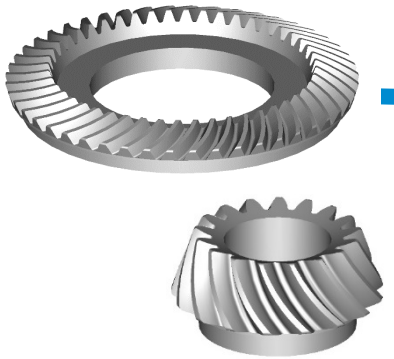
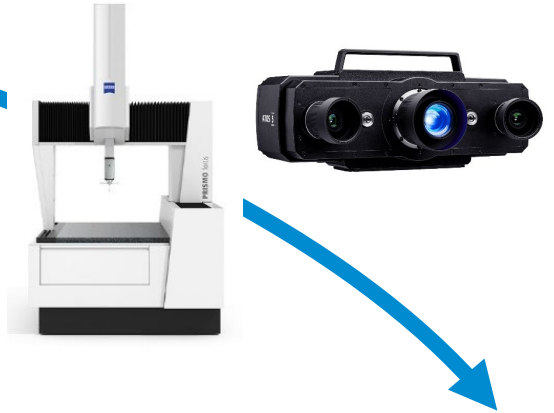
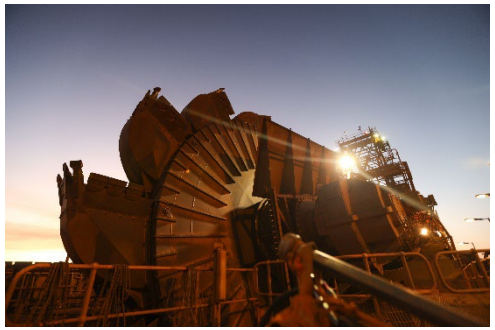
Digital Twin in the First-Part-Right production chain

WZL Seminar - Innovations in Bevel Gear Technology 2020







GWJ Technology, Gunther Weser
ZEISS Industrial Quality Solutions, Roman Groß

2020-10-08

Digital Twin in the First-Part-Right production chain
Agenda.

1 Application – bevel gear set for bucket wheel excavator

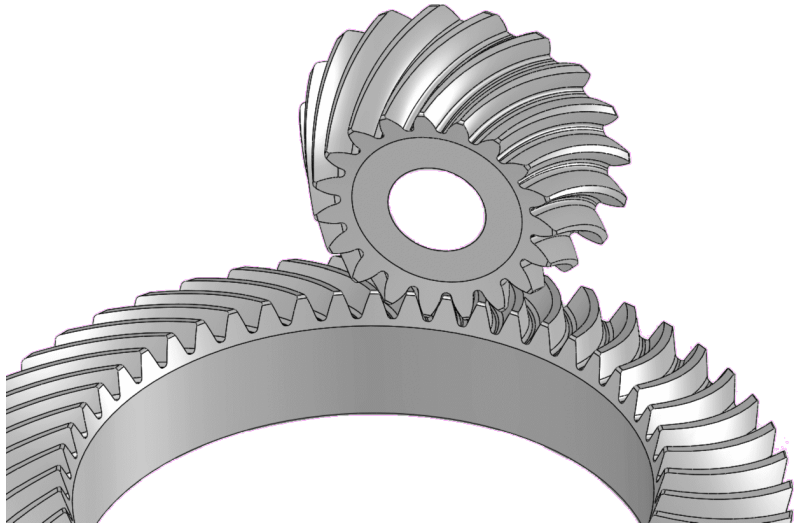
2 Bevel gear design – birth of Digital Twin

3 Single-piece production on Universal Machining Centers

4 Metrology – tactile and optical

5 Comparison of results

6 Summary & outlook



Digital Twin in the First-Part-Right production chain

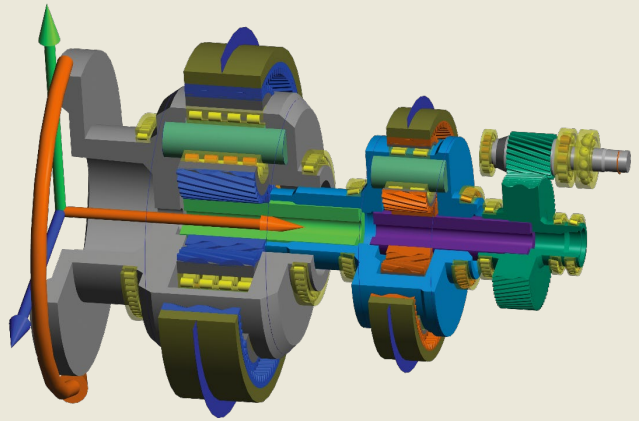
Application – bevel gear set for bucket wheel excavator.

1

1. GWJ Technology

- GWJ Technology was founded in January 2000
- Today: market-leader in web-based calculation software for standard machine elements; among Top 5 of software providers for gears, especially for cylindrical and bevel gears, and system calculation
- Individual software development
- Engineering & consulting

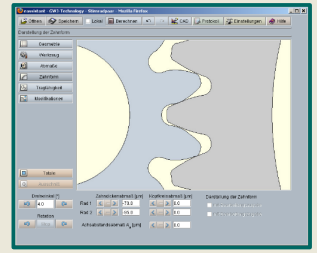
Presenter: Dipl.-Ing. Gunther Weser
CEO of GWJ Technology GmbH,
38114 Braunschweig, Germany, www.gwj.de

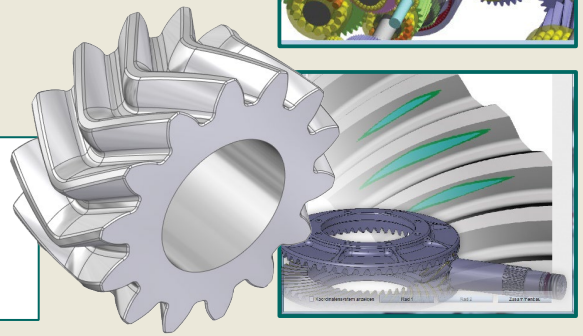


1. GWJ Technology

Products

- **eAssistant:** Web-based calculation software for machine elements such as shafts, bearings & gears = online solution of TBK including 3D CAD plugins & add-on “SystemManager”
- **TBK:** Calculation software for gear design & mechanical engineering, shafts, bearings & gears, … 3D CAD plugins available & add-on “SystemManager”
- **GearEngineer:** Special gear software as a basis for 5-axis milling of gears, provides the real 3D gear tooth form of cylindrical & bevel gears

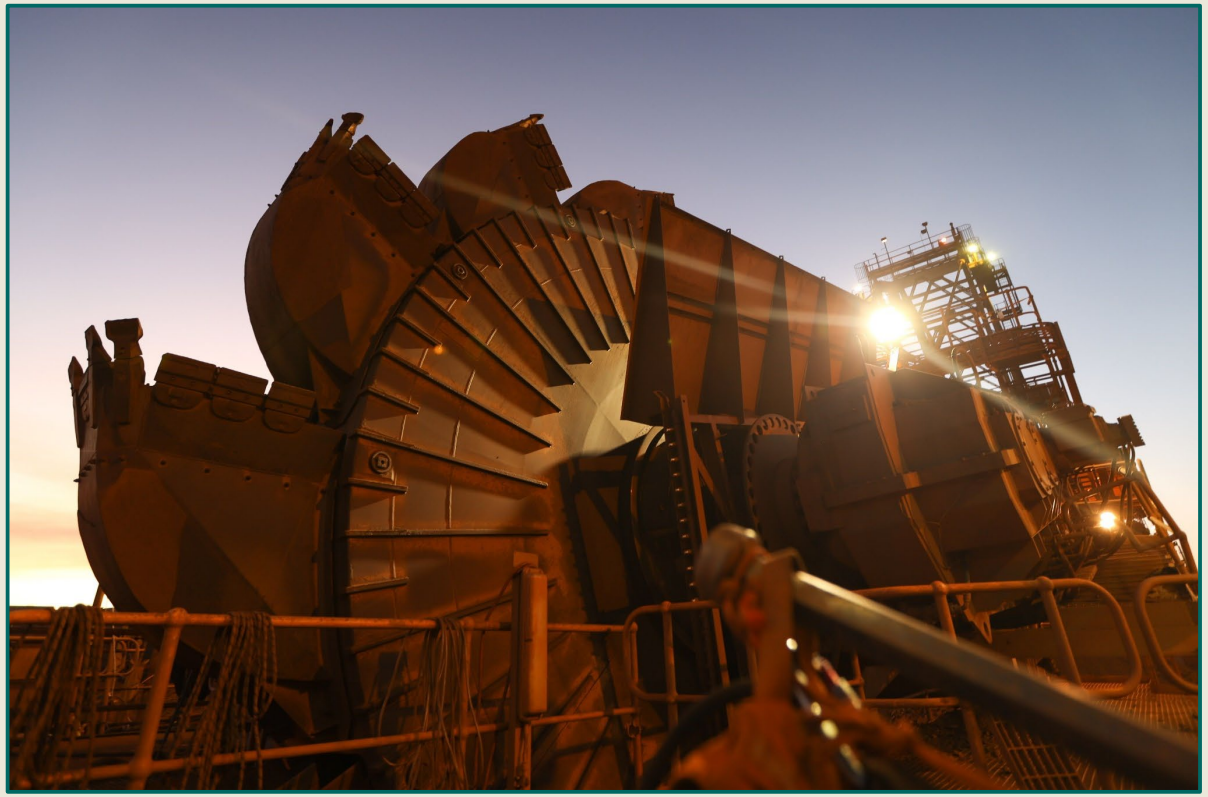




1. Application Example: Bucket Wheel Excavator

- The basic process of the first-part-right manufacturing is to be presented by using a bevel gear stage, which is used, for example, in bucket wheel excavators.
- Only soft machining was used in this application example (without hardening process)
- Spiral bevel gear set with constant tooth depth: Klingelnberg Zyklo-Palloid

  $z_1 = 17$, $d_{e1} = 270$ mm
  $z_2 = 48$, $d_{e2} = 760$ mm
  $m_{nm} = 12$ mm
  $ß_m = 30^\circ$
  $b = 100$ mm



Digital Twin in the First-Part-Right production chain

Bevel gear design – birth of Digital Twin.

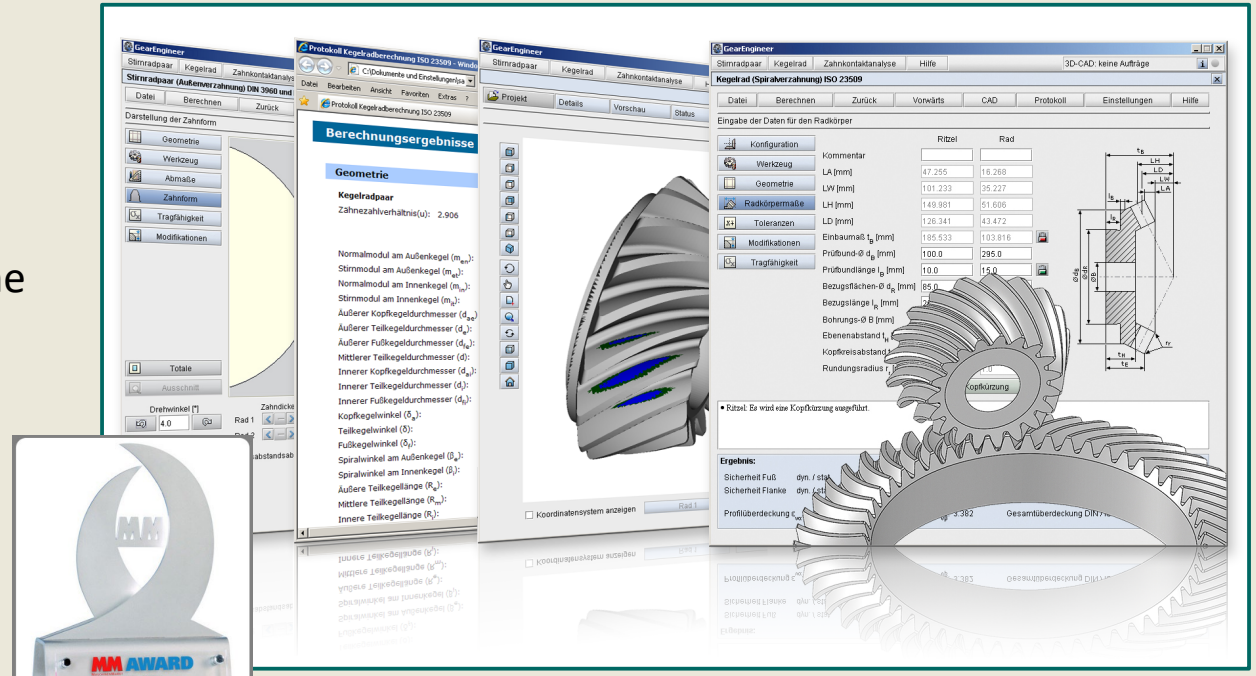
2

2. Bevel Gear Design => Birth of the Digital Twin

Calculation Software GearEngineer

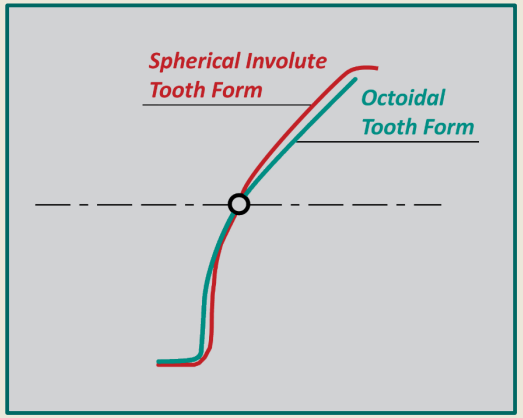
GearEngineer

- Start of the process chain:
  - Dimensioning in development/design department or
  - Customer´s drawings in work preparation department
- There is just a small number of software to determine the real gear tooth of bevel gears; often only approximate solutions based on a virtual cylindrical gear
- GWJ´s software **GearEngineer** is available worldwide since the beginning of 2010
- Supports the dimensioning of gears, re-calculation and optimization including the real tooth form

