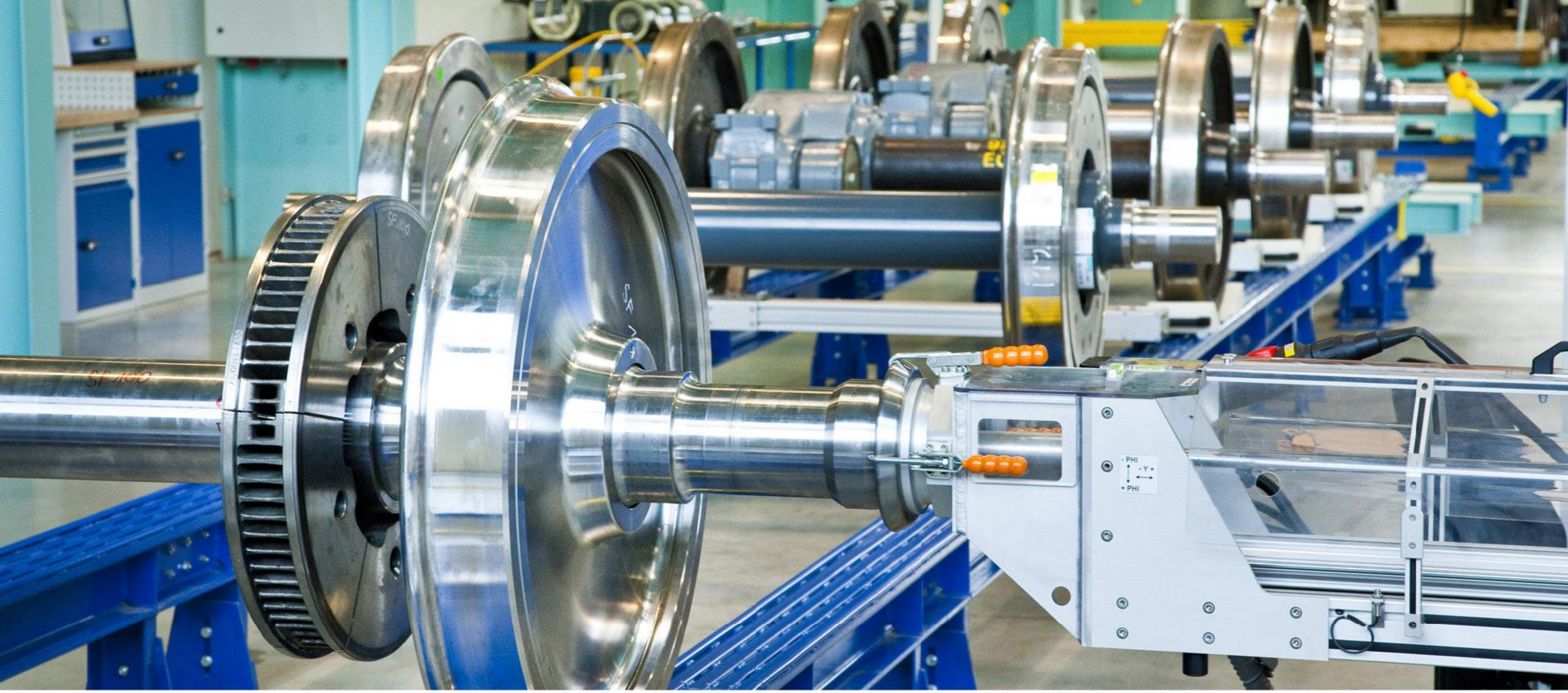

Crack growth in 1:3 scale specimens - experiments and modelling

ESIS Workshop TC24 "Integrity of Railway Structures", Leoben, 2016

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EBFW-3
EisenBahnFahrWerke

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Table of content

- Introduction
- Test rig for *1:3* scale specimens

→ Functionality and calibration of the test rig
→ Geometry of cylindrical *1:3* scale specimens
→ Optical crack length measurement technique

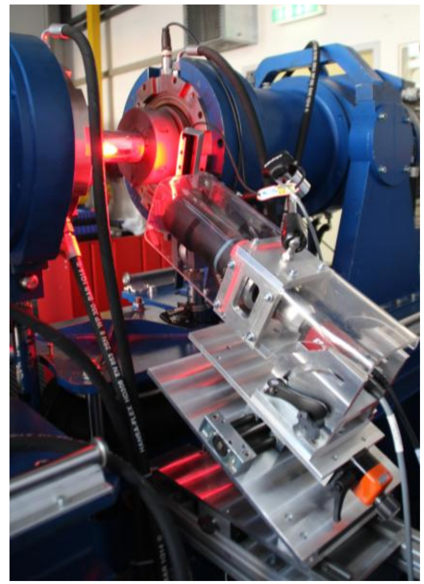
- Investigations on MUL/MCL/ESI

→ Experimental crack propagation analysis
→ Fracture surface analysis
→ Analytical assessment with INARA
→ Numerical analysis of stress intensity and crack propagation

