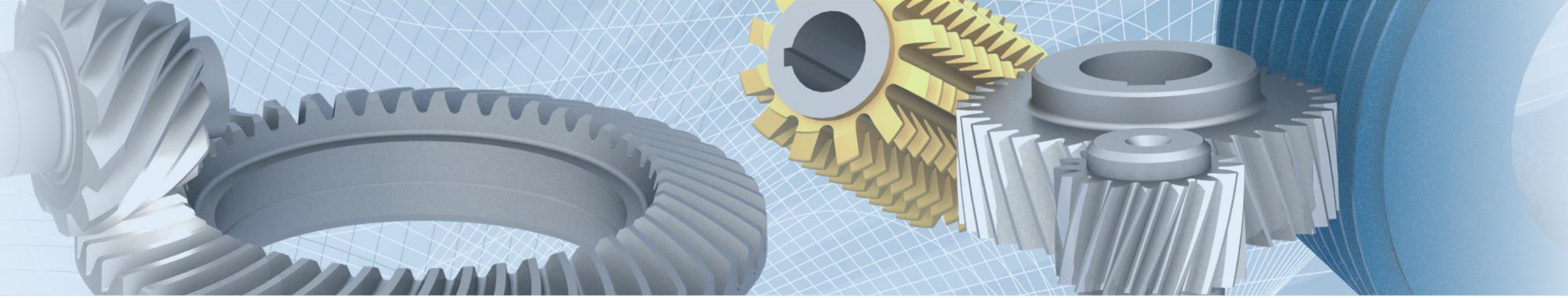

Gears with top in-service performance developed for hybrid and electric vehicles – TOPGEAR

Workshop in Aachen 08. April, 2025

Laboratory for Machine Tools and Production Engineering (WZL)
RWTH Aachen University
Chair of Machine Tools

Funding:

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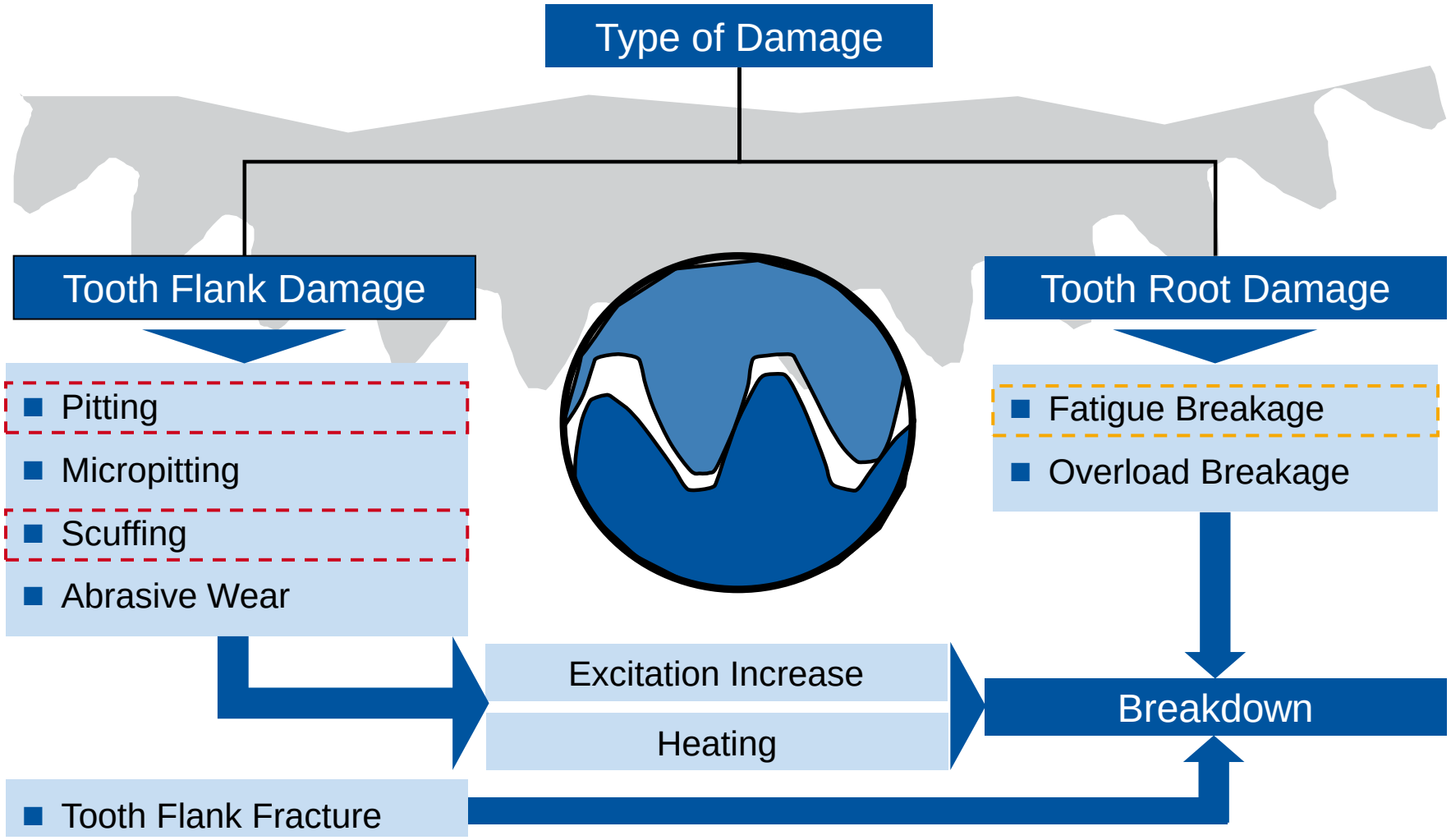
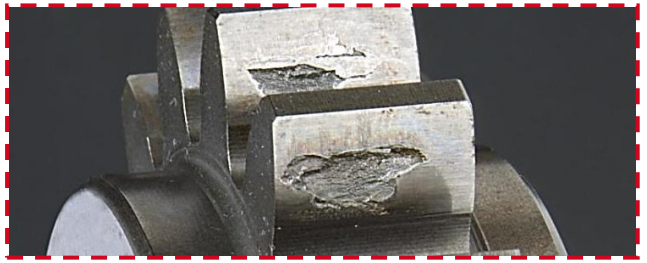
Agenda

