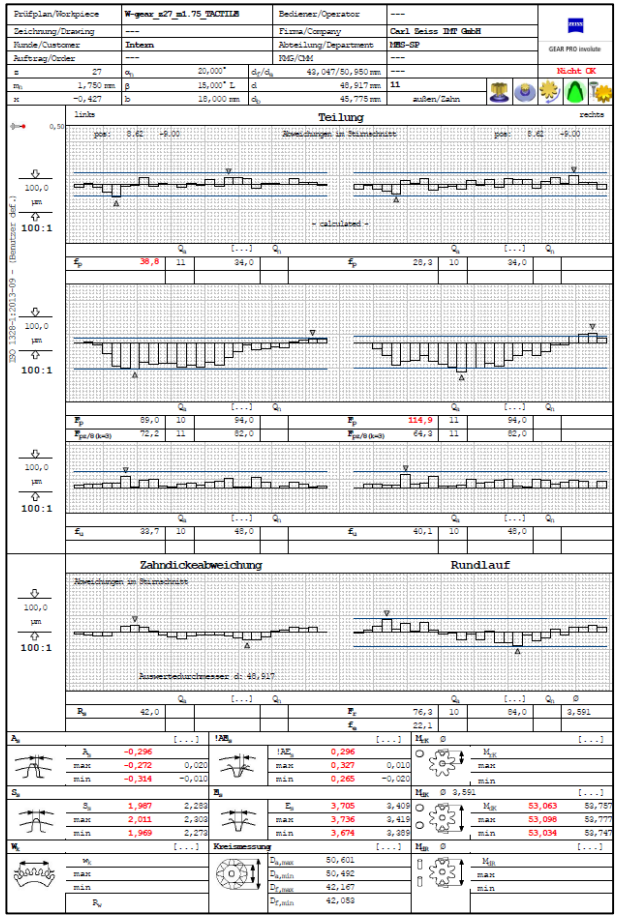
W-gear_z10_ m2.5_β0





W-gear_z27_ m1.75_β15



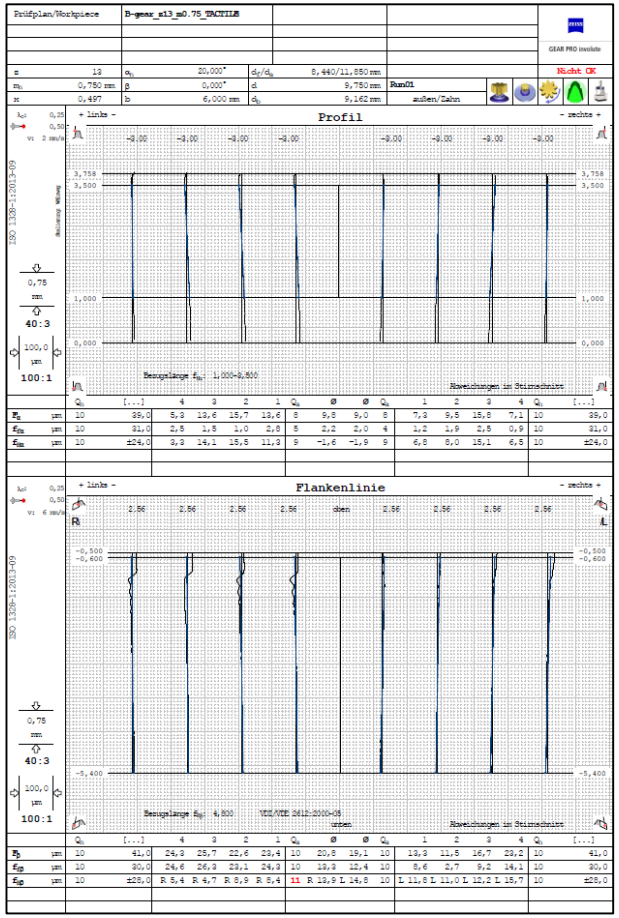


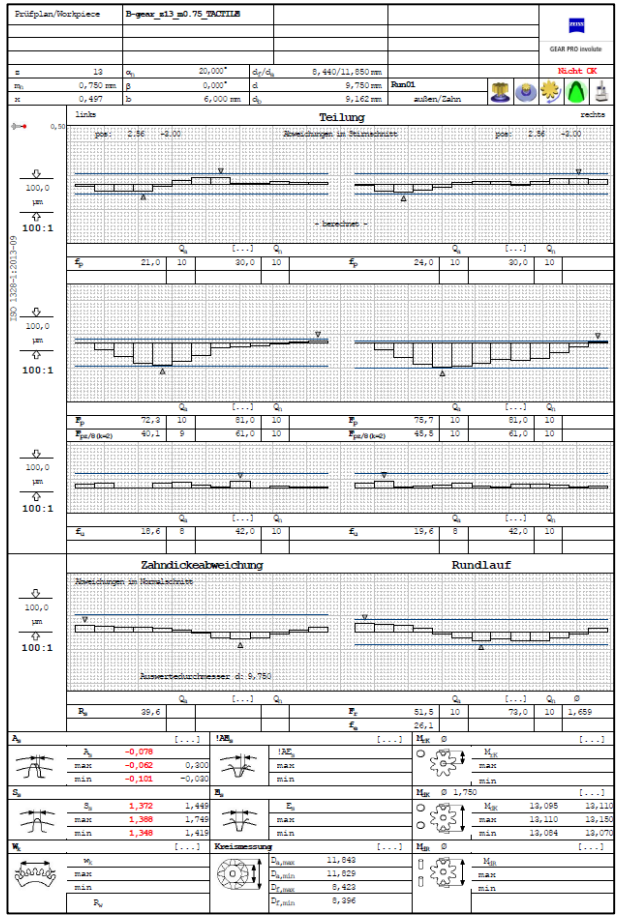
Comparison of different metrology systems for gear metrology

Measurement comparison.