- Conclusions and Outlook

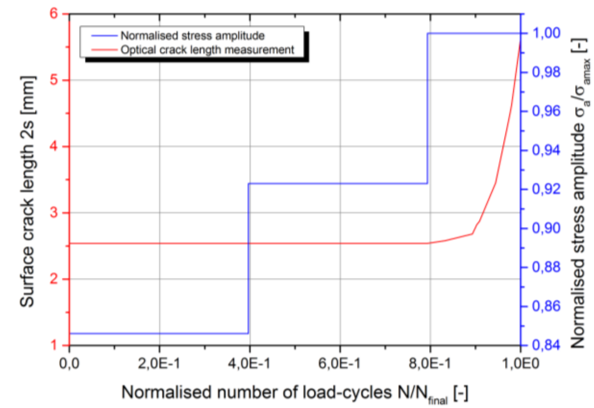
4-point-rotating bending test rig

Optical crack length measurement

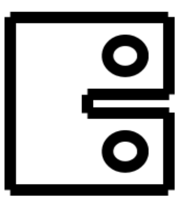


Experimental crack propagation evaluation

→ Comparison to calculations
→ Influence of size/shape

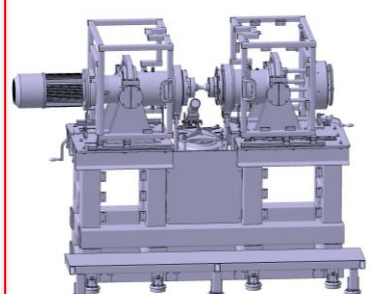


Material characterisation (Small scale specimens)



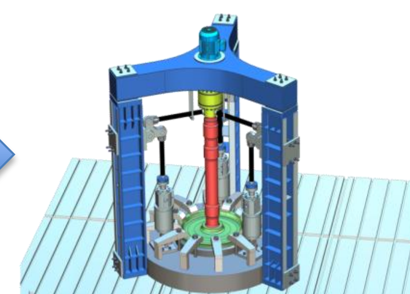
Size effect ?

1:3-tests

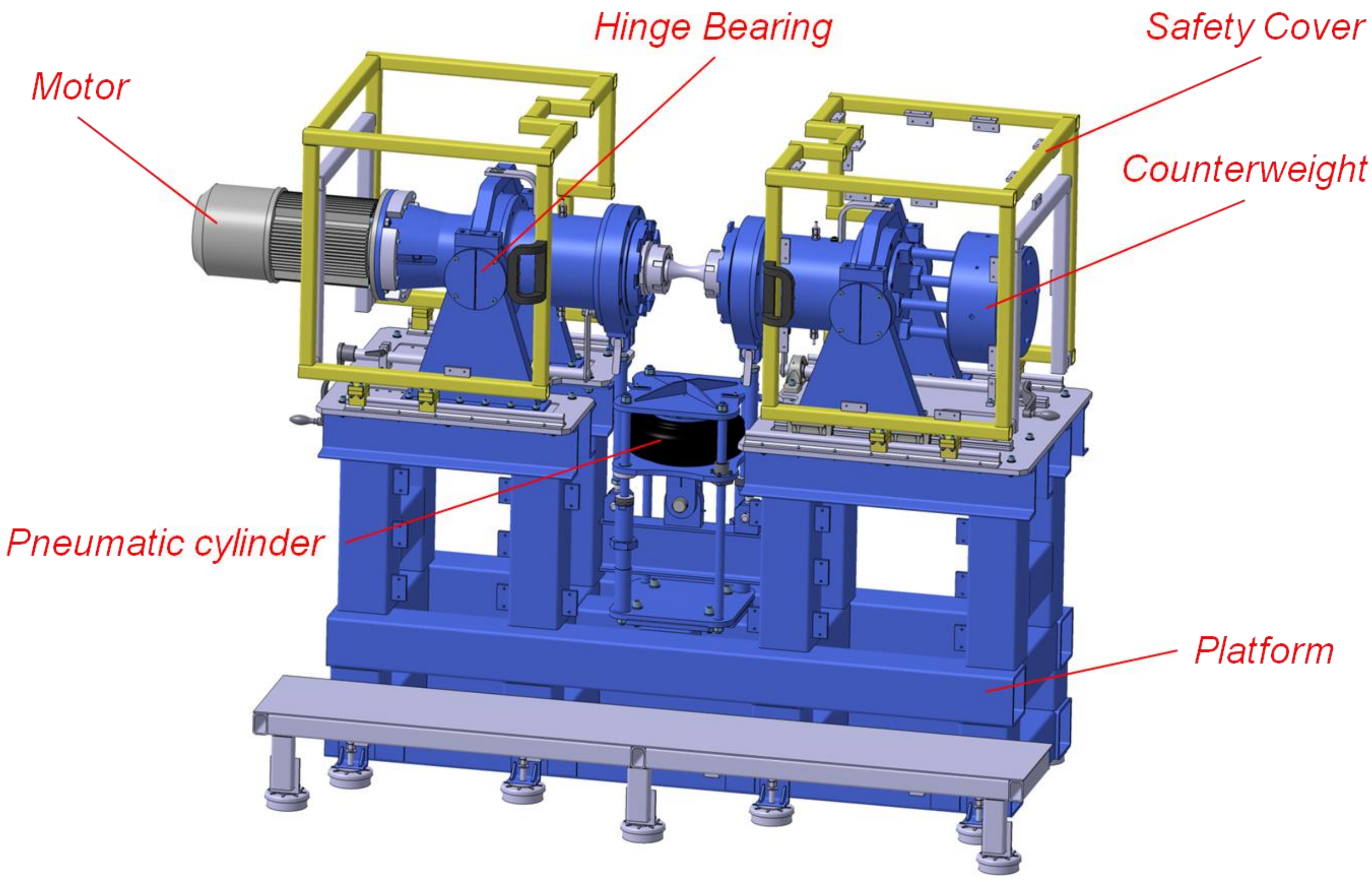


Size effect ?