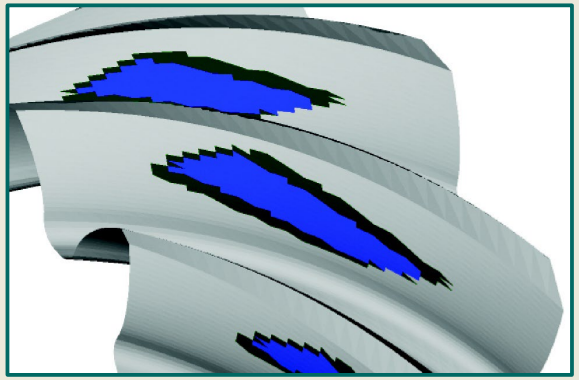


2. Bevel Gear Design => Birth of the Digital Twin

Calculation Software GearEngineer



- GearEngineer calculates the gear tooth form based on a mathematical simulation of the manufacturing process analogous to traditional manufacturing on gear cutting machines. This leads to a real 3D gear tooth geometry of bevel gears.
- **Tooth profile** is an **octoidal** tooth profile => Provides a comparable strength and running behavior identical to conventional manufactured gears!
- Calculation of load capacity is based on ISO 10300.
- Tooth contact analysis without load including collision check for determination of the micro geometry = modifications

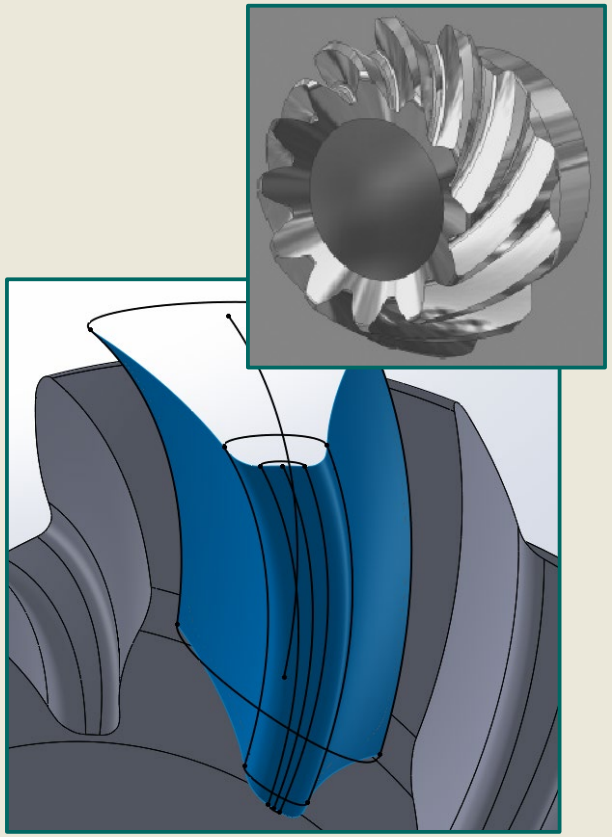


2. Bevel Gear Design => Birth of the Digital Twin

Calculation Software GearEngineer

- Output of the 3D gear tooth form including micro geometry via neutral format 3D STEP/ IGES; calculation information is saved directly in the CAD data!
- Accuracy resolution is adjustable.
- Generation of solid models, surface model of tooth space as well as curves and nominal data

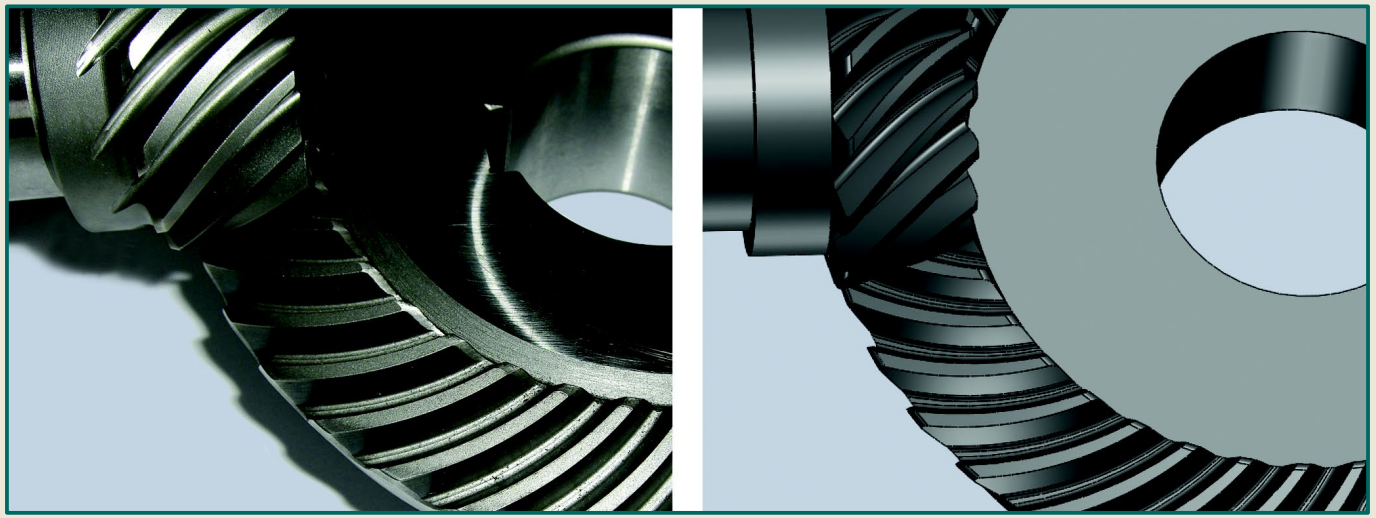
- Direct further use for manufacturing, for example transfer to CAM system or basis for other manufacturing processes such as forging, sintering or additive manufacturing (3D printing)
- In addition to straight, helical and spiral bevel gears, other gear types are supported.



2. Bevel Gear Design => Birth of the Digital Twin

Calculation Software GearEngineer

- Geometry of the CAD model matches the future product
  = digital gear twin
- Backlash (or tooth thickness tolerance for cylindrical gears) can be adjusted before the generation of the model starts.
- Further details such as safeties from the load capacity, speeds, torques and materials are stored as information and can be evaluated by subsequent processes.



Digital Twin in the First-Part-Right production chain

Single-piece production on Universal Machining Centers.

3

3. Single-Piece Production on Universal Machining Centers

Universal CAM System for 5-Axis Simultaneous Machining

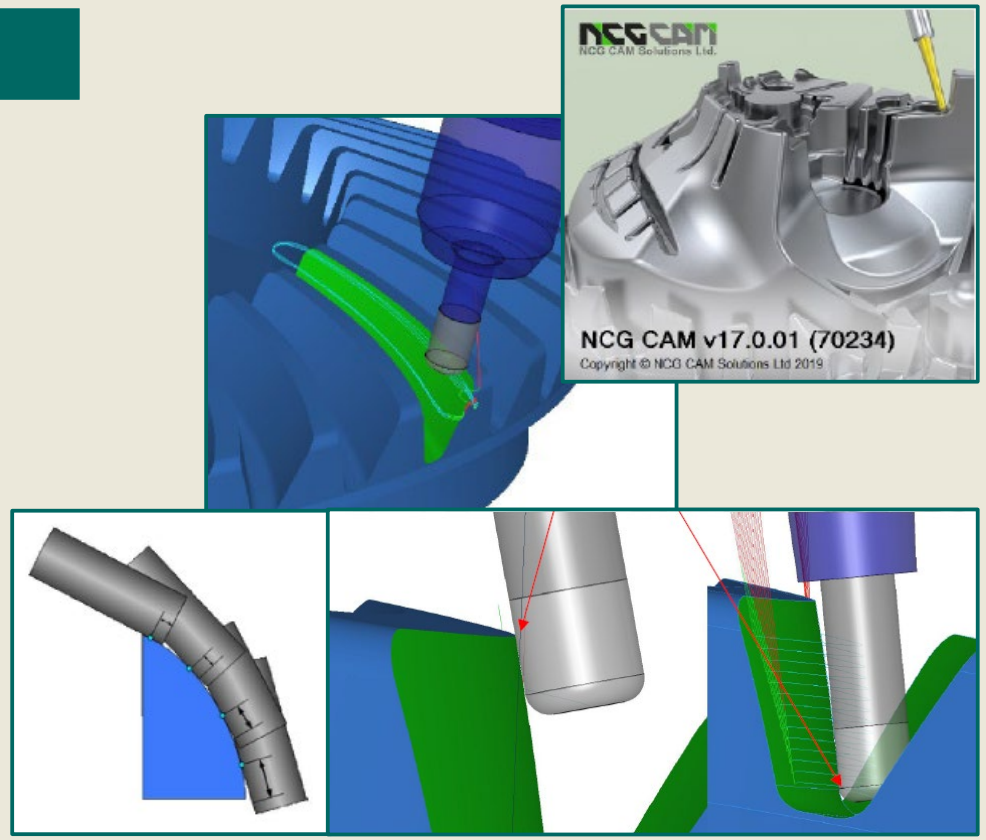
- Use of an universal CAM offers several advantages:

  - Not only gears can be machined on the universal machining center
    - Wide range of machining strategies possible
    - Import of 3D gear geometry via STEP/IGES as solid or surface model as well as curves

    => Further use of the digital gear twin

- 5-axis simultaneous machining capability for the manufacturing of helical and spiral bevel gears is required

- Function to use the entire flute length of the end mill cutter increases tool life and machining quality



3. Single-Piece Production on Universal Machining Centers

Tools

- Standard cutting tools from standard tooling catalog, as already known from mold and die industry, can be used.
- No special tools are needed, fast and easy available.
- Inserts can be rotated or exchanged.
- Solid carbide cutter can be reground.
- Form cutter or other special tools are also possible.
- In the example presented here, tools of the company Aura were used.

3. Single-Piece Production on Universal Machining Centers

Requirements on Universal Machining Centers for 5-Axis and Free-Form Milling of Gears

- Stiffness and accuracy of the machining center should be high as possible to achieve required gear tolerances.
- 5-axis simultaneous machining capability for the manufacturing of helical and spiral bevel gears.
- Workpiece Ø from large to small => 6-axis machining centers are advantageous; fork-type milling head with rotational and swivel axis for simultaneous machining without table movement, table takes over just the pitch => therefore always the same milling situation, i.e. mass moment of inertia of the workpiece plays a minor part during manufacturing.
- 6-axis machining centers are more efficient for a small number of teeth, especially with regard to necessary travel paths.
- Foundation, possible air conditioning and temperature stability are important factors for reaching gear qualities.