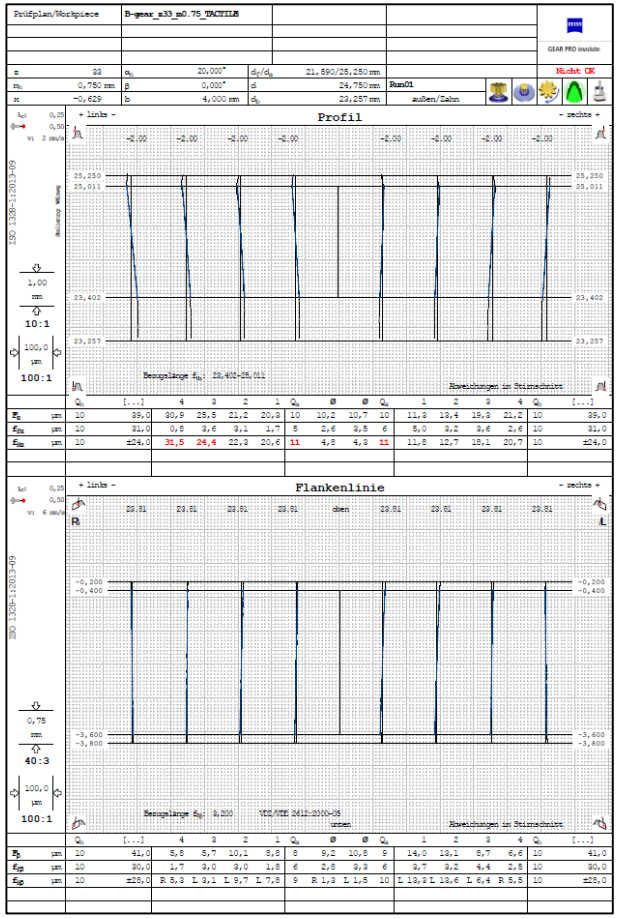
Example printout tactile B-gear

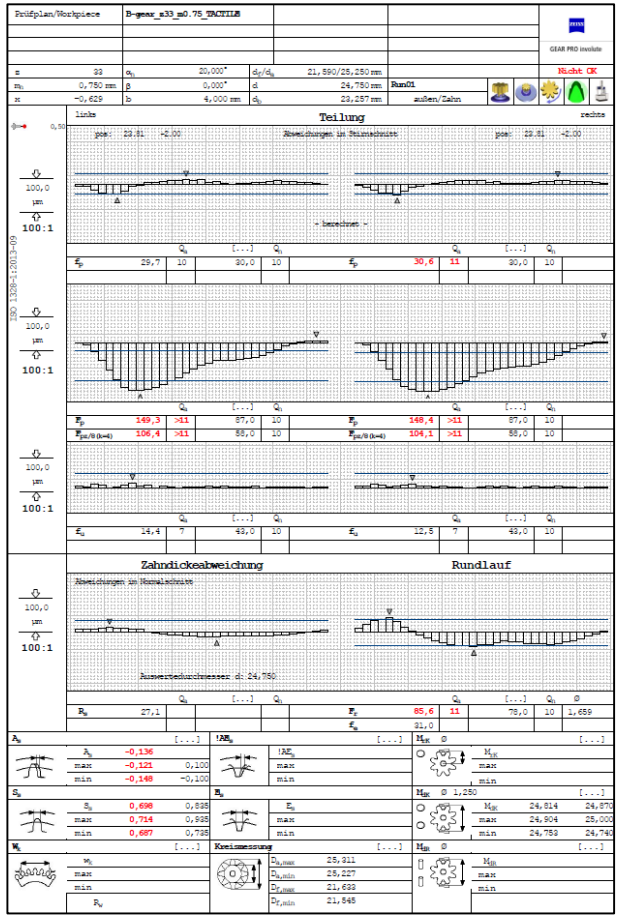
B-gear_z13_ m0.75_β0





B-gear_z33_ m0.75_β0



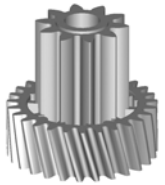


Comparison of different metrology systems for gear metrology

Measurement comparison.

Result overview over all measurements from VZ I and VZ II

W-gear



↔ D: 51 mm
↕ H: 50 mm

Measuring principle	Tactile		Chromatic confocal		Fringe projection		Computed tomography	
Metrology system	ZEISS VAST gold 		ZEISS DotScan 3 mm 		ZEISS COMET L3D 8M 		ZEISS METROTOM 1500 	
W-gear	RANGE		RANGE	BIAS	RANGE	BIAS	RANGE	BIAS
Profile form	0.2 µm		2 µm	6 µm	3 µm	2 µm	3 µm	12 µm
Profile angle	0.5 µm		3 µm	8 µm	2 µm	10 µm	2 µm	4 µm
Helix form	0.2 µm		2 µm	3 µm	3 µm	2 µm	2 µm	12 µm
Helix angle	0.5 µm		3 µm	3 µm	2 µm	10 µm	2 µm	4 µm
Pitch	0.5 µm		4 µm	2 µm	4 µm	10 µm	5 µm	4 µm
Runout	0.5 µm		4 µm	2 µm	4 µm	10 µm	5 µm	5 µm
Tooth thickness	0.5 µm		2 µm	8 µm	2 µm	20 µm	4 µm	4 µm
Dataset size	-		-		40 MB		8000 MB	
Dataset creation time [t]	-		-		20 Min		50 Min	
Preparation [t]	7 Min		9 Min		15 Min		5 Min	
Measurement time [t]	30 Min		30 Min		6 Min		10 Min	
Evaluation time [t]	< 1 Min		< 1 Min		< 1 Min		< 1 Min	
Total time [t]	38 Min		40 Min		42 Min		66 Min	