1:1-tests

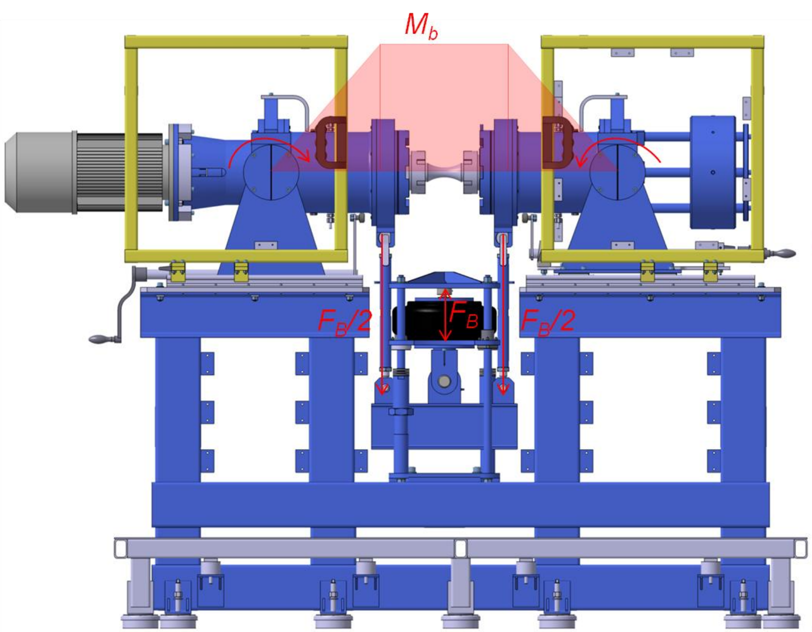


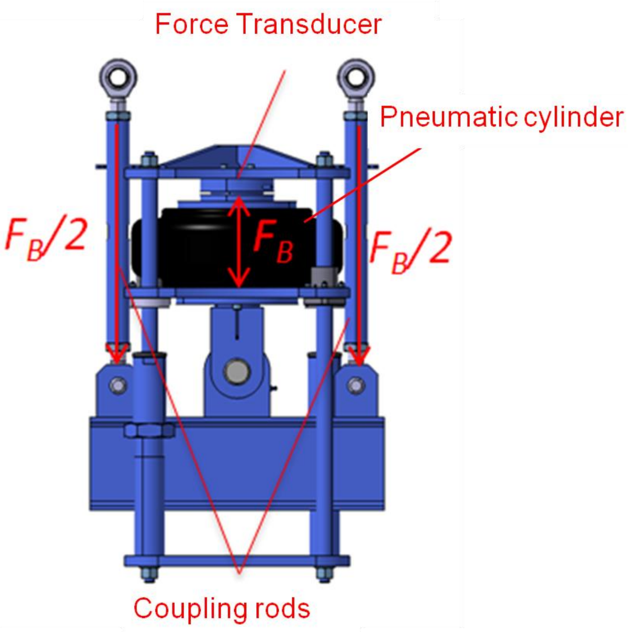
Test-rig setup for cylindrical *1:3* scale specimens



M. Doppler: Entwicklung einer Umlaufbiegeprüfmaschine zur Untersuchung des Größeneffekts an Großproben, Master thesis, Montanuniversität Leoben, 2015, (in German)

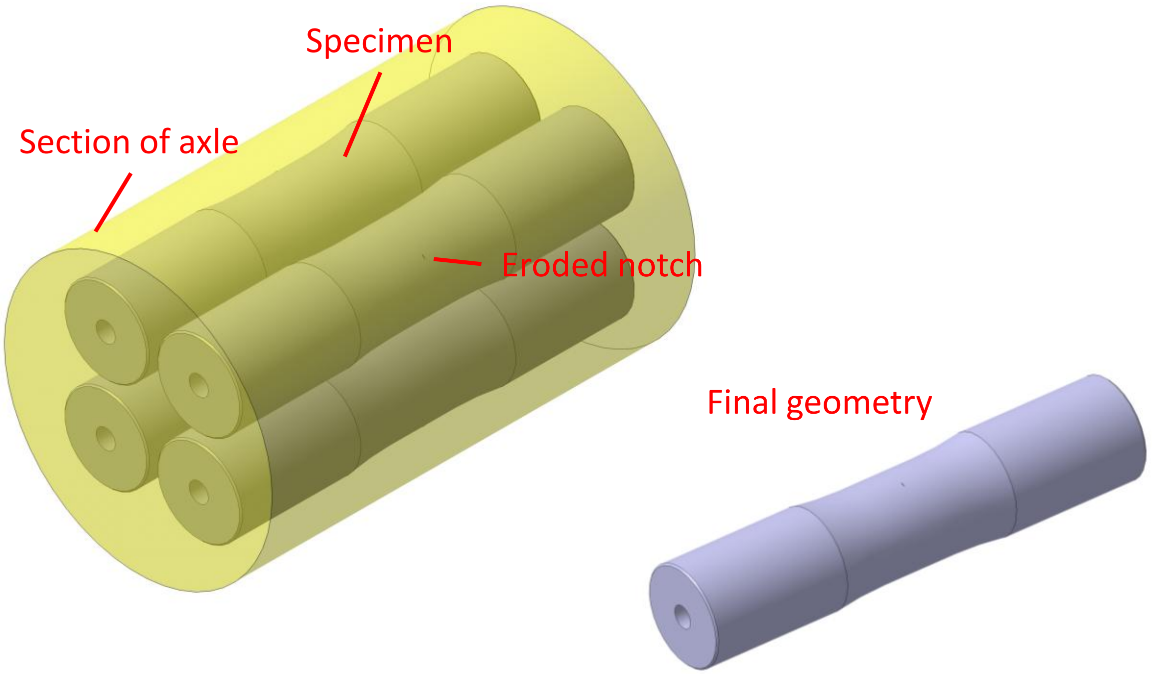
Functionality and calibration of the test-rig