3. Single-Piece Production on Universal Machining Centers

Universal Machining Center in Use

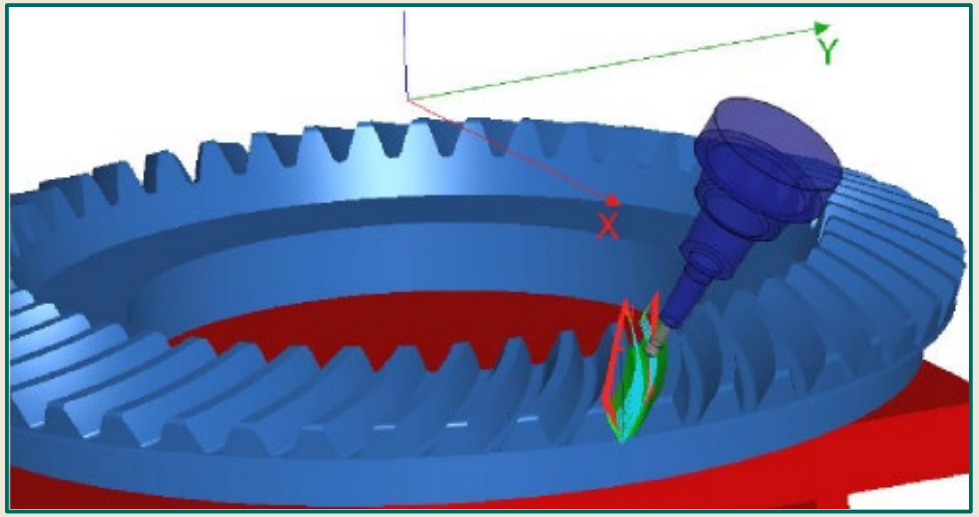
- 5- and 6-axis machine with rotary table and fork-type milling head
- 5-side machining in one setup
- Integrated air-conditioning
- Very compact machine with large working area utilizing minimal floor-space
- Customized distance between spindle nose and clamping surface
- Round rotary table with center hole for machining pinion shafts

TRIMILL GmbH
info@trimill.de
www.trimill.de

3. Single-Piece Production on Universal Machining Centers

Milling Simulation and Collision Check with Digital Tool and Machine Twins

Simulation of the tool paths in CAM system by means of digital **tool twins**.



Simulation of the travel paths with collision check by means of digital **machine twin**.

3. Single-Piece Production on Universal Machining Centers

Machining time for gear cutting process

Machining time for gear cutting: approx. **10.5 hours**

Machining time for gear cutting: approx. **7 hours**

Digital Twin in the First-Part-Right production chain

Metrology – tactile and optical.

4

Digital Twin in the First-Part-Right production chain

Metrology – tactile with ZEISS PRISMO fortis.

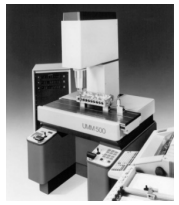
4.1

ZEISS Solutions for gear metrology

Successful concept.

1975 – First CNC CMM

- System - UMM 500
- Probe - measuring probe
- Software - GON + RAM (OS - CMS)



1984 – ZEISS Gear Metrology concept established

- System - ZMC 550
- Probe - HSS
- Accessories - RT05-400 Tailstock
- Software - GON (OS - UNIX)

1989 – Company Höfler as a part of ZEISS

- System - EMZ, ZP
- Software - GEAR-INVOLUTE GEAR-BEVEL (OS - UNIX)

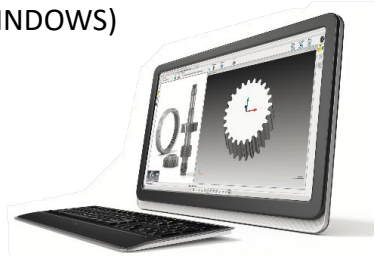
www.wekogear.eu/index_start_de.php

1995 – Modern CMM concept established

- System - PRISMO
- Probe - VAST

2003 – Modern Gear Metrology software established

- Software - GEAR® PRO product family (OS - WINDOWS)



2007 – First step non-contact gear evaluations

- System - METROTOM
- Software - GEAR® PRO
- Dataset - VOXEL

2017 – Next step non-contact gear evaluations

- System - COMET
- Software - GEAR® PRO
- Dataset - STL

ZEISS PRISMO fortis
Tailored to your demands.

ZEISS PRISMO fortis

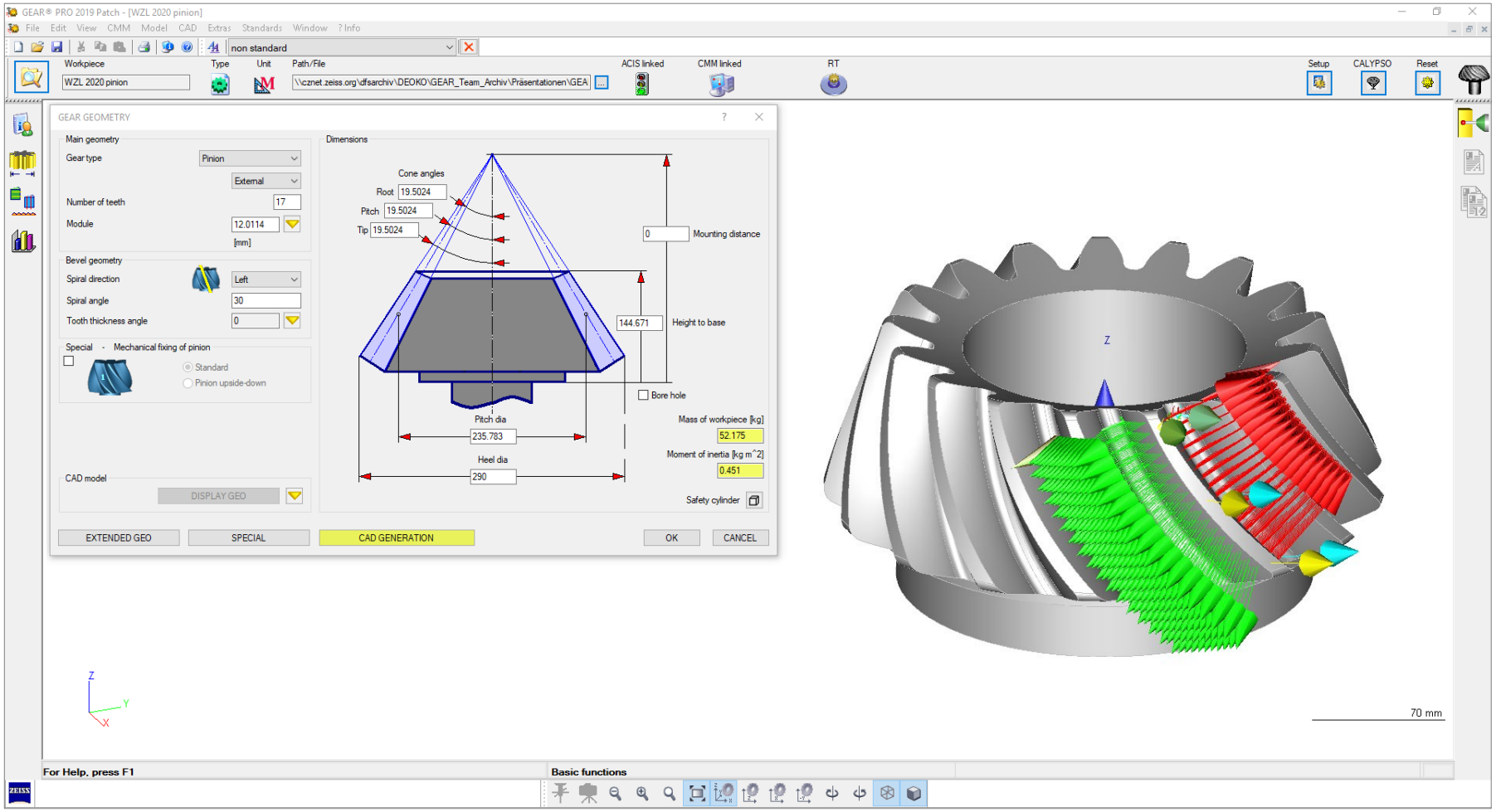
- Precise and robust bridge-type CMM
- Measuring volume [X/Y/Z] 1200/1800/1000 [mm]
- Active probing system VAST gold
- Air bearing rotary table RT-AB
- Maximum environmental temperature up to 37°C (optional 40°C)

  Hardware stability due to
  - additional CAA-corrections (thermal bending corrections)
  - floating mounted ZERODUR® scales
  - pneumatic damping system
  - optimized air bearings on the Y-carriage
- Environmental conditions: 18-37°C: 5 K/d – 2 K/h – 1 K/m

Bevel gear metrology software ZEISS GEAR PRO bevel

Measuring program definition on Digital Twin.

- Definition of measuring program is based on Digital Twin / CAD model
- New in 2020 version of ZEISS GEAR PRO bevel: extraction of geometry parameters from CAD
- Automatic measuring run based on data matrix (grid)



Metrology – tactile with ZEISS PRISMO fortis

Video.

Video

Rotary table face plate for diameters up to 630 mm

Face plate extension for diameters up to 800 mm

Metrology – tactile with ZEISS PRISMO fortis

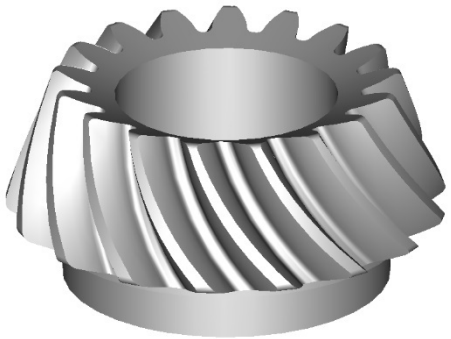
Results – Evaluation with ZEISS GEAR PRO bevel.

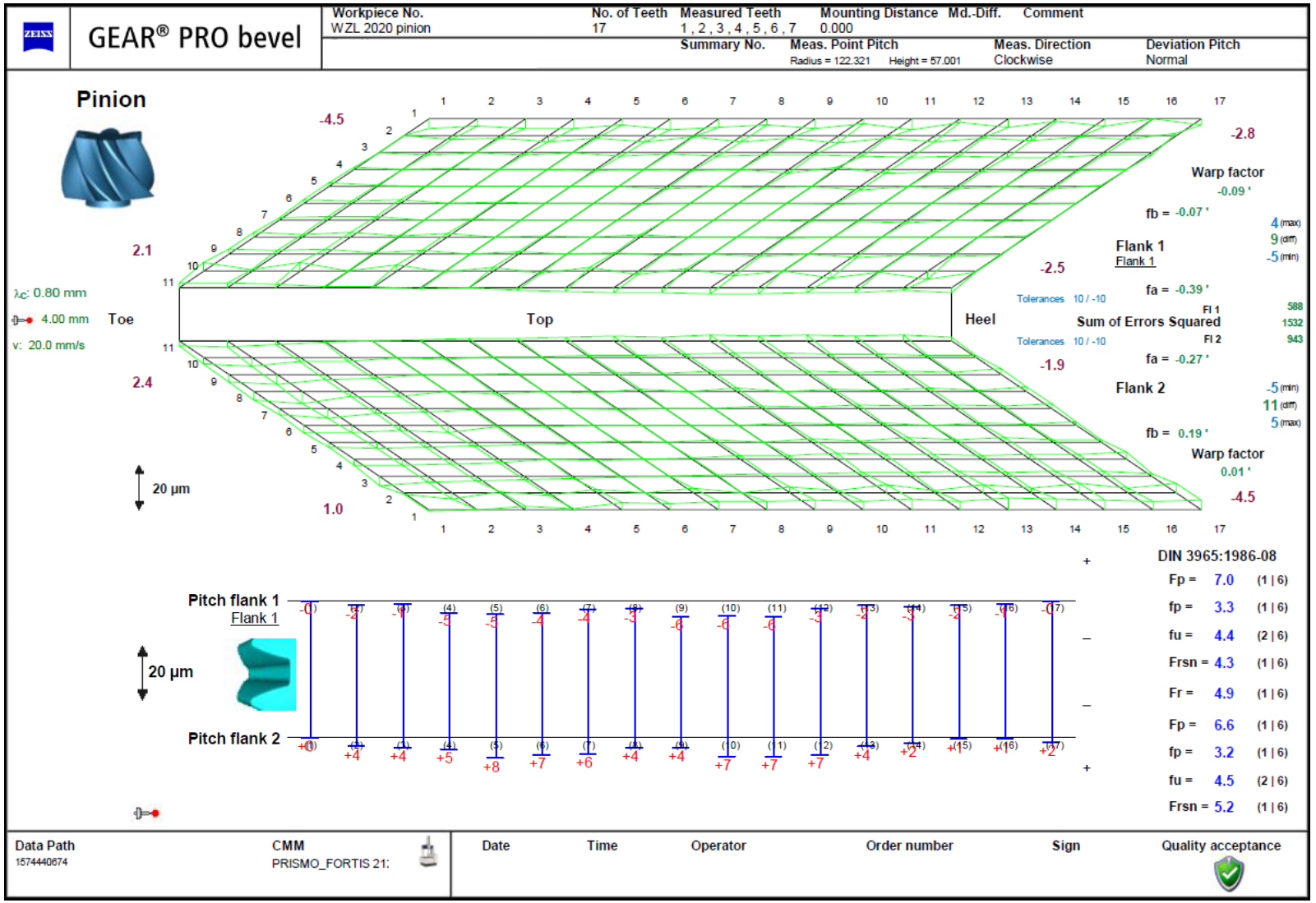
- Conventional reporting
- Topography:

  ± 5 µm deviations from nominal
- Pitch and runout:

  actual values ≤ 7 µm

  actual tolerance grade 2





Digital Twin in the First-Part-Right production chain

Metrology – optical with GOM ATOS 5 for Airfoil.