B-gear

↔ D: 25 mm
↕ H: 10 mm

Measuring principle	Tactile		Chromatic confocal		Fringe projection		Computed tomography	
Metrology system	ZEISS VAST gold 		ZEISS DotScan 3 mm 		ZEISS COMET L3D 8M 		ZEISS METROTOM 1500 	
W-gear	RANGE		RANGE	BIAS	RANGE	BIAS	RANGE	BIAS
Profile form	0.2 µm		2 µm	3 µm	2 µm	3 µm	3 µm	4 µm
Profile angle	0.5 µm		1 µm	3 µm	2 µm	6 µm	2 µm	2 µm
Helix form	0.2 µm		2 µm	3 µm	2 µm	3 µm	3 µm	4 µm
Helix angle	0.5 µm		1 µm	3 µm	2 µm	6 µm	2 µm	2 µm
Pitch	0.5 µm		3 µm	4 µm	5 µm	10 µm	3 µm	2 µm
Runout	0.5 µm		3 µm	4 µm	5 µm	12 µm	4 µm	5 µm
Tooth thickness	0.5 µm		1 µm	5 µm	4 µm	10 µm	4 µm	4 µm
Dataset size	-		-		40 MB		4500 MB	
Dataset creation time [t]	-		-		20 Min		50 Min	
Preparation [t]	7 Min		9 Min		15 Min		5 Min	
Measurement time [t]	22 Min		22 Min		4 Min		9 Min	
Evaluation time [t]	< 1 Min		< 1 Min		< 1 Min		< 1 Min	
Total time [t]	30 Min		32 Min		40 Min		65 Min	

Comparison of different metrology systems for gear metrology.

Analysis.

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Comparison of different metrology systems for gear metrology

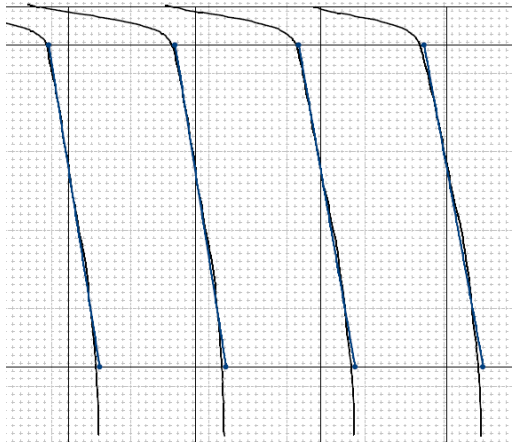
Analysis.

Chromatic confocal – ZEISS DotScan

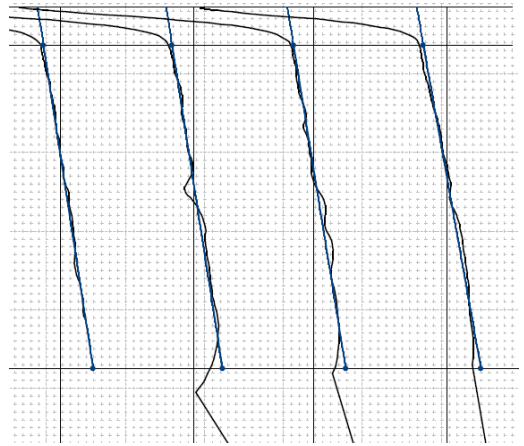
Measuring principle	Chromatic confocal	
Metrology system	ZEISS DotScan 3 mm 	
W-gear	RANGE	BIAS
Profile form	2 µm	6 µm
Profile angle	3 µm	8 µm
Helix form	2 µm	3 µm
Helix angle	3 µm	3 µm
Pitch	4 µm	2 µm
Runout	4 µm	2 µm
Tooth thickness	2 µm	8 µm
Dataset size		-
Dataset creation time [t]		-
Preparation [t]		9 Min
Measurement time [t]		30 Min
Evaluation time [t]		< 1 Min
Total time [t]		40 Min

- Profile and tooth thickness conspicuous
- W-gear z27 m1.75 β15

Profile tactile



Profile chromatic confocal



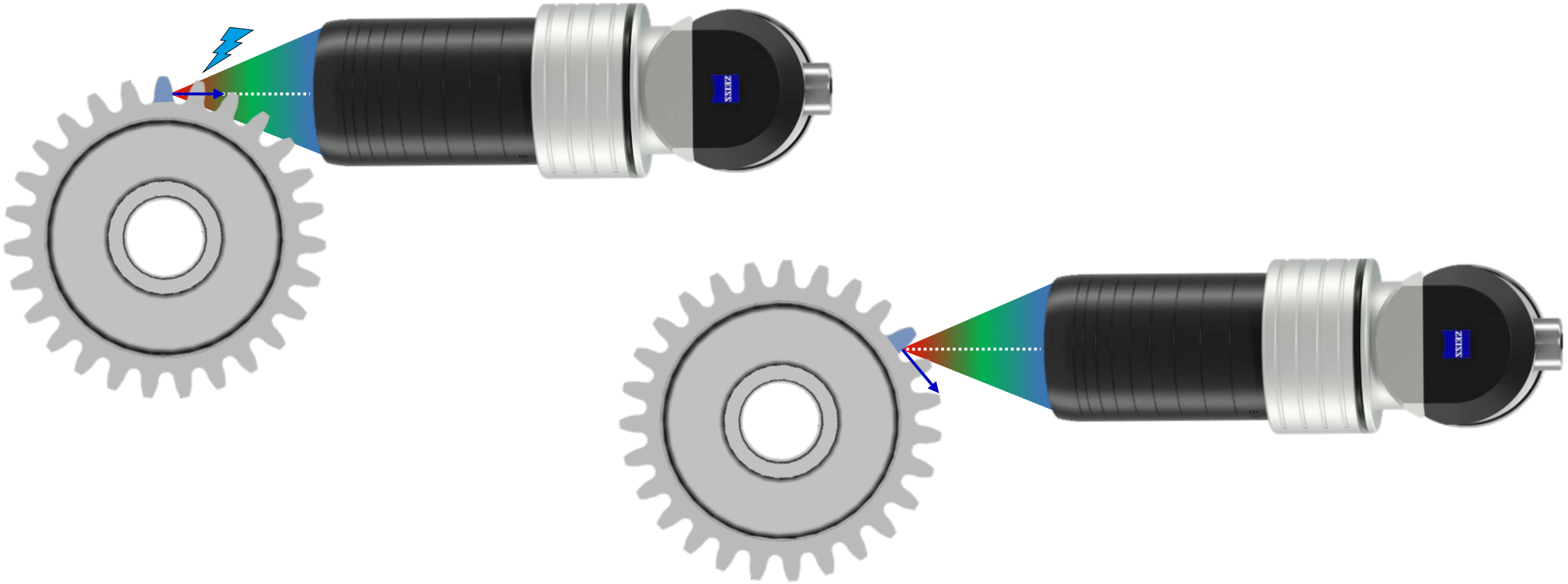
- Due to the probing system housing poor accessibility into small bores
- For the workpiece alignment maybe a probing system change to a tactile probing system is necessary (total time and measurement uncertainty are increasing)
- Limited accessibility especially in the root area of the gaps (acceptance angle is limiting)
- Semitransparent surface is distorting the measurement signal, due to the volume scattering no clear measurement point at the surface of the W-gear is possible (focus point inside the material)