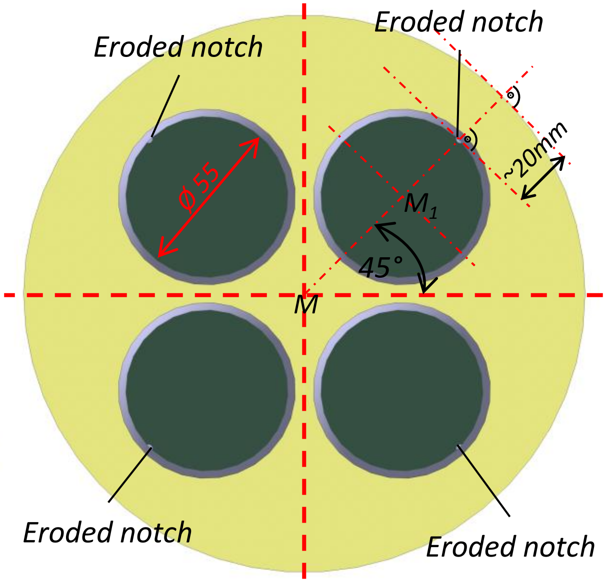




- Loading via pneumatic cylinder and coupling rods
- Four-point rotating bending moment
- Maximum bending moment M_{bmax} = 4200Nm (equates $\sigma_{nom} \approx$ 260MPa at D=55mm)
- Maximum revolution speed n_{max} = 3000 min^{-1} (50Hz)
- Switch off criterion via maximum deflection of the specimen and vibration sensors
- Calibration with strain-gauges on coupling rods and the specimen

Geometry for cylindrical *1:3* scale specimens





→ Four specimens per section
→ Orientation of the eroded notch to the surface of the section
→ Surface of the specimen *20mm* bellow the primary surface of the axle
→ Testing diameter *d=55mm* of the specimen
→ Polished surface at the eroded notch
→ Manufacturing of the notches at TU-Clausthal (same procedure as for full-scale specimen)

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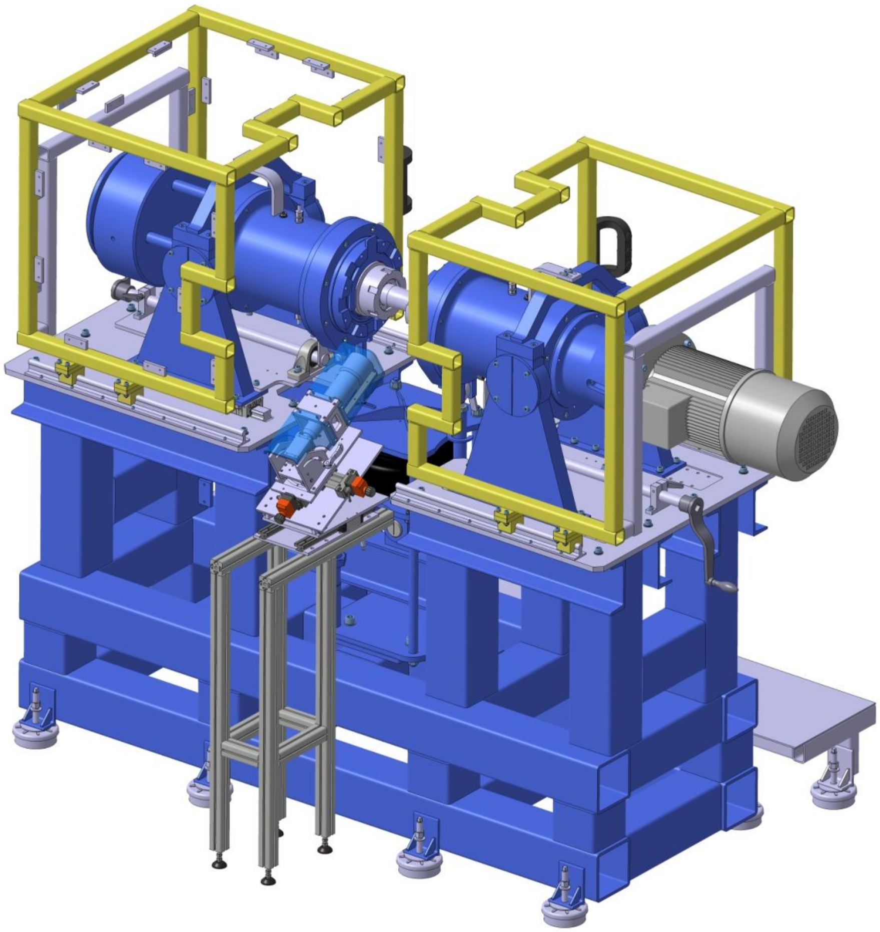
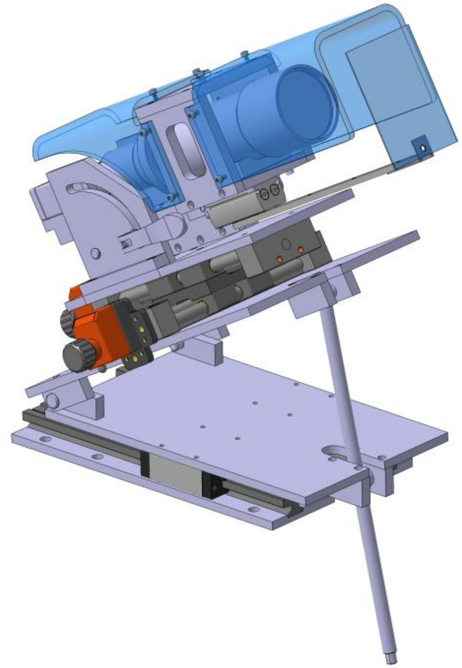
Optical crack length measurement