4.2

The ATOS 5 family
ATOS 5 | ATOS 5X | ATOS 5 for Airfoil.

Industrial Optical 3D Metrology with High-Speed Technology

ATOS 5
High-speed 3D scanning system

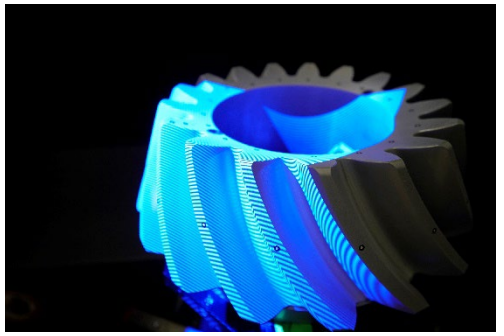
ATOS 5 for Airfoil
Precise scanning of smallest details

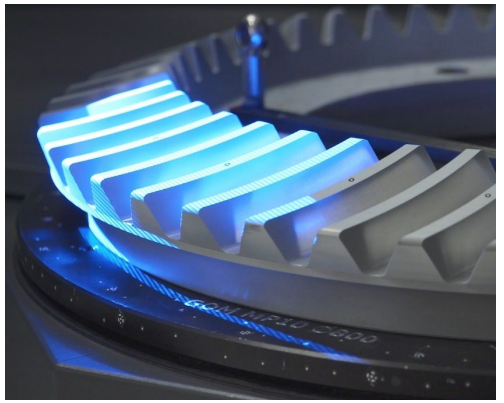
ATOS 5X
Automated scanning for large measuring areas

GOM ATOS 5 for Airfoil
High-Speed with High Detail Resolution.

ATOS 5 for Airfoil – High-Speed with High Detail Resolution

- Fringe projection with LED light source
- Resolution 12 Megapixel
- Measuring volume 100, 170, 270, 400
- Applied focal plane 270 x 200 mm²
- Working distance 530 mm
- Precise scanning of smallest details
- Optimized, shortened working distance
- Extremely high stability in automated applications, originally designed for application in jet engines and gas turbines

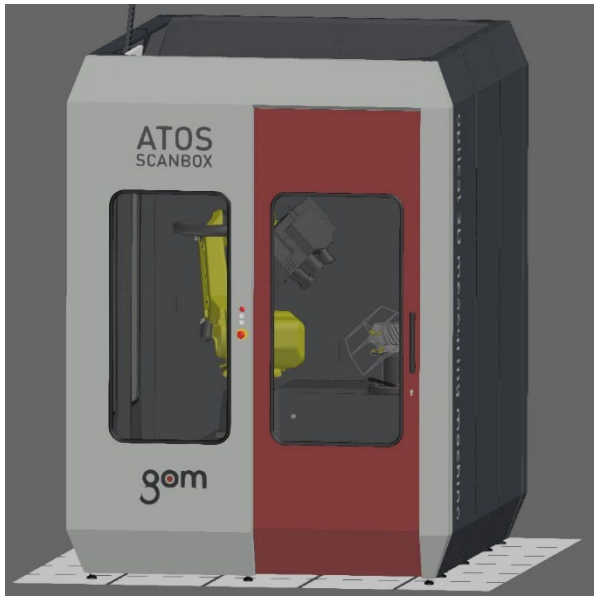


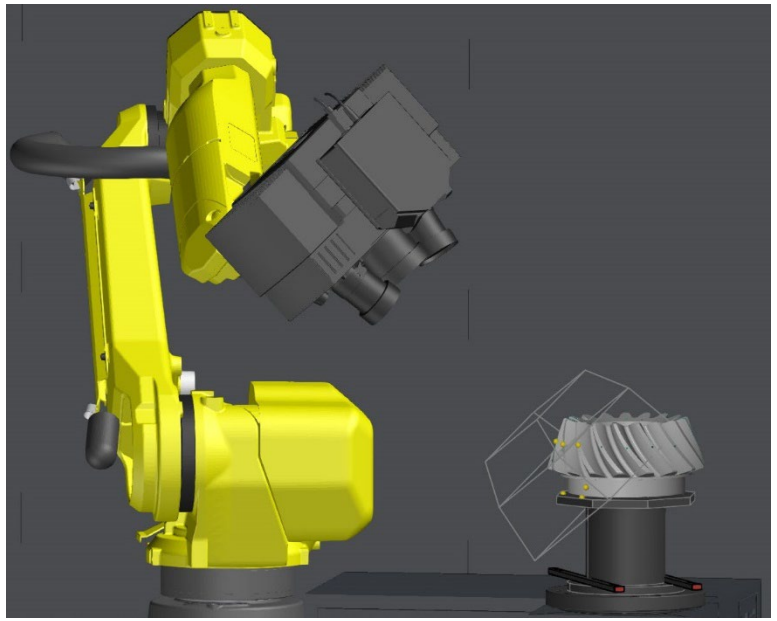


Robot teaching with GOM Software
Measuring program definition on Digital Twin.

GOM Software – Virtual Measuring Room (Digital Machine Twin)

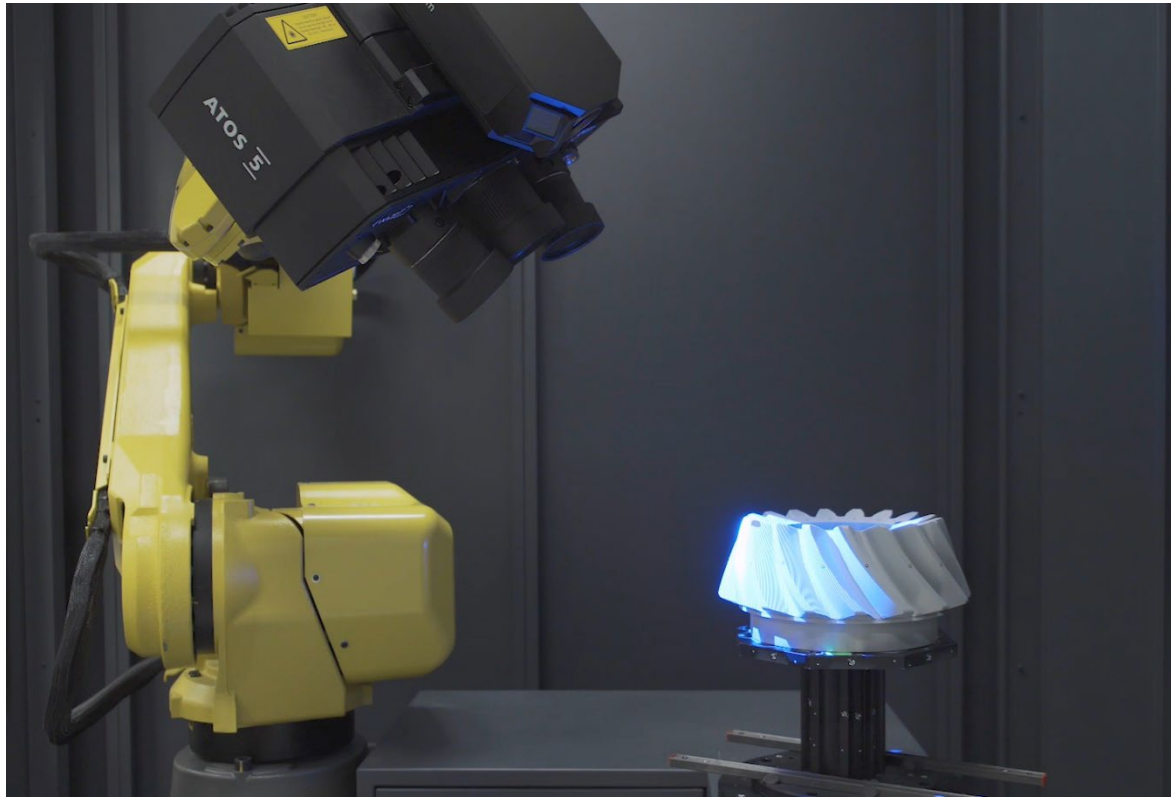
- Exact, high resolution CAD model is basis for fully automatic sensor positioning
- Normal vectors from CAD define the measuring strategy
- Possibility of virtual measuring run definition with CAD model (Offline programming)
- Automatic collision detection and correction in path planning
- Measuring run simulation

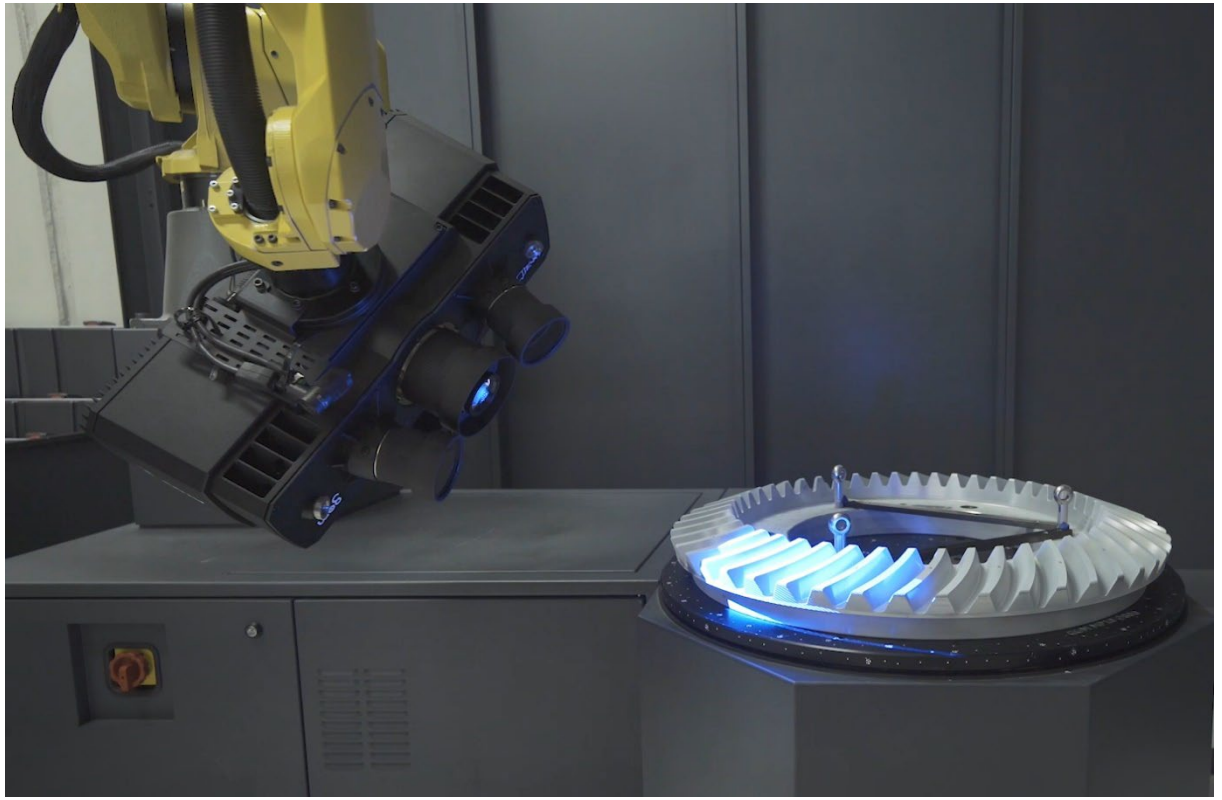




Metrology – optical with GOM ATOS 5 for Airfoil

Video.





Video

Metrology – optical with GOM ATOS 5 for Airfoil

Results – Evaluation with ZEISS GEAR PRO bevel.