Gear Damage Types & Design Limitations
Overview of the Different Gear Damage Types



Tooth Root Fatigue Breakage

Pitting



Scuffing

Gear Damage Types & Design Limitations
Test Rig and Current Test Gear Geometries

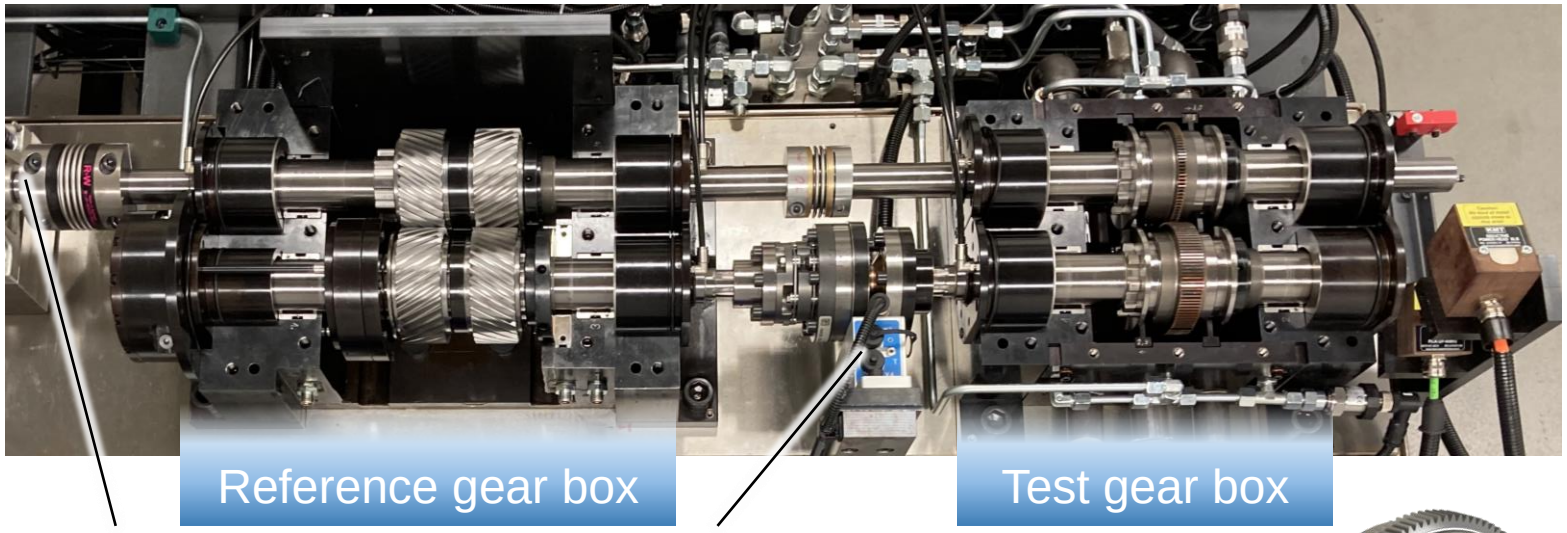
Test gear geometry

- m_n = 1 mm
- z_1 / z_2 = 99 / 102
- b_1 / b_2 = 7 / 30 mm
- a = 99.5 mm
- β = 0°
- d_{a1} / d_{a2} = 101.5 / 103.5 mm
- Tooth root critical test gear

Reference gear geometry

- m_n = 2.5 mmm
- z_1 / z_2 = 33 / 34
- b_1 / b_2 = 40 / 40 mm
- a = 99.5 mm
- β = 30°
- d_{a1} / d_{a2} = 103.3 / 106.15 mm