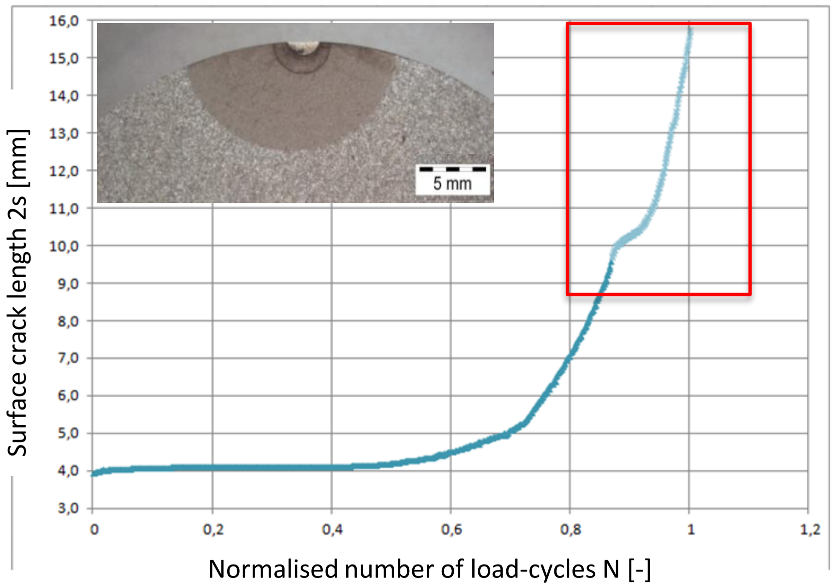
www.stemmer-immaging.de

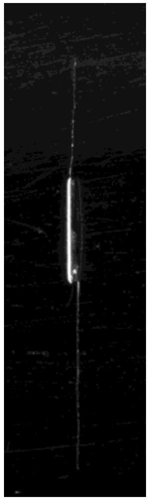
www.stemmer-immaging.de

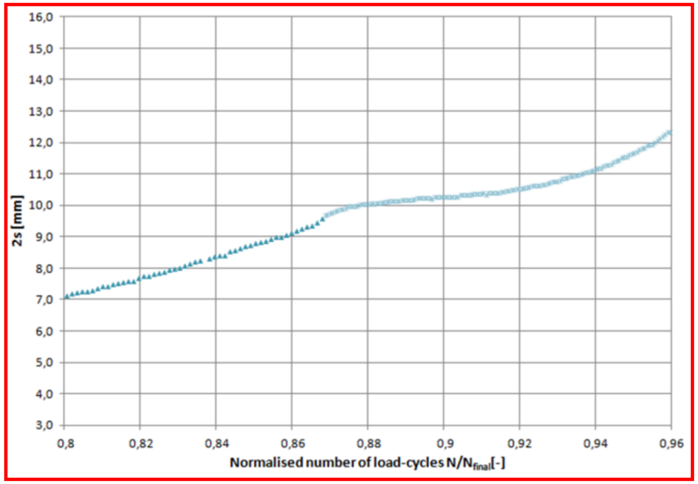
- *5MP* CCD GigE Vision camera
- Telecentric lens with variable iris
- Decoupled mounting to reduce vibration
- Measurement at slow speed or at stopped machine
- Calibration via cross table and tilt unit

Investigations on MUL/MCL/ESI

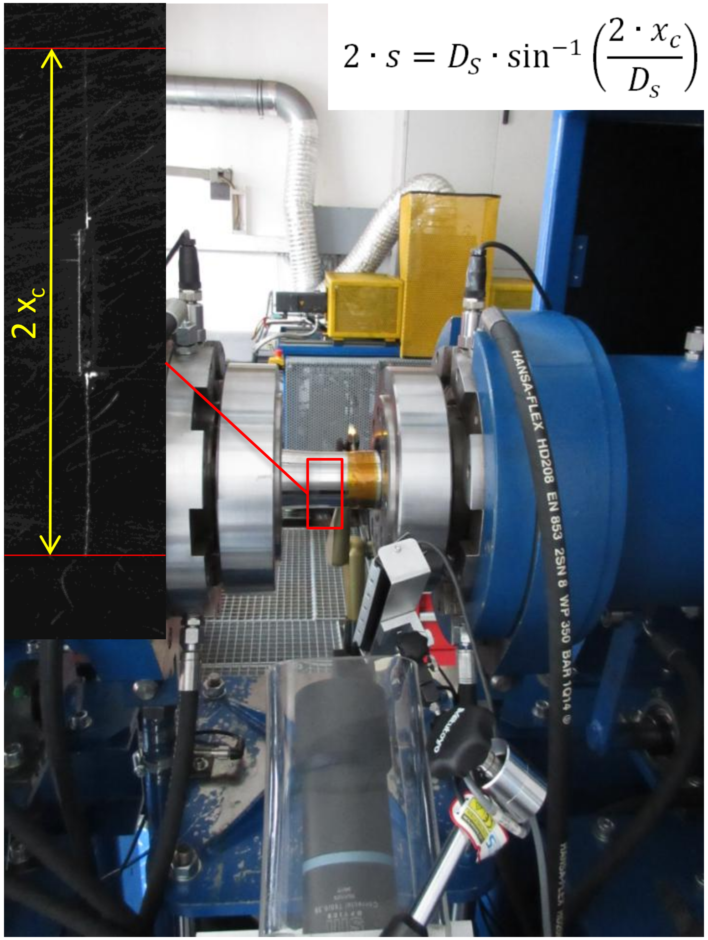
- *35* cylindrical small scale specimens (*1:3* scale specimens)
- Investigation of crack propagation at constant amplitude loading (CAL), retardation effects due overloads and oxide induced crack closure
- Investigation of crack propagation for typical load spectra (VAL)
- Comparison to experimental investigations of small scale flat specimens with different crack geometries (MCL/ESI) and *1:1*-full-scale specimens (TU-Graz)
- Comparison to analytical and numerical assessments