- Conventional reporting

  as the tactile world

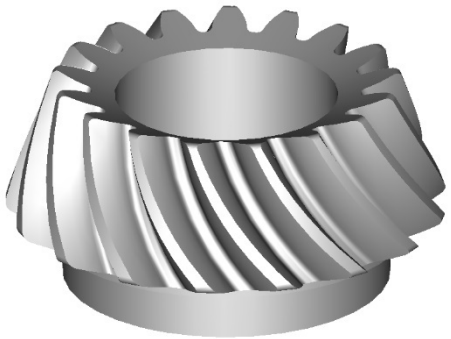
- Topography:

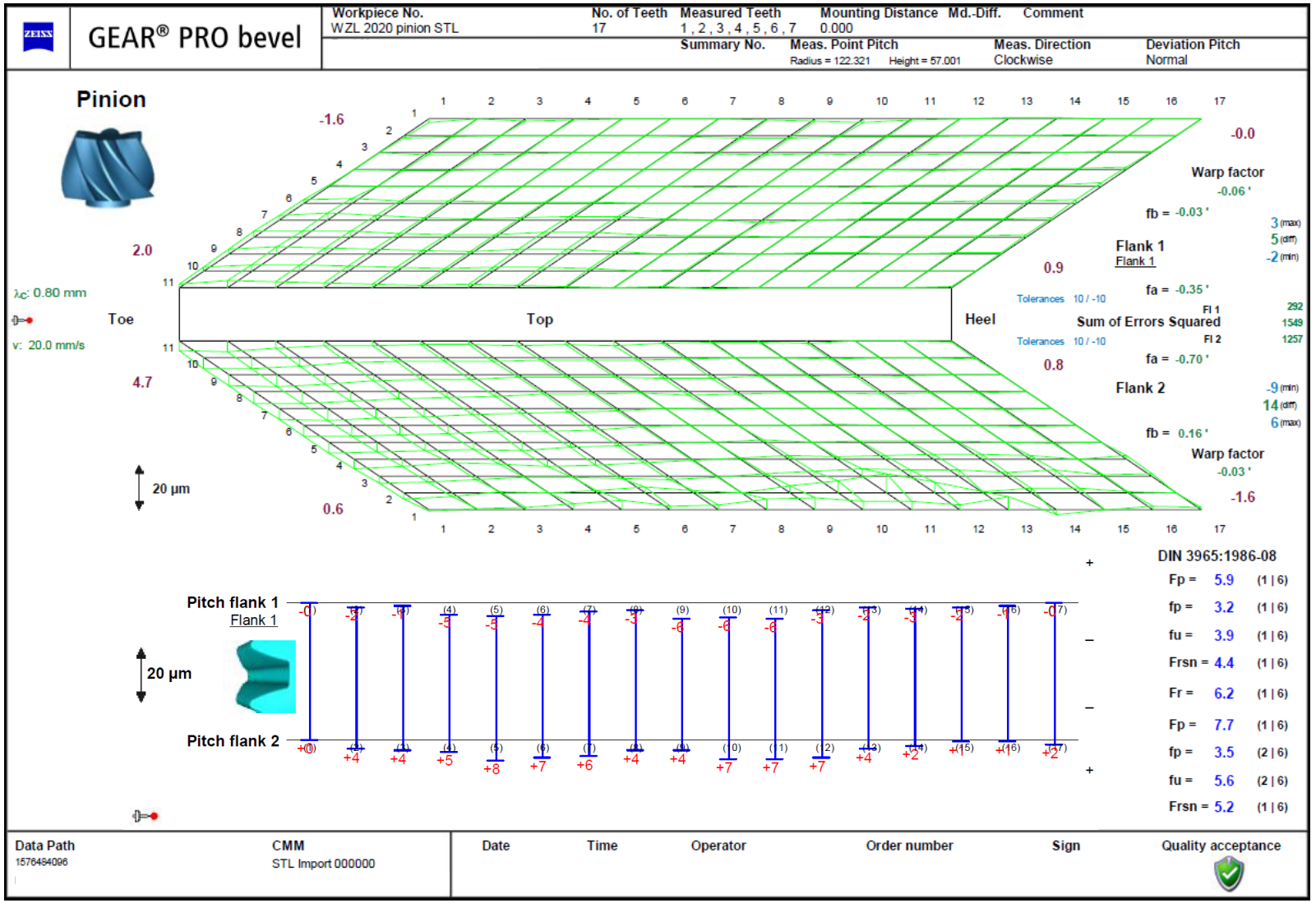
  ± 9 µm deviations from nominal

- Pitch and runout:

  actual values ≤ 8 µm

  actual tolerance grade 2

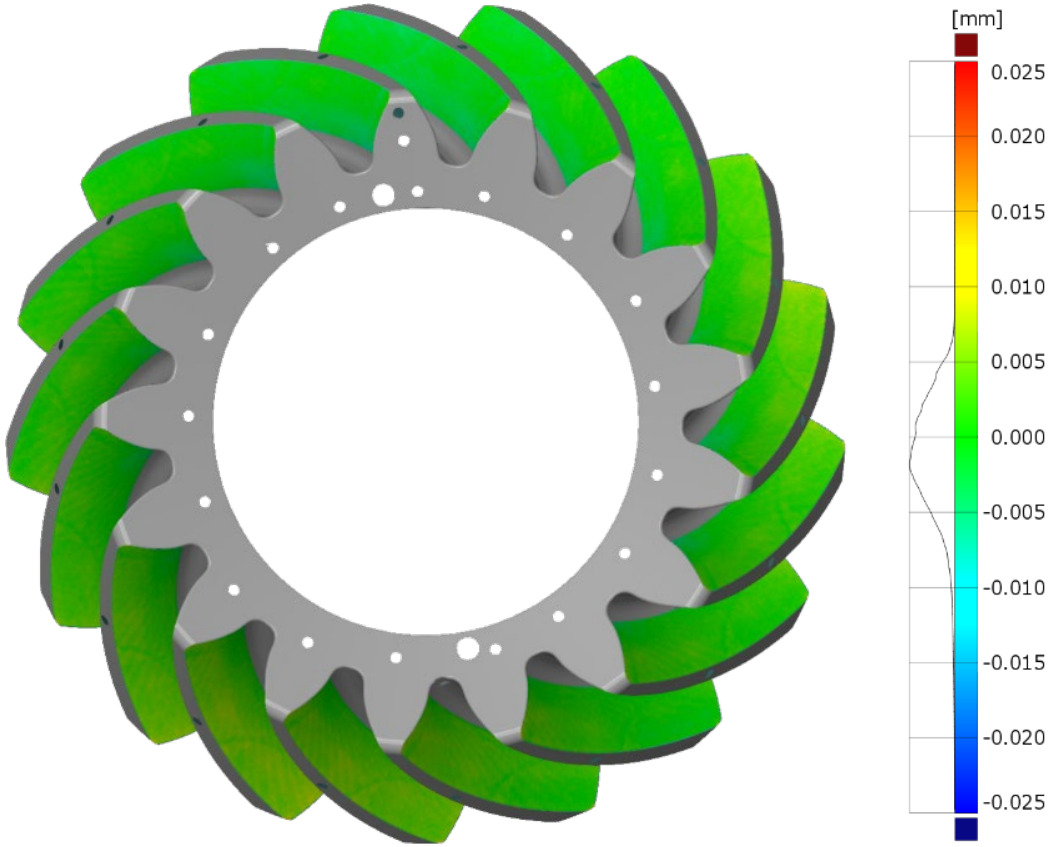


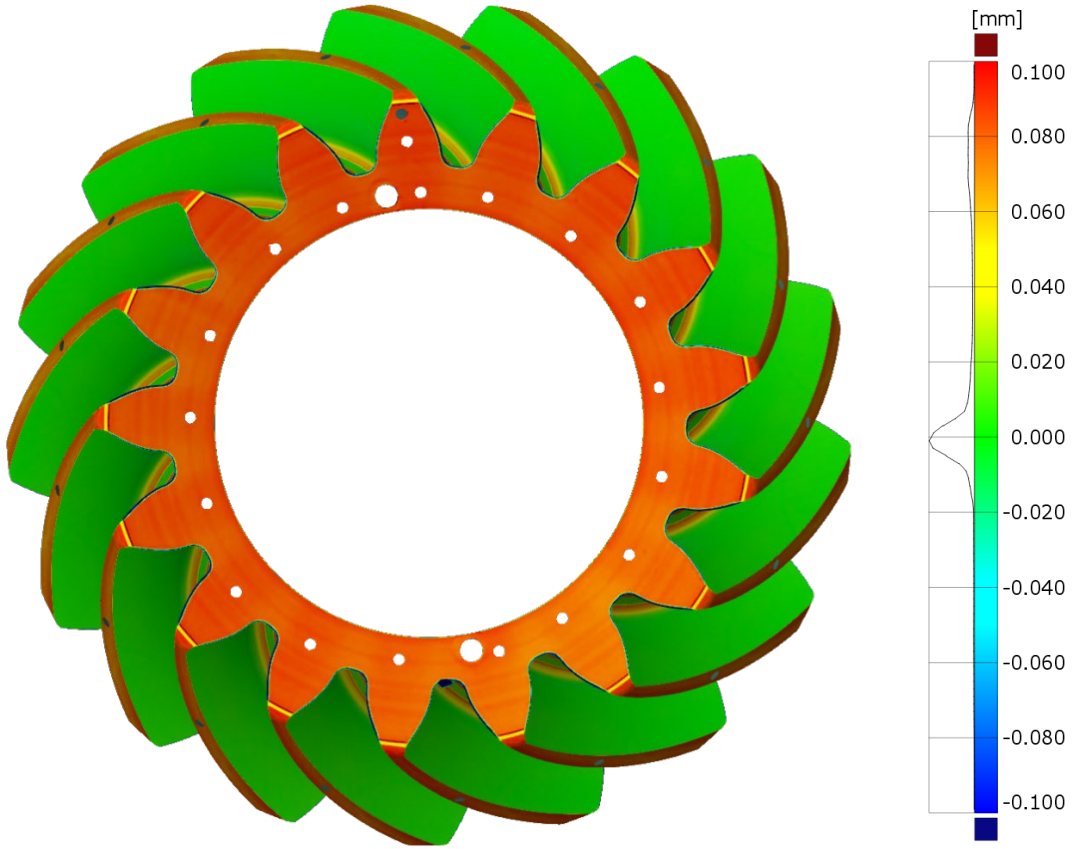


Metrology – optical with GOM ATOS 5 for Airfoil

Results – added value with GOM Software evaluation.

- Evaluation of the complete flanks with histogram visualization
- Fast and holistic overview of the complete workpiece