High-speed back-to-back gear test rig



Predefined parameter:

Centre distance	a	= 99.5 mm
Tooth ratio	z_1 / z_2	= 99/102 or 33/34
Max. torque	$M_{in,max}$	= 200 Nm

Hub – Shaft connection by spline shaft

Axial displacement of test wheel due to torque application

Agenda

Gear Manufacturing

Gear Manufacturing Process Chain of both Material Variants

Variant 01: Reference Material – 27MnCr5

Raw material → Sawing & soft turning → Hobbing → Spline Shaft → Heat treatment → Surface & bore grinding → Gear grinding → Quality control & testing

Pitting Test Gear
for high speed tests

Scuffing Test Gear
for high speed tests

Variant 02: 40CrMoBi4

Raw material → Sawing & soft turning → Hobbing → Spline Shaft → Surface & bore grinding → Gear Grinding → Heat treatment → Quality control & testing

Maschinenübersicht für Fertigung am WZL

Soft machining

Liebherr LC 150

Hard machining

Viper 500W

Quality control

Klingelnberg P65

Agenda

Test Gear Design – Damage Type Pitting
Design of Macro Geometry

Test gear geometry

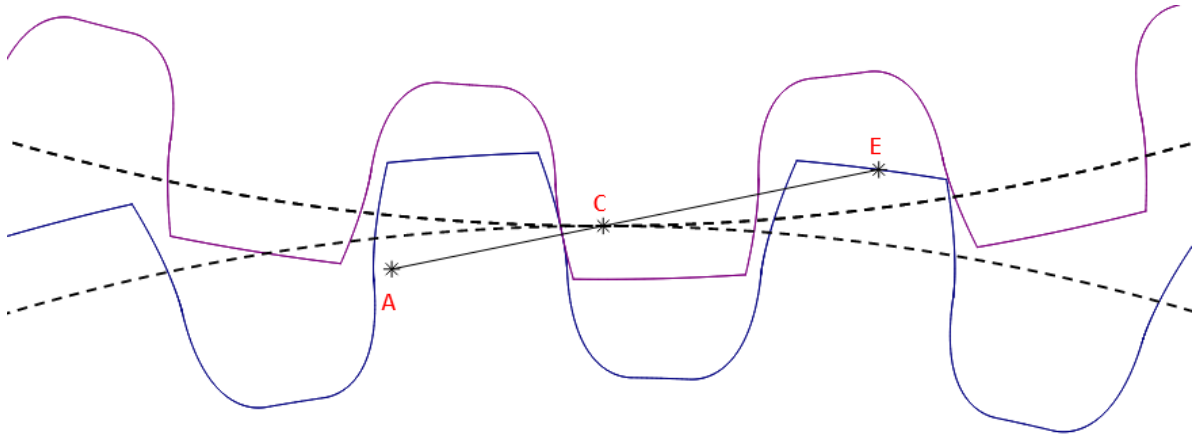
- m_n = 3.06 mm
- z_1 / z_2 = 33 / 34
- b_1 / b_2 = 7 / 30 mm
- a = 99.5 mm
- α_n = 18°
- β = 0°
- x_1* / x_2* = -0.55 / -0.45
- d_{a1} / d_{a2} = 101.5 / 103.5 mm
- FE-STIRNRADKETTE W4.3.7

Legend

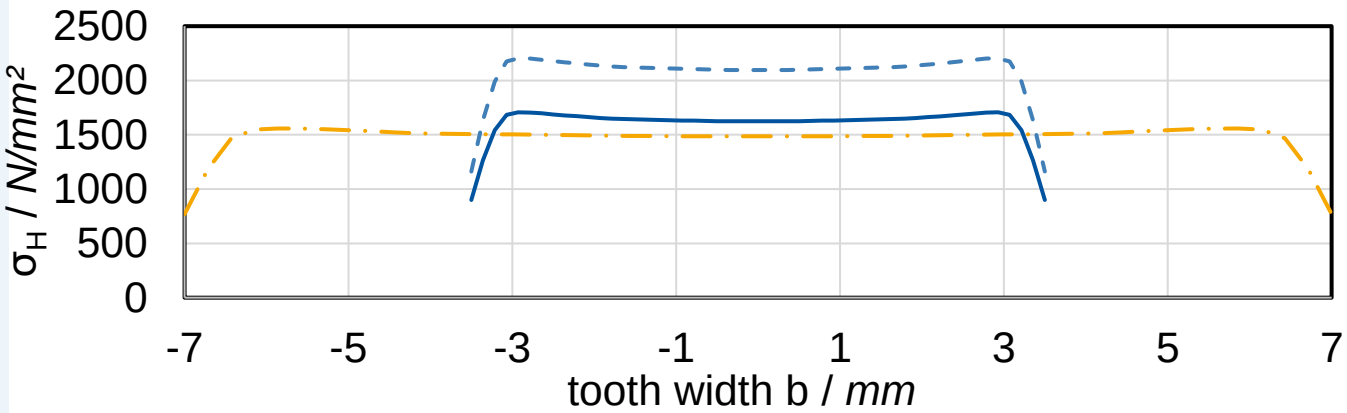
- Test gear M_{in} = 120 Nm
- Test gear M_{in} = 200 Nm
- Standard test gear (Typ-C)

Tooth mesh and contact stress

Cross section of tooth mesh



Contact stress at the rolling diam.