Comparison of different metrology systems for gear metrology

Analysis.

Chromatic confocal – ZEISS DotScan

- Limited accessibility especially in the root area of the gaps (acceptance angle is limiting)



Comparison of different metrology systems for gear metrology

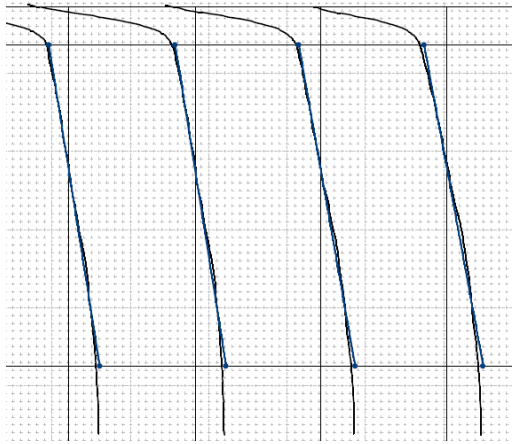
Analysis.

Triangulation / fringe projection – ZEISS COMET

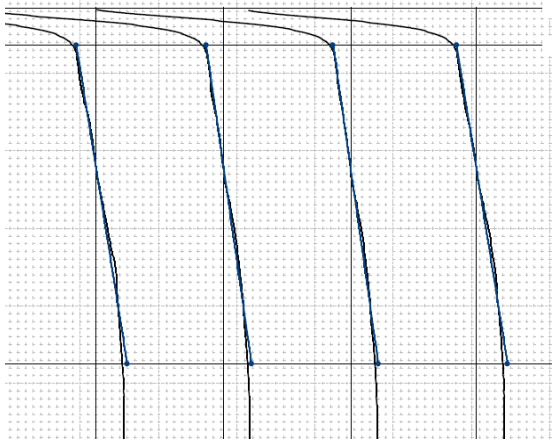
Measuring principle	Fringe projection	
Metrology system	ZEISS COMET L∃D 8M 	
W-gear	RANGE	BIAS
Profile form	3 µm	2 µm
Profile angle	2 µm	10 µm
Helix form	3 µm	2 µm
Helix angle	2 µm	10 µm
Pitch	4 µm	10 µm
Runout	4 µm	10 µm
Tooth thickness	2 µm	20 µm
Dataset size		40 MB
Dataset creation time [t]		20 Min
Preparation [t]		15 Min
Measurement time [t]		6 Min
Evaluation time [t]		< 1 Min
Total time [t]		42 Min

- Angle deviations, pitch, runout and tooth thickness conspicuous
- W-gear z27 m1.75 β15