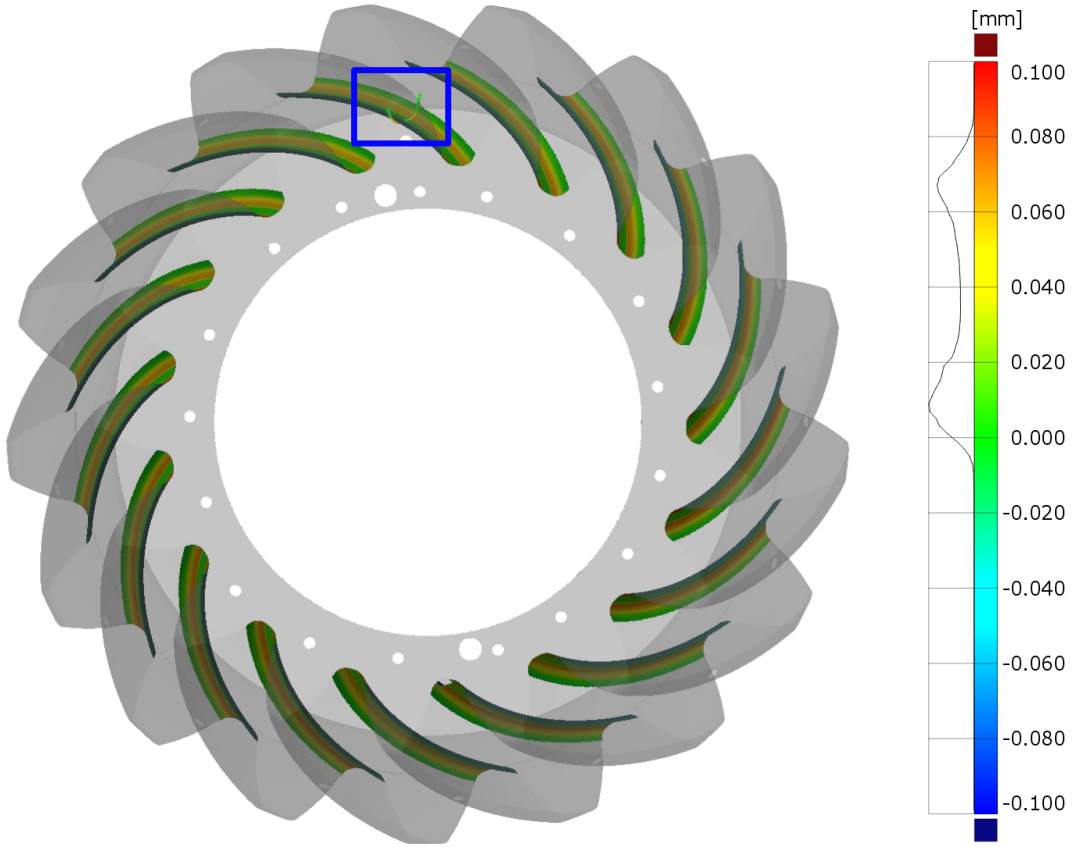


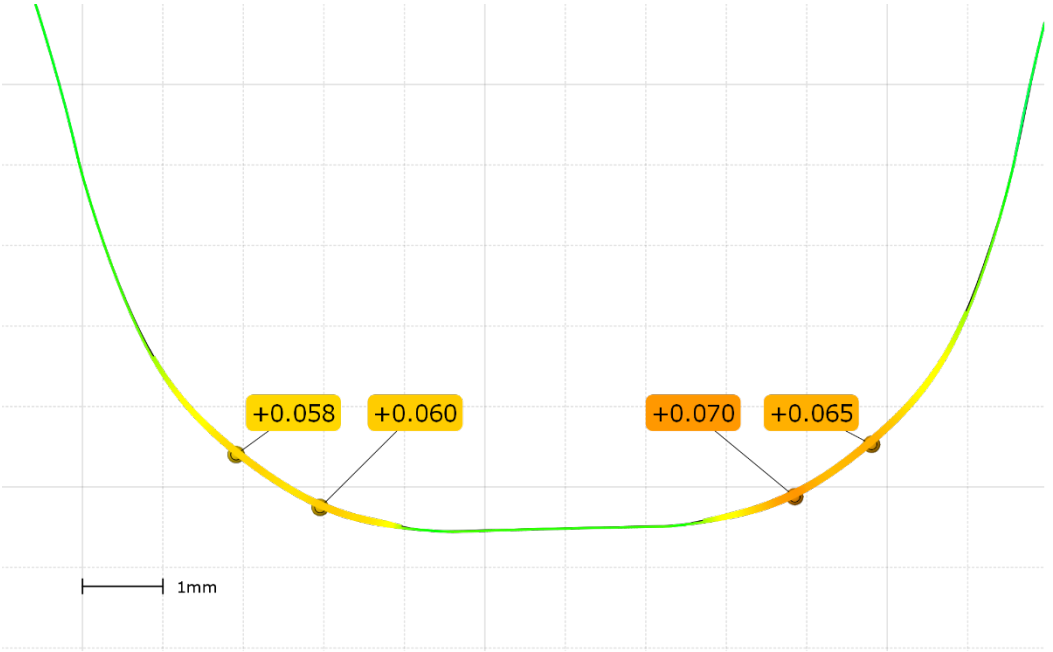


Metrology – optical with GOM ATOS 5 for Airfoil

Results – added value with GOM Software evaluation.

- Not visible with conventional evaluation – root radius curve

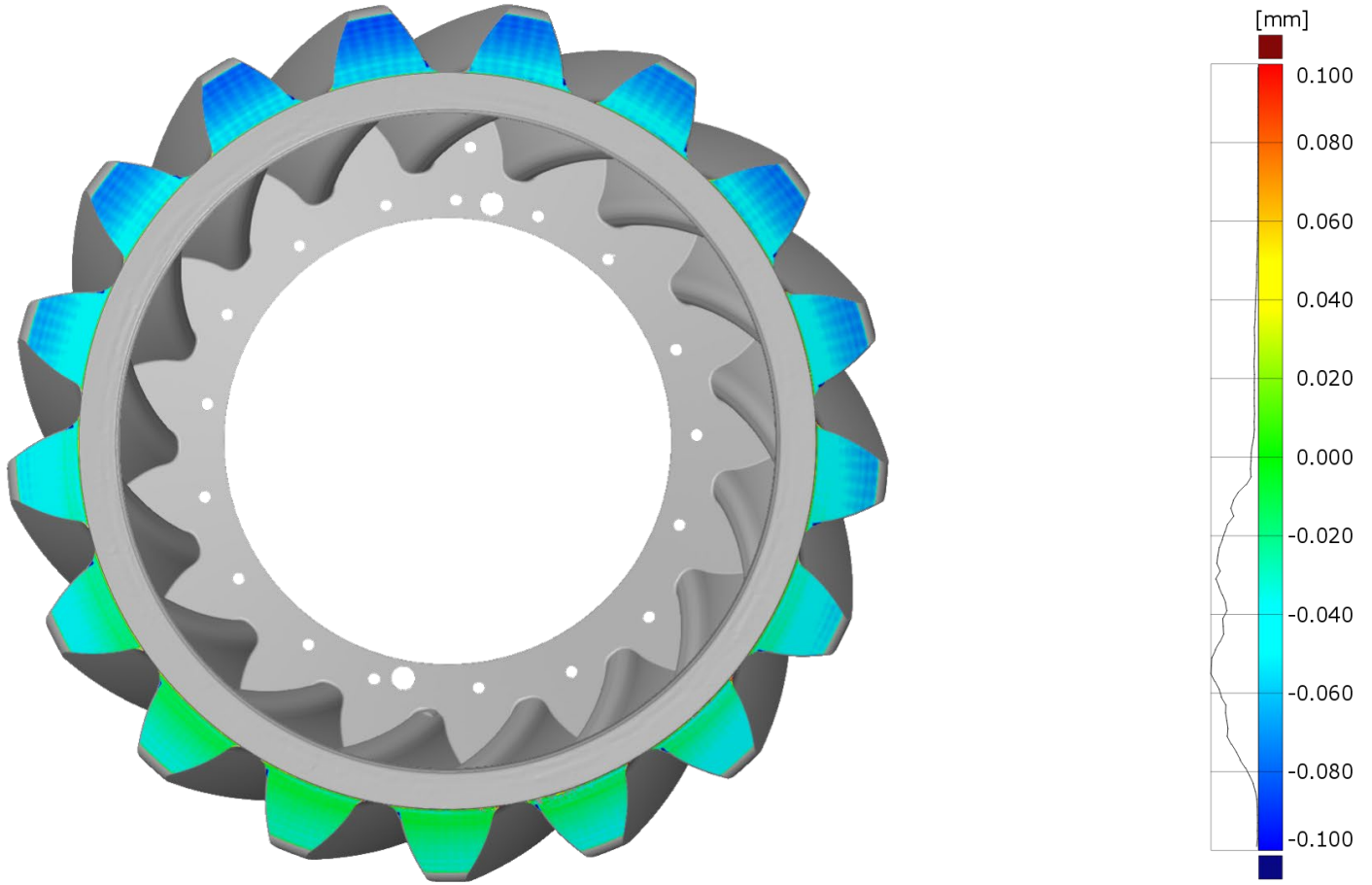




Metrology – optical with GOM ATOS 5 for Airfoil

Results – added value with GOM Software evaluation.

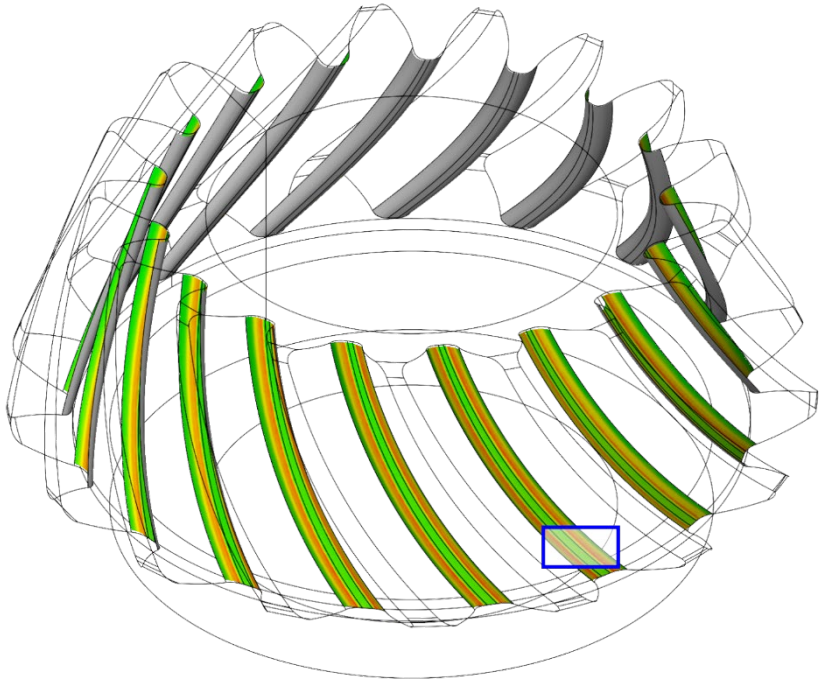
- Not visible with conventional evaluation – lower side of gear / back cone deviations from nominal

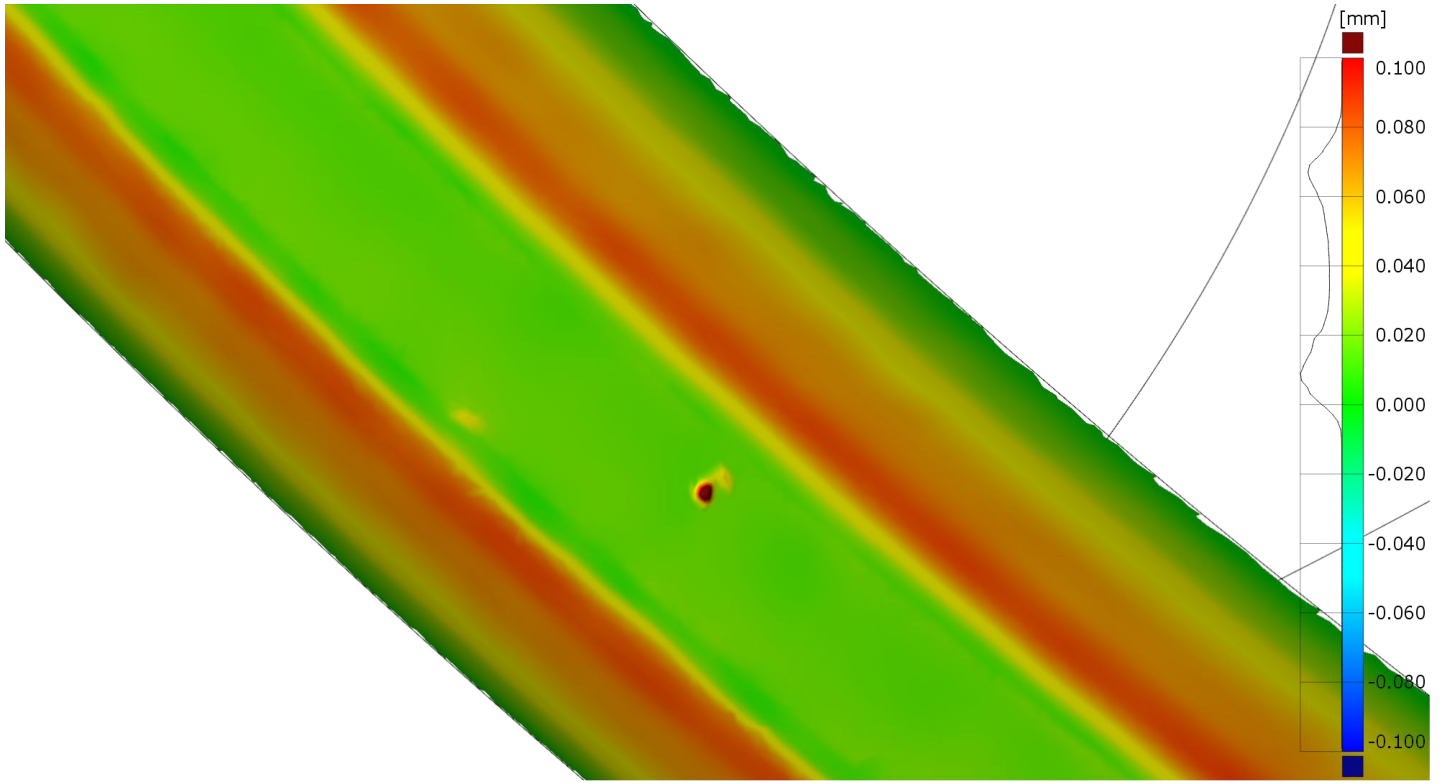


Metrology – optical with GOM ATOS 5 for Airfoil

Results – added value with GOM Software evaluation.