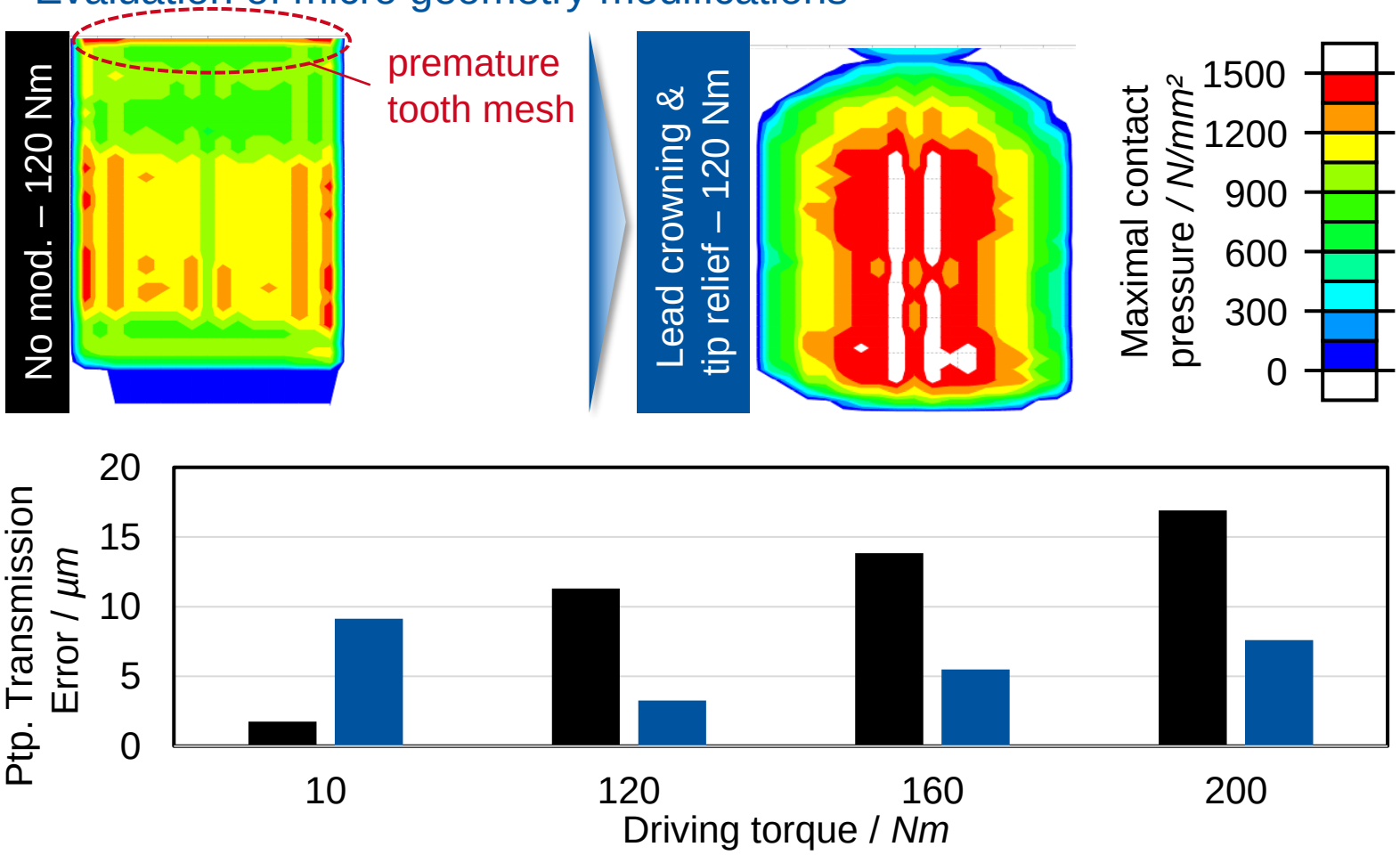
Test Gear Design – Damage Type Pitting
Design of Micro Geometry

Test gear geometry

- m_n = 3.06 mm
- z_1 / z_2 = 33 / 34
- b_1 / b_2 = 7 / 25 mm
- a = 99.5 mm
- α_n = 18°
- β = 0°
- x_1* / x_2* = -0.55 / -0.45
- d_{a1} / d_{a2} = 101.5 / 103.5 mm
- S_F > 2.27 (M_{in} = 200 Nm)
- ZAKO3D Version 2.10

Parameter	Pinion	Wheel
Lead Crow. C_β / *µm*	8	0.5
Tip relief C_a / *µm*	27	20
Start Dia. d_{Ca} / *mm*	99.1	101.3