Profile tactile



Profile fringe projector



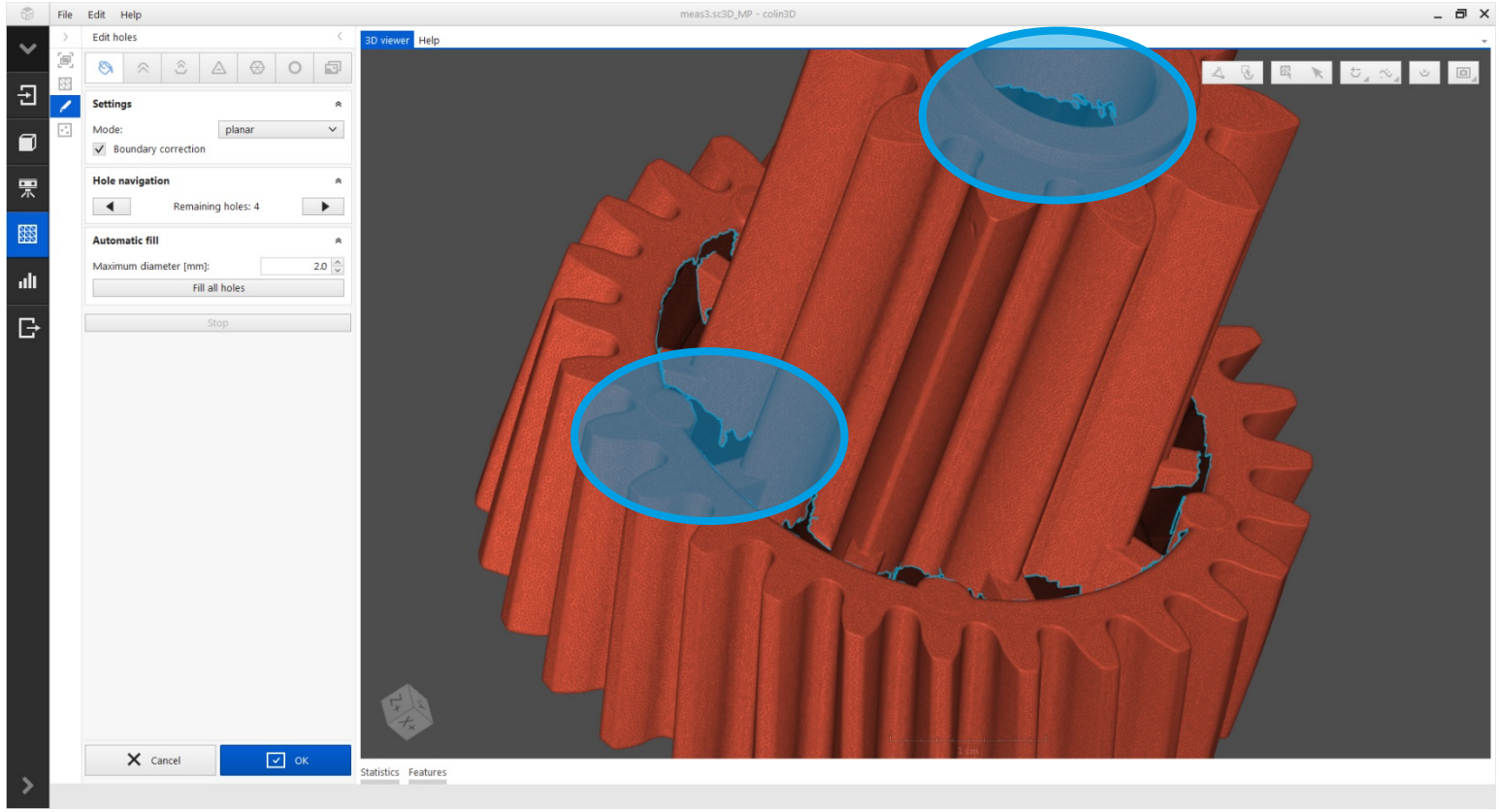
- Determined by the system poor accessibility in small bores
- For an almost complete capturing 2 orientations with 30 angle steps are necessary
- Antireflection spray necessary (minimization of reflections at mirroring surfaces)
- Homogeneous spraying of antireflection spray over the tooth height/face width is not easy, angle deviations and tooth thickness is influenced by factor 2

Comparison of different metrology systems for gear metrology

Analysis.

Triangulation / fringe projection – ZEISS COMET

- For an almost complete capturing 2 orientations with 30 angle steps are necessary