- Not visible with conventional evaluation – chip in the root cone





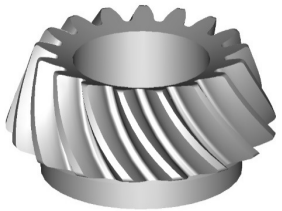
Digital Twin in the First-Part-Right production chain

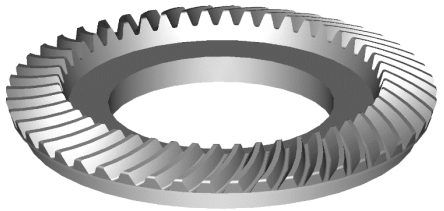
Comparison of metrology.

5

Digital Twin in the First-Part-Right production chain

Metrology – comparison – time.



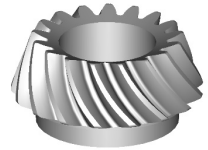


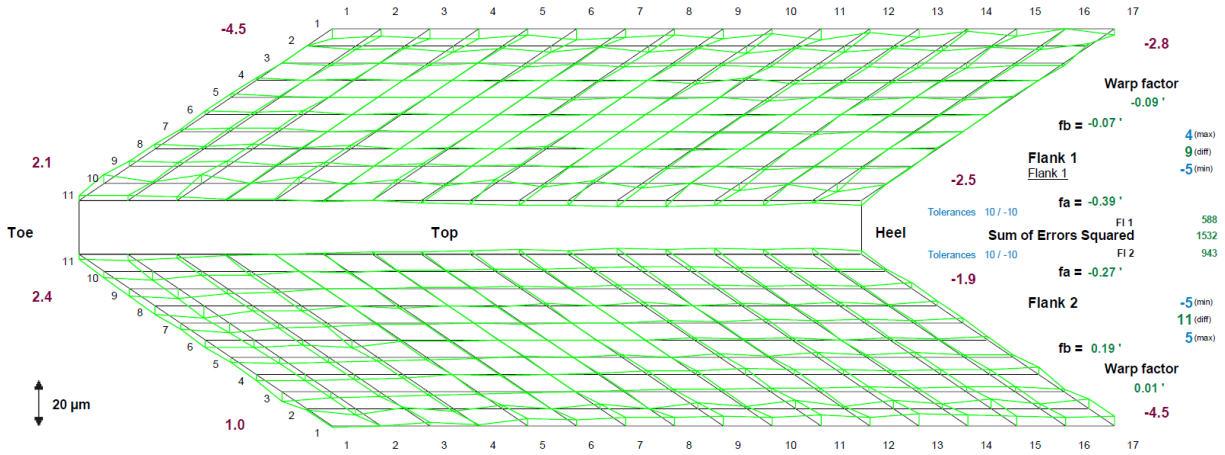
System	ZEISS PRISMO fortis 	GOM ATOS 5 for Airfoil 	ZEISS PRISMO fortis 	GOM ATOS 5 for Airfoil 
Dataset size STL	-	350 MB	-	1,000 MB
Measuring points	≈ 7,000	≈ 3,500,000	≈ 18,000	≈ 10,000,000
Preparation time [t]	10 Min	30 Min	10 Min	40 Min
Dataset creation time [t]	-	17 Min	-	35 Min
Polygonization time [t]	-	14 Min	-	35 Min
Measuring time [t]	40 Min	9 Min*	90 Min	30 Min*
Total time [t]	50 Min	61 Min (70 Min*)	100 Min	110 Min (140 Min*)

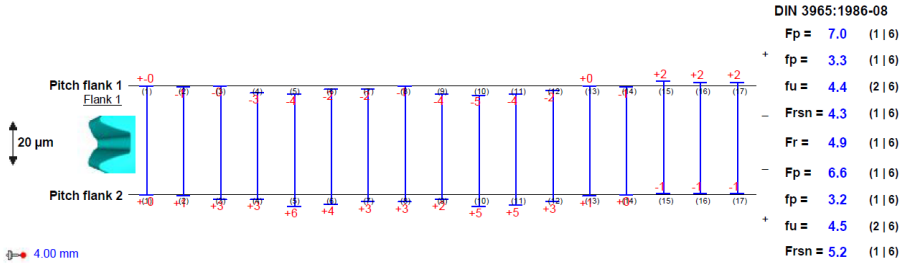
*time for conventional gear evaluation with ZEISS GEAR PRO bevel

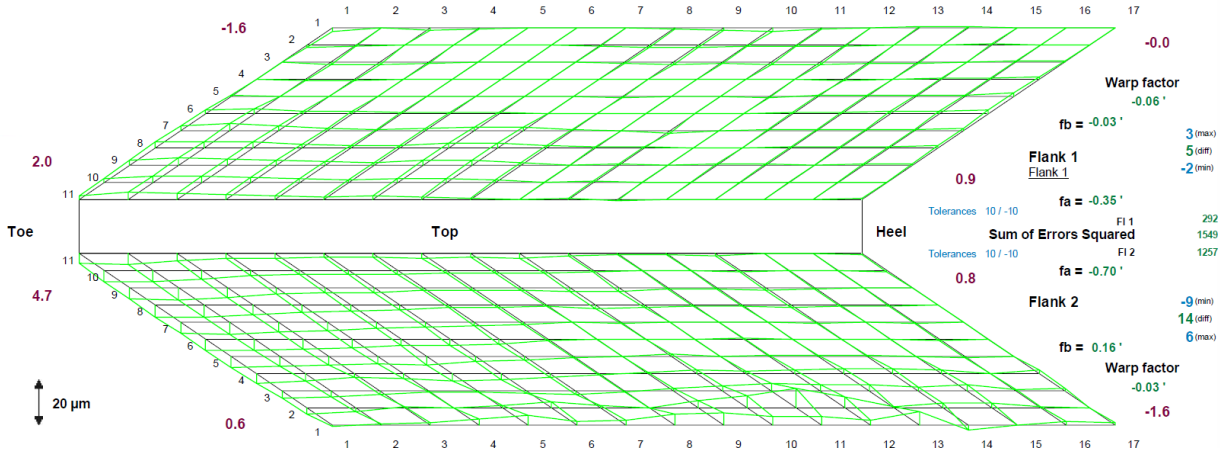
Digital Twin in the First-Part-Right production chain

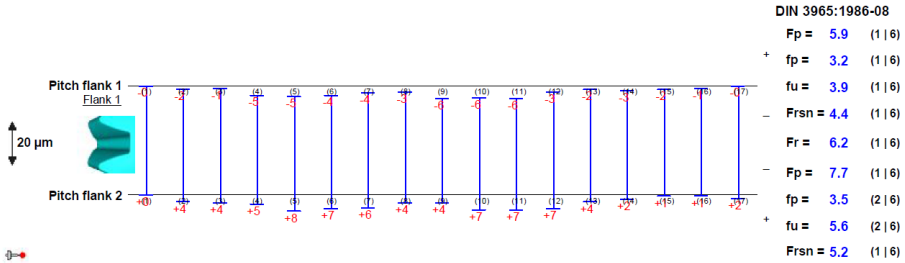
Metrology – comparison – results pinion.







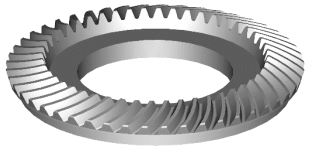


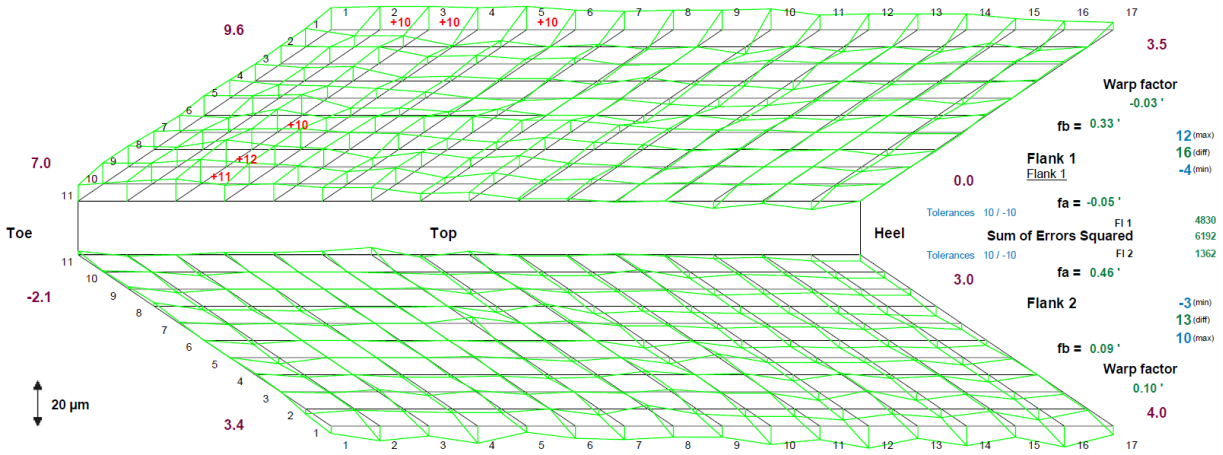


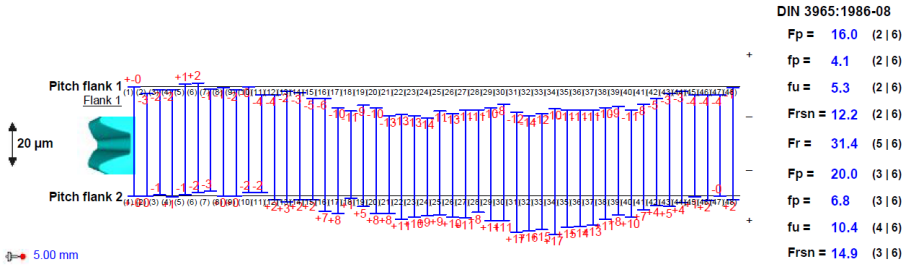
Difference optical / tactile // topography ≤ 5 µm // pitch ≤ 1,5 µm // runout ≤ 1,5 µm

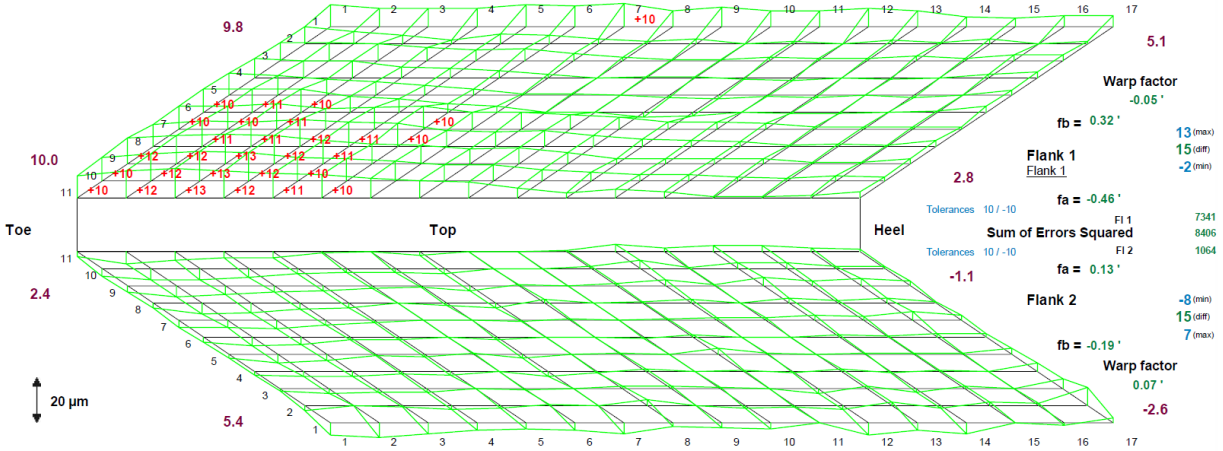
Digital Twin in the First-Part-Right production chain

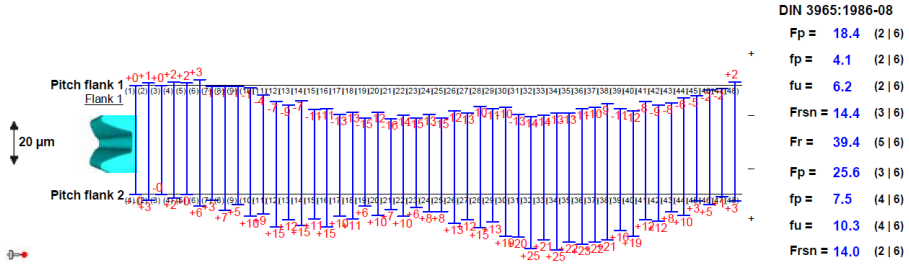
Metrology – comparison – results ring gear.