Evaluation of micro geometry modifications

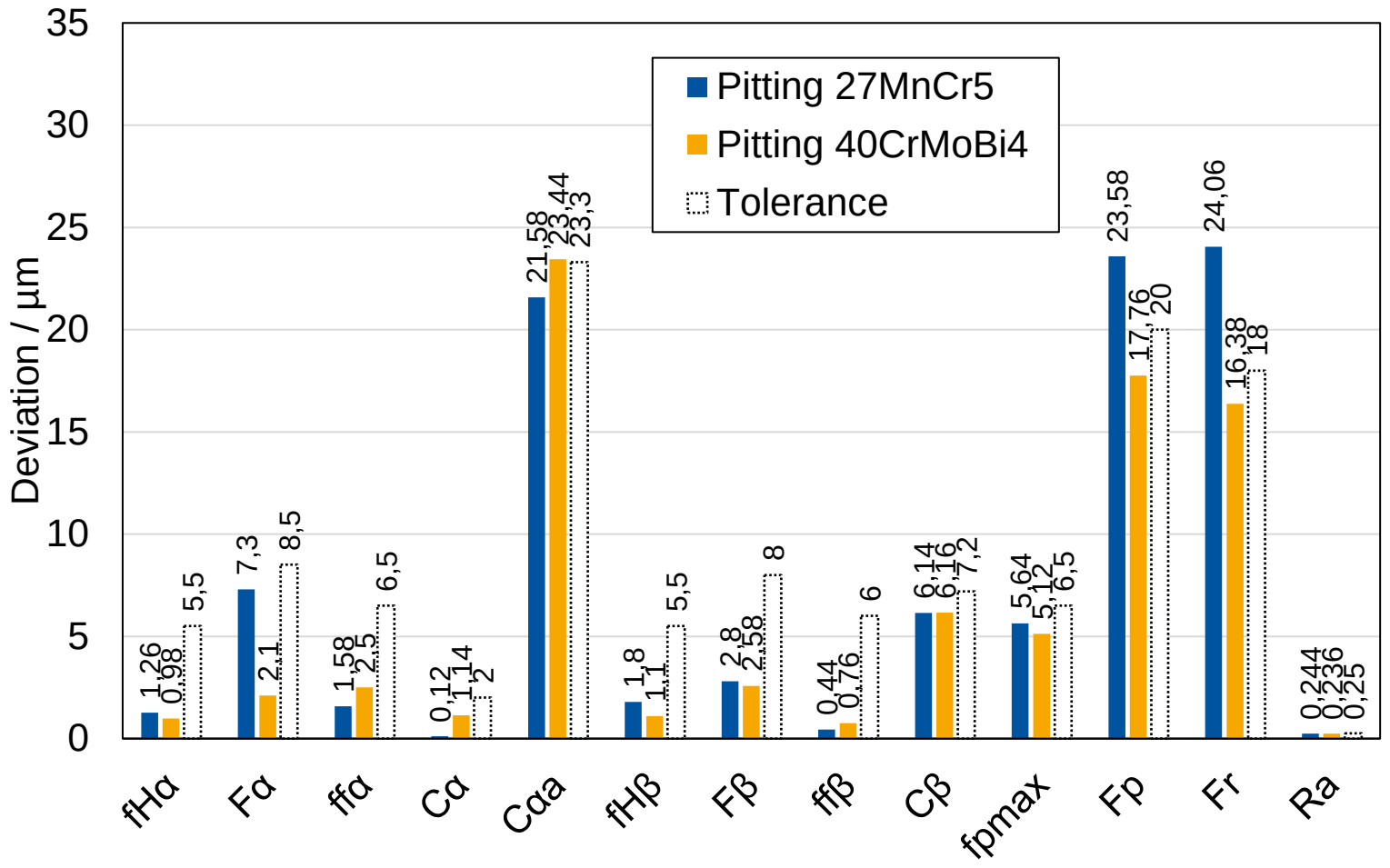


Gear Manufacturing and Quality

Test gear geometry

- m_n = 3.06 mm
- z_1 / z_2 = 33 / 34
- b_1 / b_2 = 7 / 25 mm
- a = 99.5 mm
- α_n = 18°
- β = 0°
- x_1^* / x_2^* = -0.55 / -0.45
- d_{a1} / d_{a2} = 101.5 / 103.5 mm
- S_F > 2.27 (M_{in} = 200 Nm)
- ZAKO3D Version 2.10

Parameter	Pinion	Wheel
Lead Crow. C_β / *µm*	8	0.5
Tip relief C_a / *µm*	27	20
Start Dia. d_{Ca} / *mm*	99.1	101.3