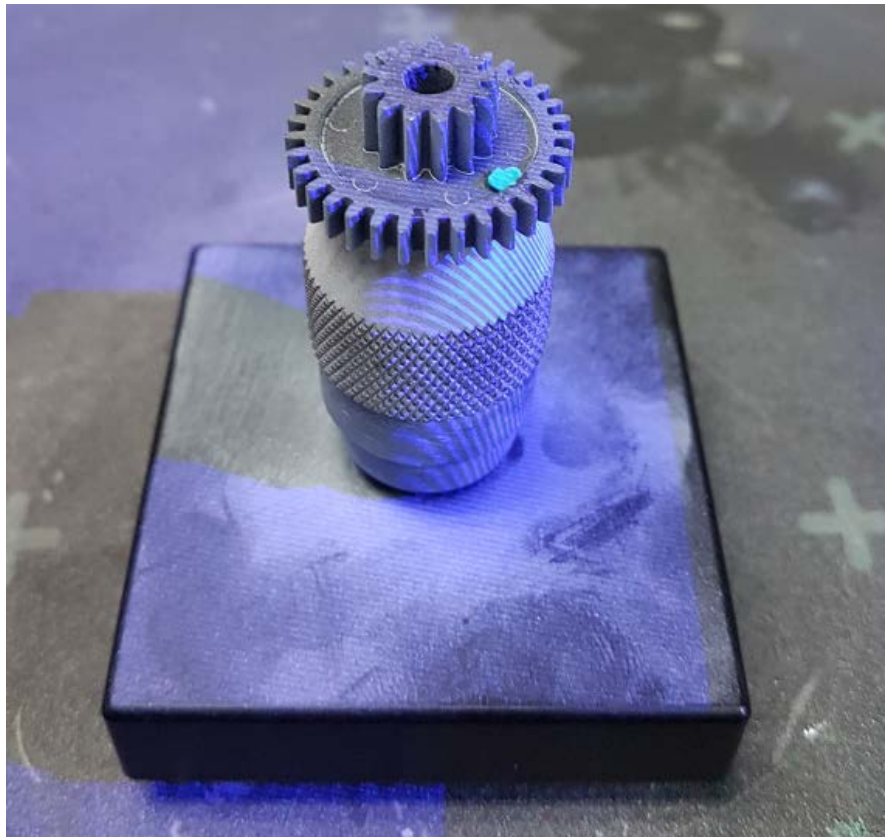


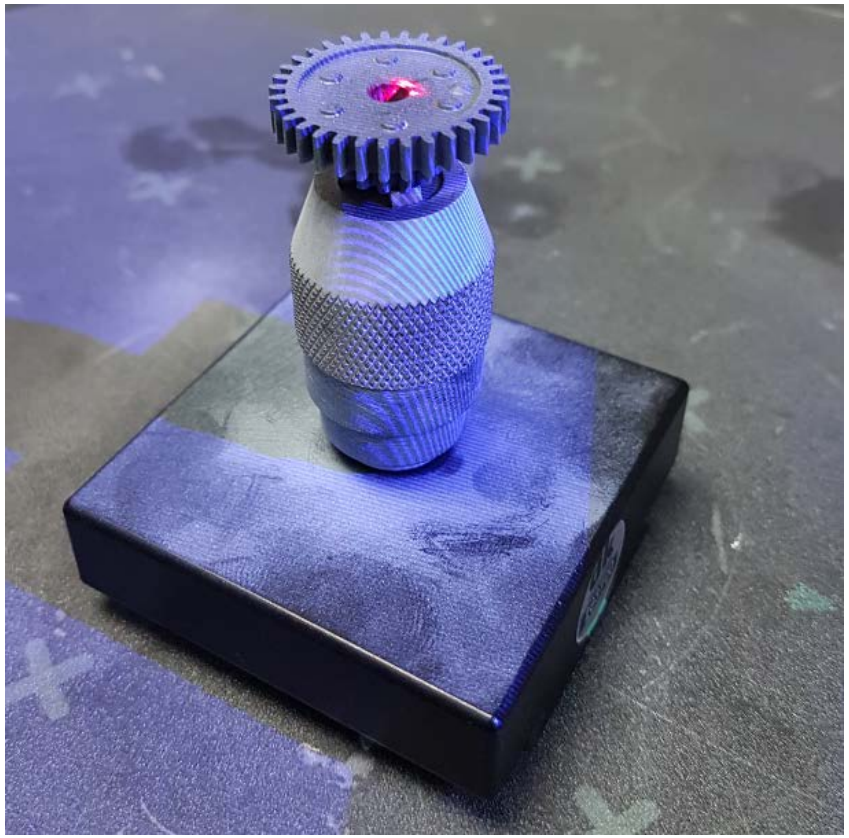
Comparison of different metrology systems for gear metrology

Analysis.

Triangulation / fringe projection – ZEISS COMET

- Homogeneous spraying of antireflection spray over the tooth height/face width is not easy





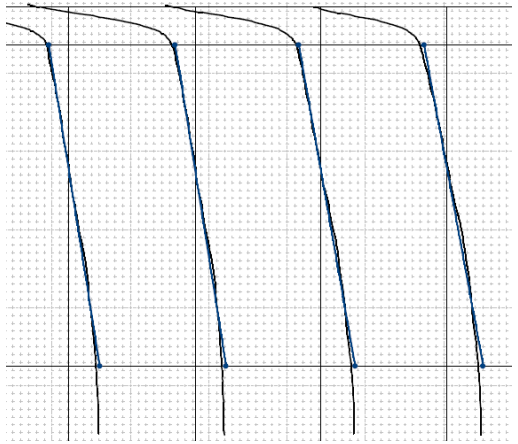
Comparison of different metrology systems for gear metrology

Analysis.

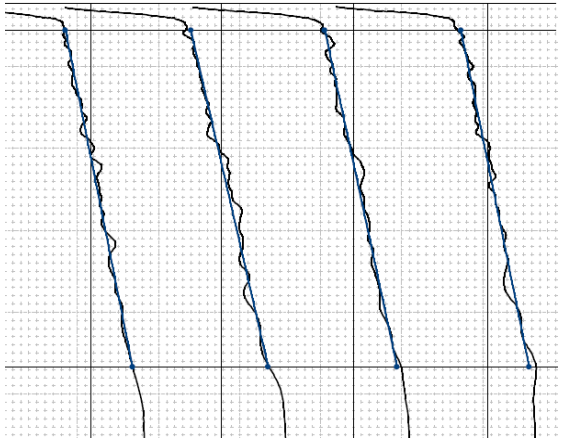
Computed tomography – ZEISS METROTOM

Measuring principle	Computed tomography	
Metrology system	ZEISS METROTOM 1500 	
W-gear	RANGE	BIAS
Profile form	3 µm	12 µm
Profile angle	2 µm	[illegible]
Helix form	2 µm	12 µm
Helix angle	2 µm	[illegible]
Pitch	5 µm	4 µm
Runout	5 µm	5 µm
Tooth thickness	4 µm	4 µm
Dataset size		8000 MB
Dataset creation time [t]		50 Min
Preparation [t]		5 Min
Measurement time [t]		10 Min
Evaluation time [t]		< 1 Min
Total time [t]		66 Min

- Form deviations conspicuous
- W-gear z27 m1.75 β15 Profile tactile



Profile computed tomography



- Determined by the system the resolution is depending from the necessary radiography power
- The bigger and thick-walled the workpiece is, the more power is required
- The higher the power, the bigger the arising focal spot on the object surface is and due to this less measurement points or less accurate points can be captured
- Higher filter settings can achieve better comparable form deviations

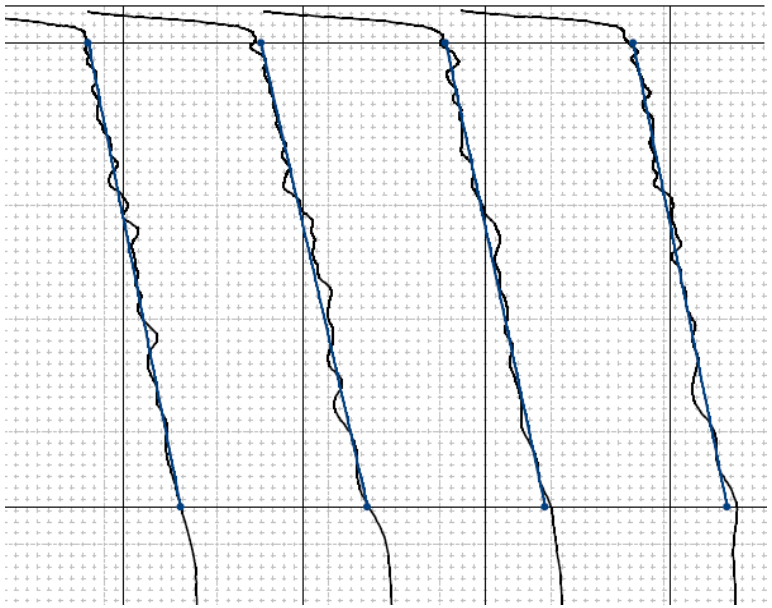
Comparison of different metrology systems for gear metrology

Analysis.