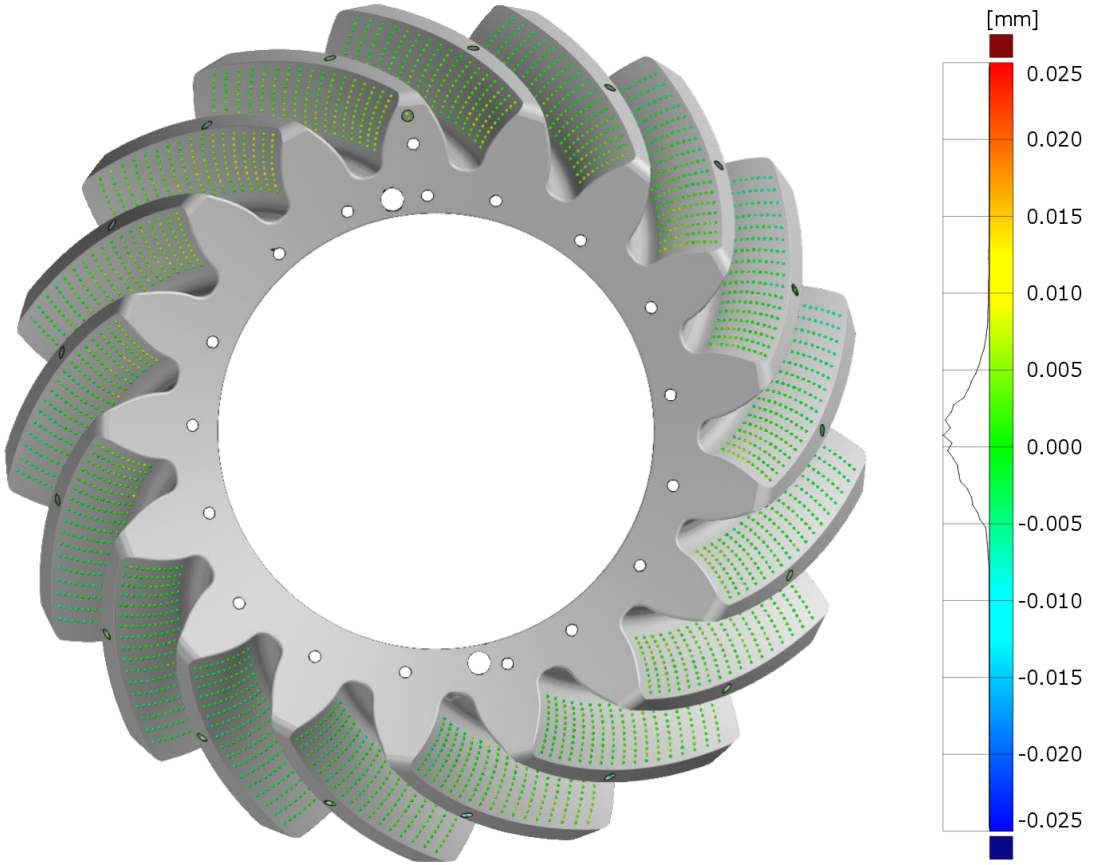


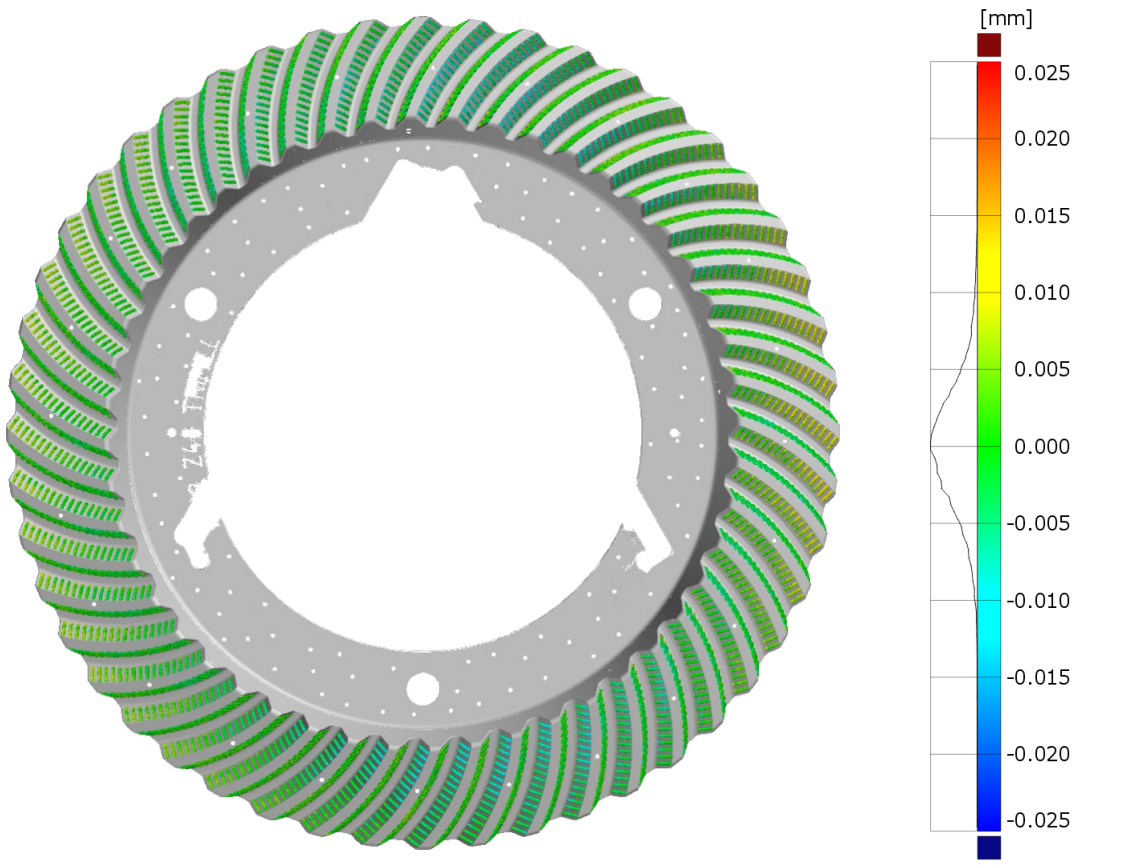
Difference optical / tactile // topography ≤ 5 µm // pitch ≤ 6 µm // runout ≤ 8 µm

Digital Twin in the First-Part-Right production chain

Metrology – comparison optical / tactile with GOM Software.

- Actual - actual comparison of optical and tactile measurement with GOM Software





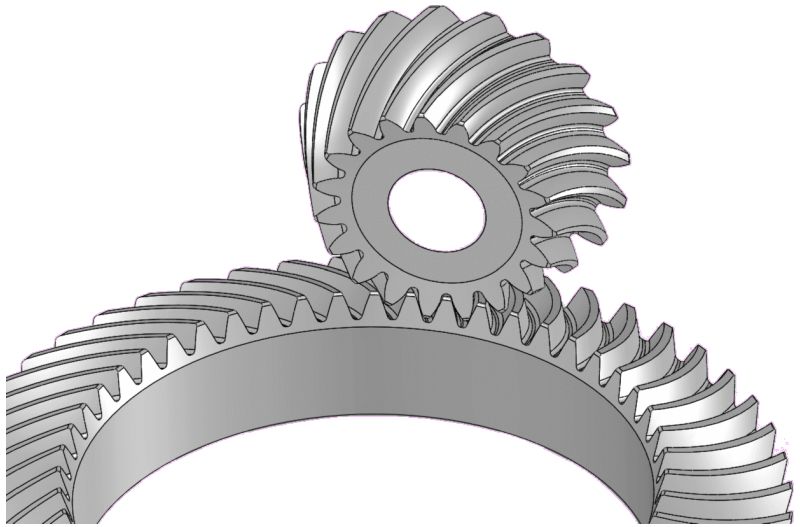
Digital Twin in the First-Part-Right production chain

Summary & outlook.

6

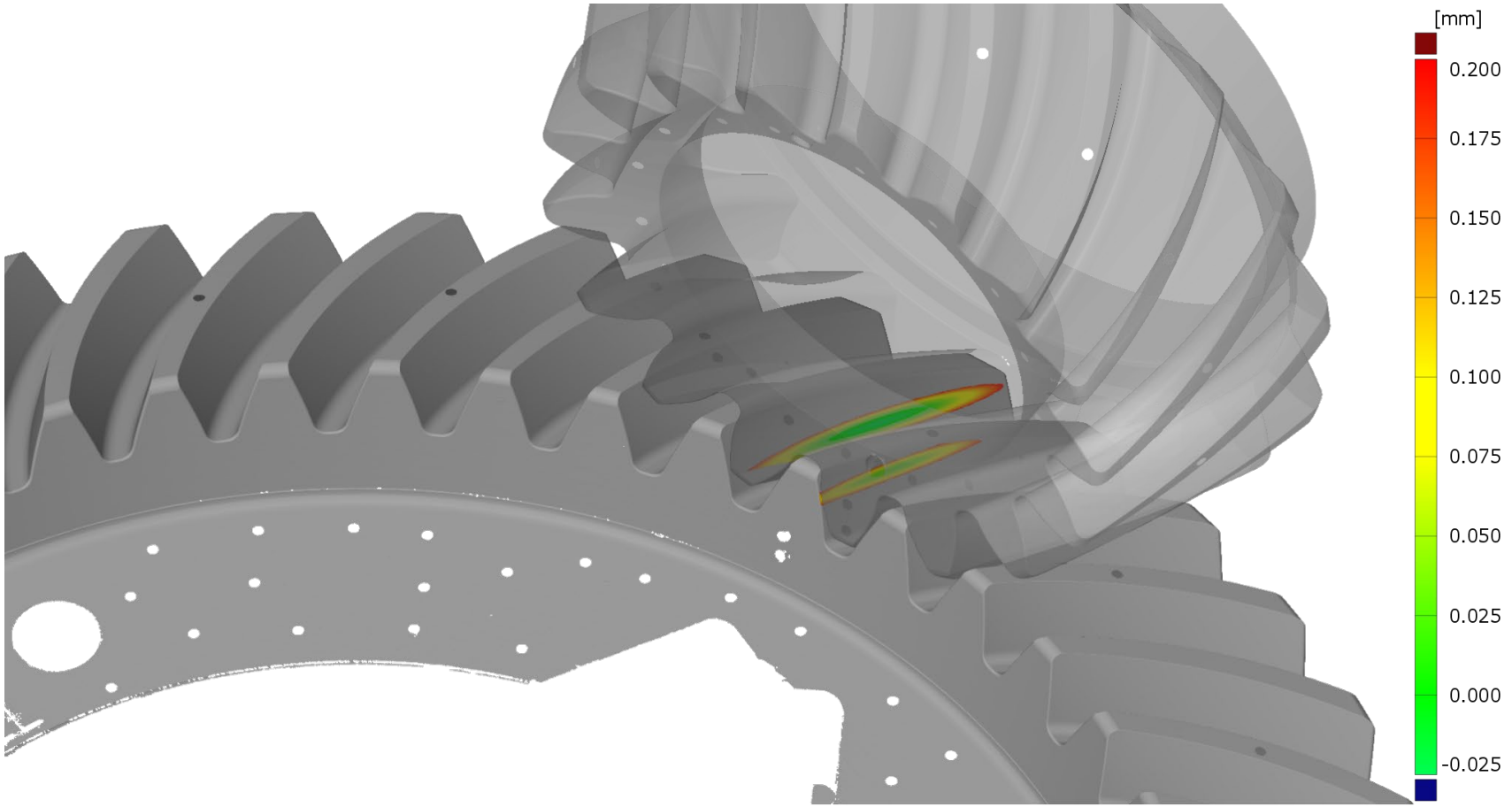
Digital Twin in the First-Part-Right production chain
Summary & outlook.

- Exact CAD models are state of the art, also at bevel gear design process
- Continuous data use is possible by means of Digital Gear Twin
- Digital twin enables the manufacturing of the first part as well as further quantities or spare parts
- The first part can be reproduced at any time
- Different production chain steps use the same data base
  (manufacturing, metrology, quality assurance)
- Comparability between optical and tactile metrology on application example
  in the range of less than ± 5 - 10 µm
- Optical metrology offers new insights in evaluation possibilities,
  e.g. holistic evaluation of the complete workpiece



Digital Twin in the First-Part-Right production chain
Outlook.

Experimental tooth contact analysis on real holistic surface measuring data ?



Thank you for your attention!

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Seeing beyond