Agenda

Test Gear Design – Damage Type Scuffing
Design of Macro Geometry

Test gear geometry

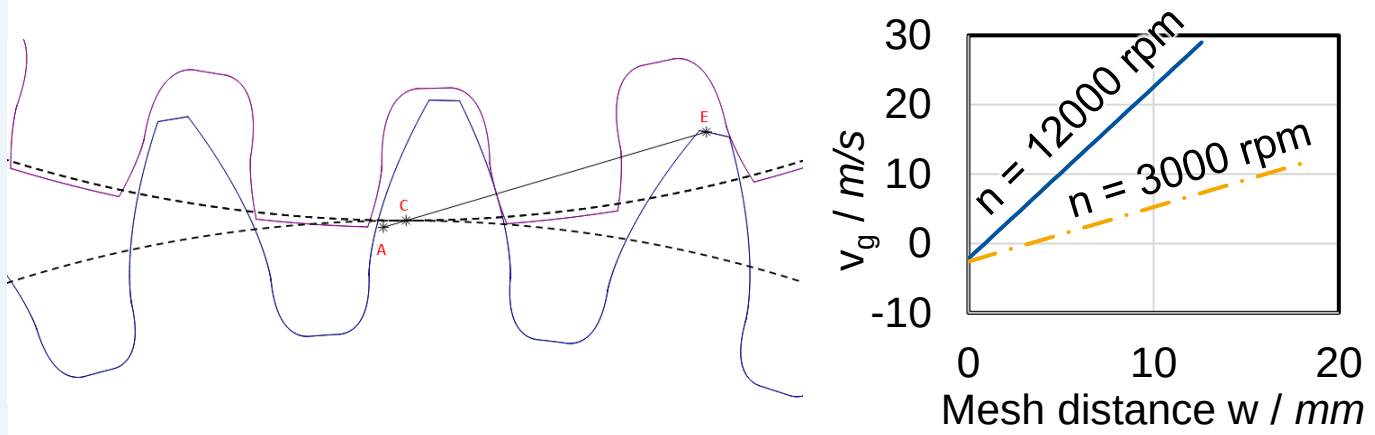
- m_n = 2.95 mm
- z_1 / z_2 = 33 / 34
- b_1 / b_2 = 7.5 / 25.6 mm
- a = 99.5 mm
- α_n = 15°
- β = 0°
- x_1^* / x_2^* = 0.15 / -0.1
- d_{a1} / d_{a2} = 106.2 / 101.5 mm
- FE-STIRNRADKETTE W4.3.7

Legend

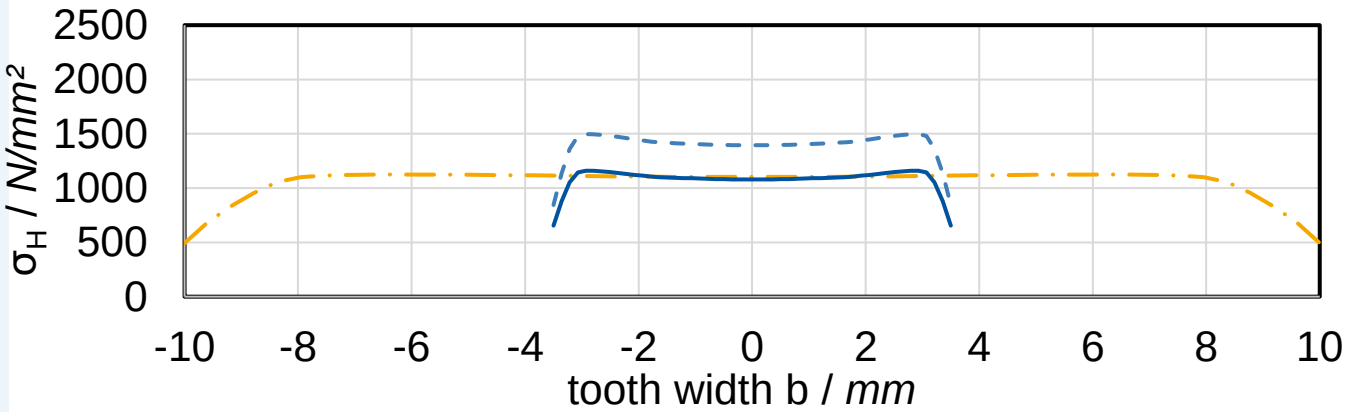
- Test gear M_{in} = 120 Nm
- Test gear M_{in} = 200 Nm
- Stand. test gear (Typ-A)

Tooth mesh and contact stress

Cross section & sliding speed



Contact stress at the rolling diam.