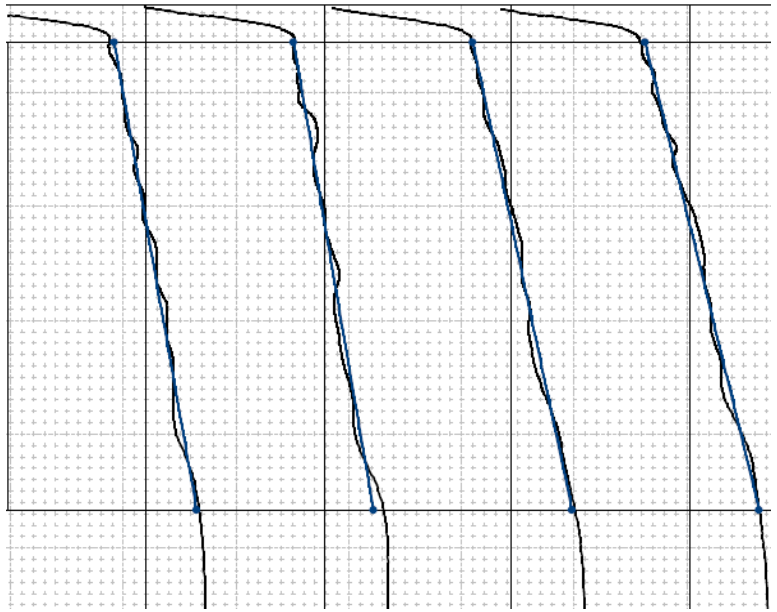
Computed tomography – ZEISS METROTOM

- Higher filter settings can achieve better comparable form deviations

W-gear z27 m1.75 β15



resulting ISO filter 0,27 mm

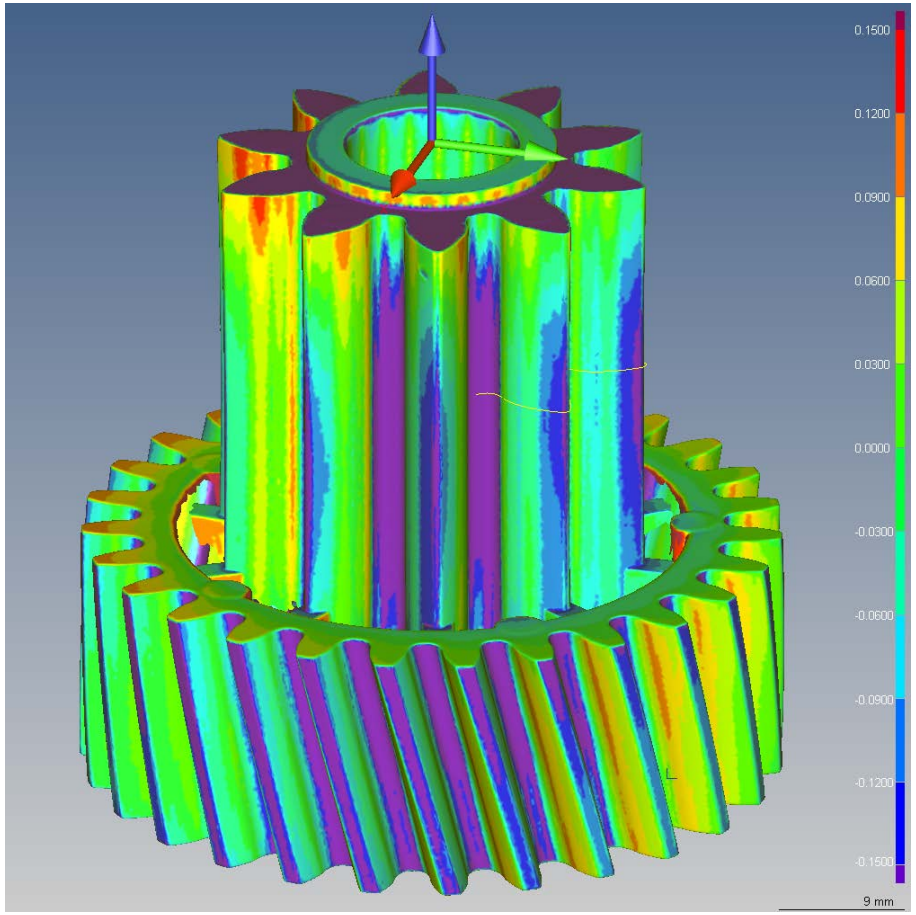


double ISO filter 0,54 mm

Comparison of different metrology systems for gear metrology

Analysis.