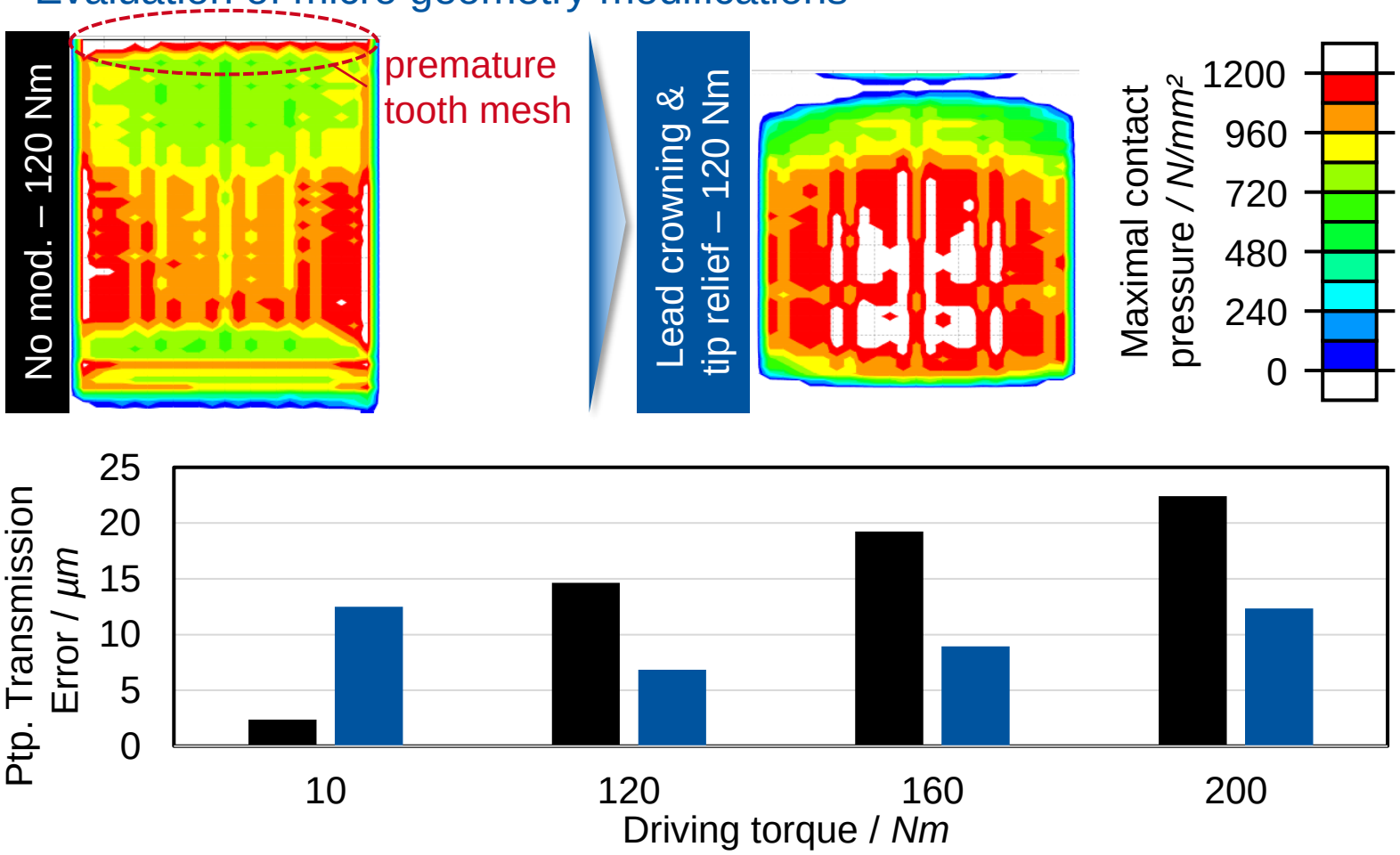
Test Gear Design – Damage Type Scuffing
Design of Micro Geometry

Test gear geometry

- m_n = 2.95 mm
- z_1 / z_2 = 33 / 34
- b_1 / b_2 = 7.5 / 25.6 mm
- a = 99.5 mm
- α_n = 15°
- β = 0°
- x_1* / x_2* = 0.15 / -0.1
- d_{a1} / d_{a2} = 106.2 / 101.5 mm
- S_F > 1.82 (M_{in} = 200 Nm)
- ZAKO3D Version 2.10

Parameter	Pinion	Wheel
Lead Crow. C_β / *µm*	4	0.5
Tip relief C_a / *µm*	35	30
Start Dia. d_{Ca} / *mm*	101.79	98.72