Advantages of surface capturing non-contact metrology systems

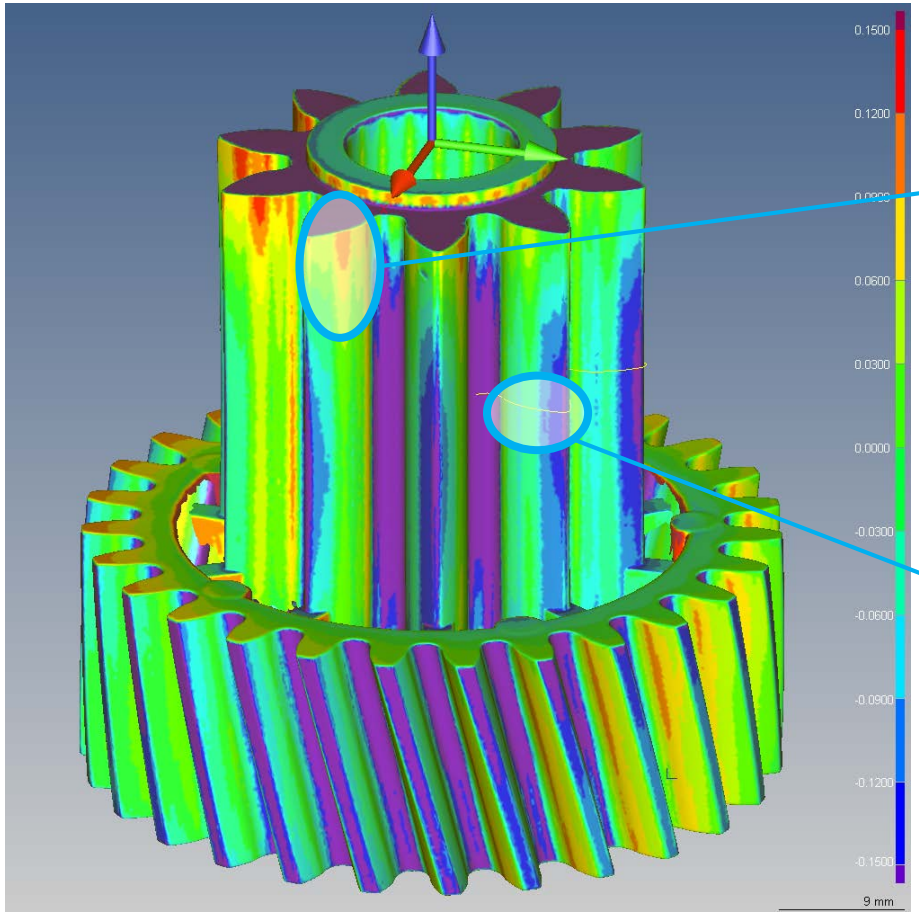


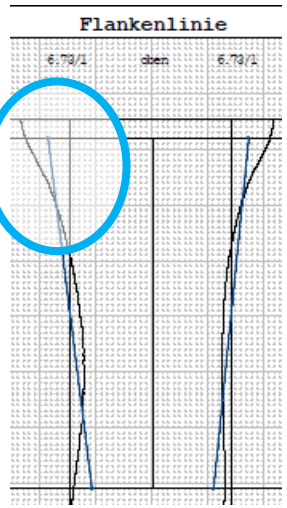
- Complete surface capturing
- Comprehensive visualization
- Colored chromatic deviation presentation / nominal/actual comparison directly on CAD model
- Gear specific parameters from the report can be completely visualized in a 3D view

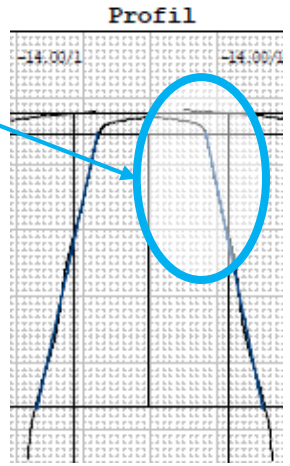
Comparison of different metrology systems for gear metrology

Analysis.

- Gear specific parameters from the report can be completely visualized in a 3D view







Helix

Concave flank in axial direction

with plus material (red)

at the upper reference plane

Profile

Minus material (blue)

in the area

tooth tip / middle of face width

Comparison of different metrology systems for gear metrology.

Summary.

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Comparison of different metrology systems for gear metrology

Summary.

Plastic gears on Coordinate Measuring Machines und non-contact metrology systems

Tactile

- Highest accuracy for gear specific parameters
- Repeatability << 1 µm *
- Surface capturing very time-consuming
- Measurement force can have negative influence on soft materials - active probing systems offer benefits

Triangulation / fringe projection

- Very good suitable for surface capturing
- Color chromatic deviation presentation
- Antireflection spray is influencing the result
- Disadvantages at mirroring surfaces (scattered reflections)
- Repeatability < 5 µm *
- Bias < 20 µm *

Chromatic confocal

- Good accuracy for good accessible gears (splines and spur gears)
- Advantages at 360° transversal intersection measurements (cycloids, rotors)
- Surface capturing very time-consuming
- Repeatability < 5 µm *
- Bias < 8 µm *

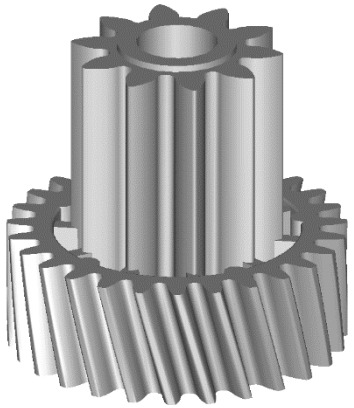
Computed tomography

- Very good suitable for surface capturing and non-destructive testing inside the material
- Color chromatic deviation presentation
- Strong limitations regarding object size and workpiece properties
- Repeatability < 5 µm *
- Bias < 15 µm *

* workpiece specific values resulting out of the comparison

Comparison of different metrology systems for gear metrology

Acknowledgement



W-gear

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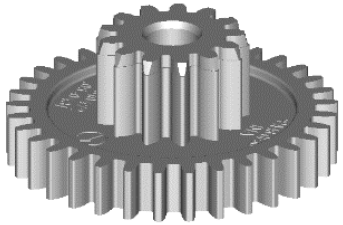
Herr Dr.-Ing. Andreas Langheinrich

Entwicklung Antriebstechnik in Kunststoff



B-gear

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Leiter Qualität Zentraler Feinmessraum


ZEISS