Evaluation of micro geometry modifications



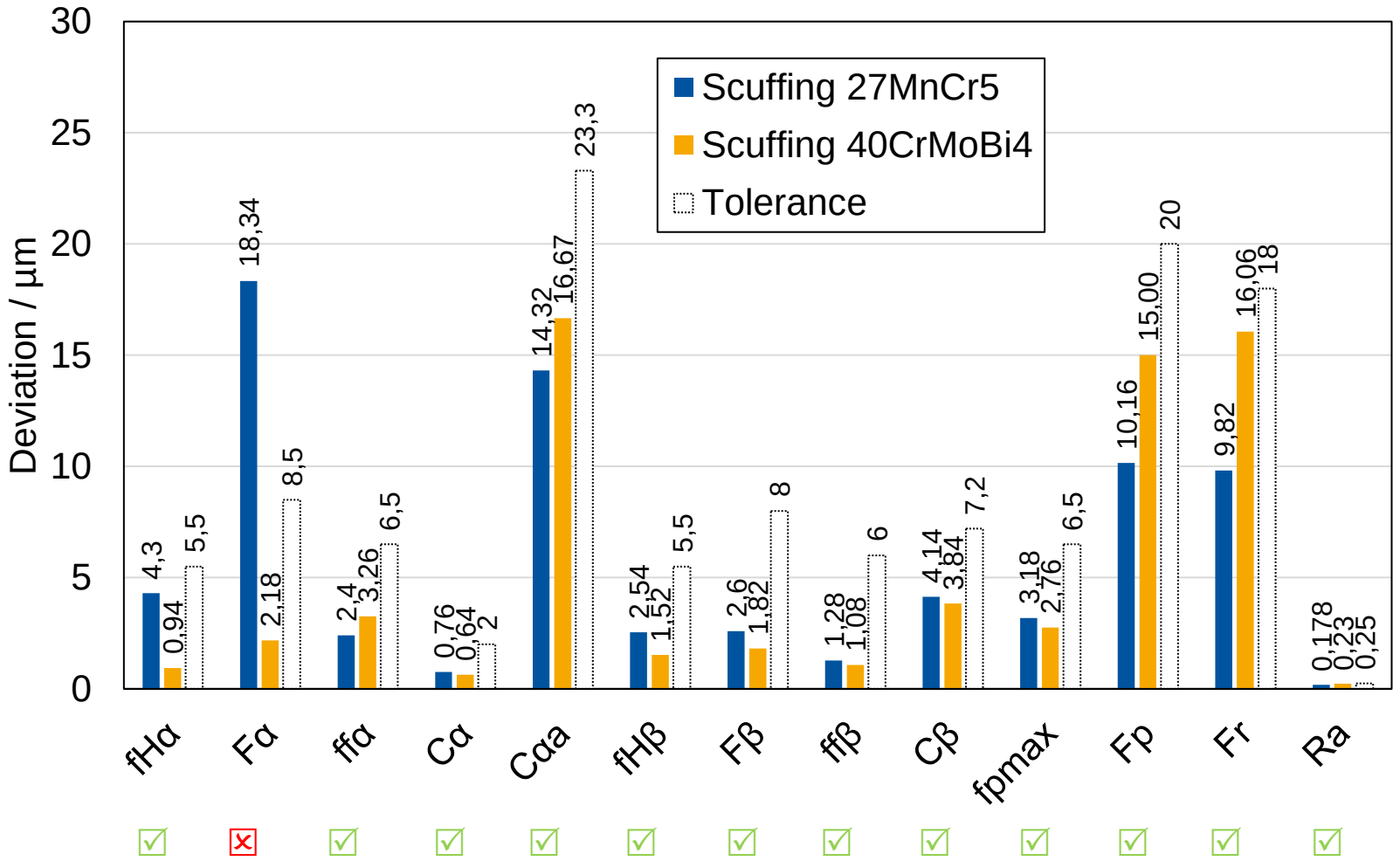
Test Gear Design – Damage Type Scuffing
Manufacturing Quality

Test gear geometry

- m_n = 2.95 mm
- z_1 / z_2 = 33 / 34
- b_1 / b_2 = 7.5 / 25.6 mm
- a = 99.5 mm
- α_n = 15°
- β = 0°
- x_1^* / x_2^* = 0.15 / -0.1
- d_{a1} / d_{a2} = 106.2 / 101.5 mm
- FE-STIRNRADKETTE W4.3.7

Legend

- Test gear M_{in} = 120 Nm
- Test gear M_{in} = 200 Nm
- Stand. test gear (Typ-A)



Agenda

1	Highspeed Test Rig Overview
2	Gear Design and Manufacturing
	Gear Geometry for Highspeed Pitting Tests
	Gear Geometry for Highspeed Scuffing Tests
3	Conclusions

Summary and Outlook

Test gear – Pitting

- Design of test gear geometry regarding pitting strength
- Limitation of design due to existing test rig (maximum torque, centre distance, tooth ratio, etc.)
- Comparison of contact stress to standardized pitting test gear set (Type – C)
- Final test gear geometry is critical regarding pitting at M_{In} = 120 Nm and has sufficient tooth root safety factor (S_F = 2.27 @ M_{max} = 200 Nm)
- Tip relief prevents premature tooth mesh and unwanted damage patters
- Lead crowning ensures centred contact pattern and increases overall contact stress level
- Soft machining of gear blanks ongoing

Test gear – Scuffing

- Design of test gear geometry regarding scuffing strength
- Limitations as for pitting design
- Comparison of contact stress and sliding velocity to standardized scuffing test gear (Type – A)
- Final test gear geometry with high contact stress than standardized test gears and higher sliding velocities → both more critical
- Sufficient tooth root safety factor (S_F = 1.82 @ M_{in} = 200 Nm)
- Tip relief prevents premature tooth mesh and unwanted damage patters
- Lead crowning ensures centred contact pattern and increases overall contact stress level
- Soft machining of gear blanks ongoing