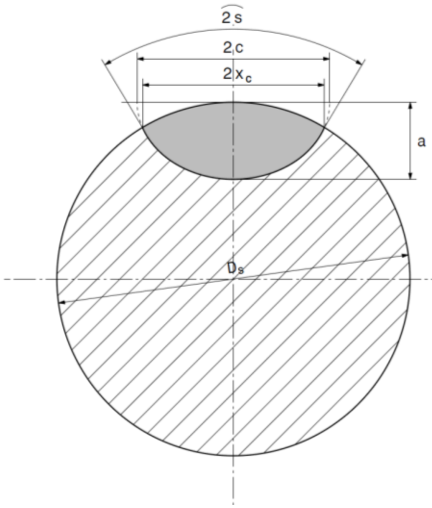


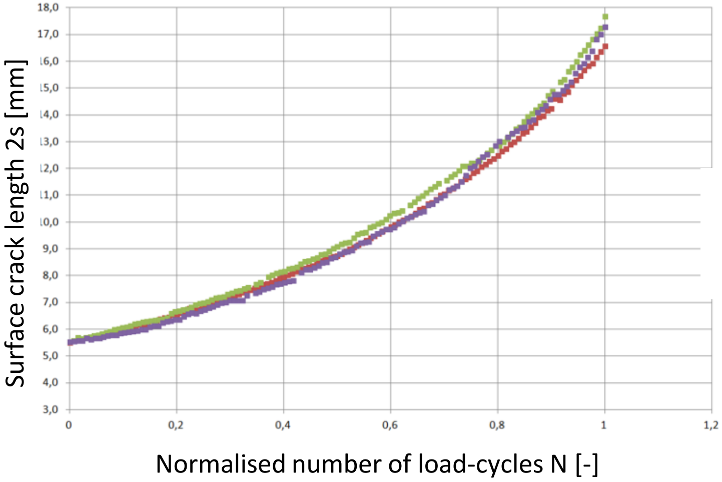




Experimental crack propagation analysis







→ Measurement of projected crack length $2x_C$ on surface

→ Recalculation to surface crack length *2s*

→ Investigation of crack propagation after crack initiation procedure to ensure comparability of test results

→ Crack depth can be additionally evaluated after testing by microscopic analysis

Fracture surface analysis

→ Cool down of specimens in liquid nitrogen atmosphere

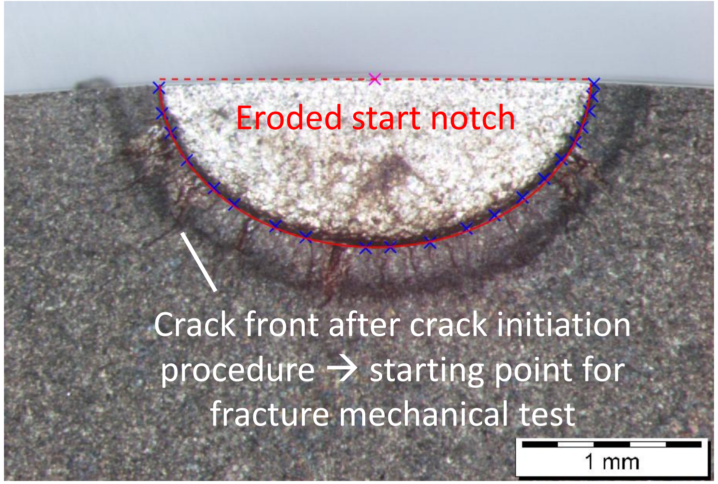
→ Burst fracturing (see video)

→ Microscopical investigation of fracture surface

→ Analysis of (half-elliptical) crack propagation

Fracture surface analysis

Eroded start notch:

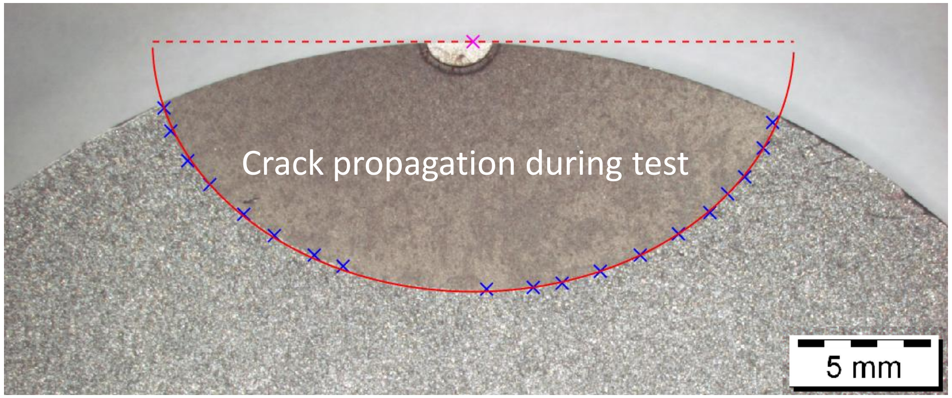


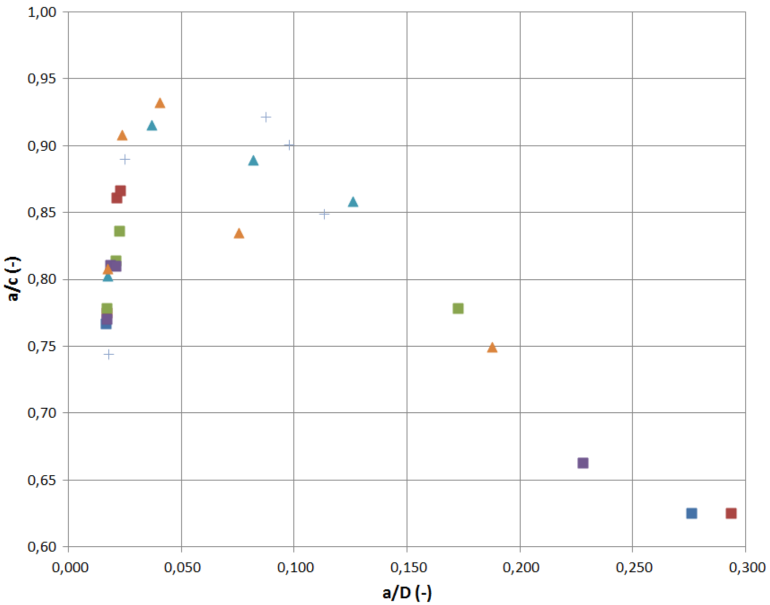
→ Selection of points on start notch, beach marks and final fracture surfaces

→ Evaluation of the half-elliptical crack propagation and a/c-ratio

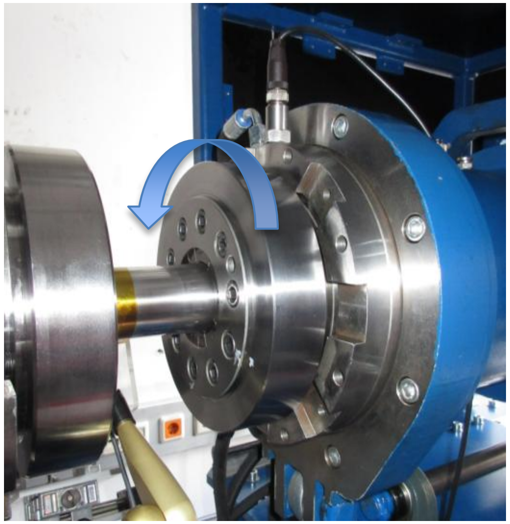
→ Comparison between tested specimens

Final fracture surface:





Fracture surface analysis

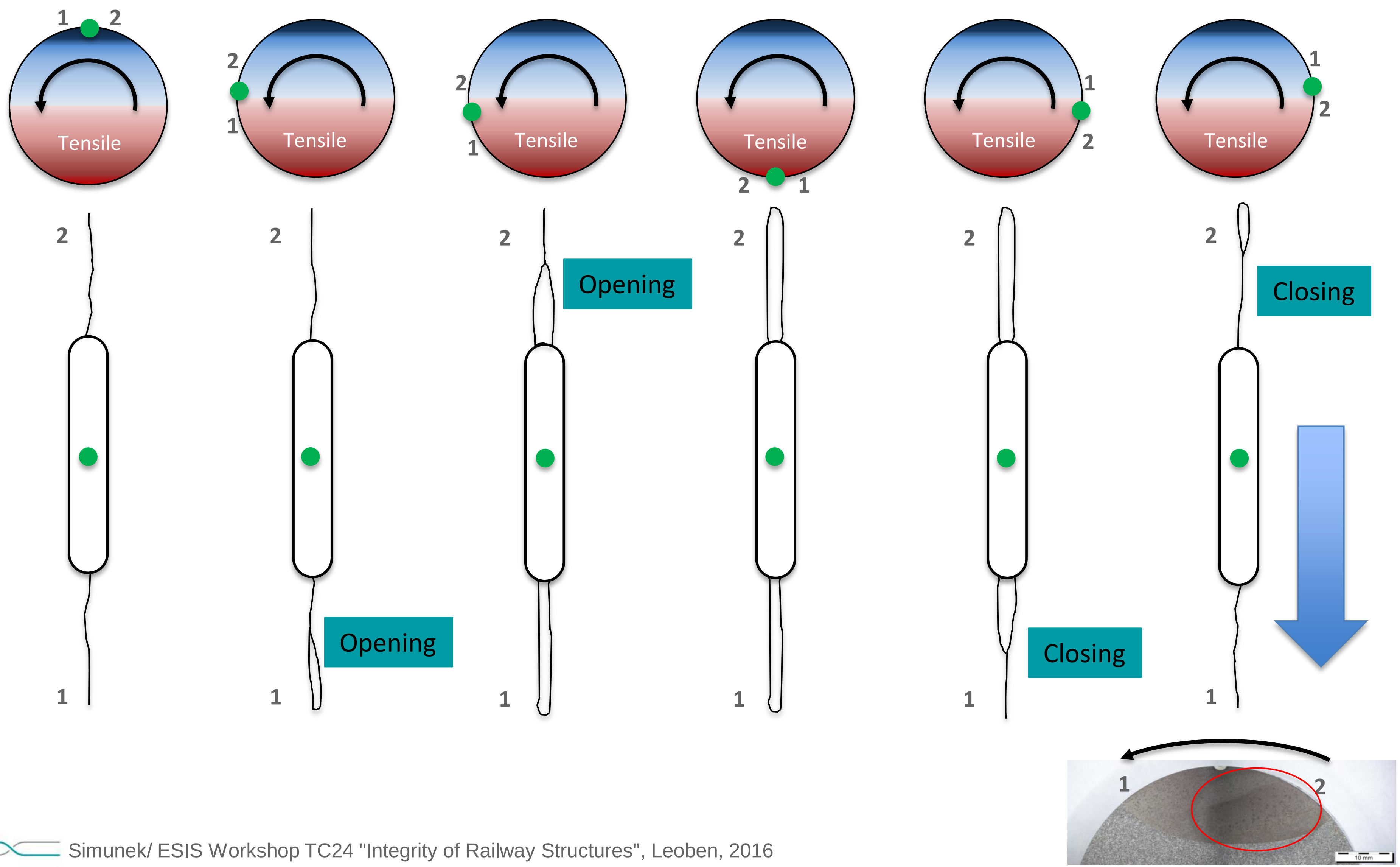


→ Dark regions at long crack lengths

→ Investigations of different specimens showed dependency of rotating direction

→ Explanation of phenomenon?

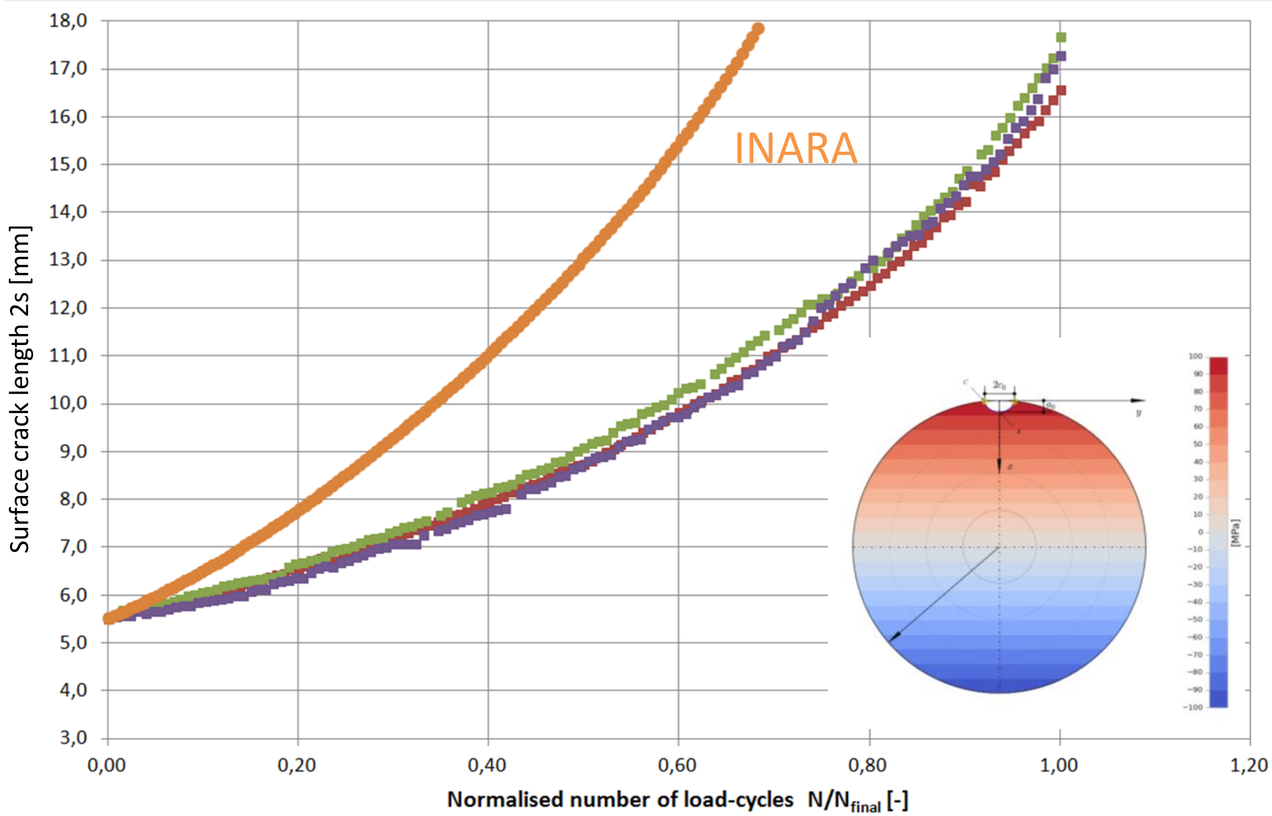
Explanation of phenomenon



Analytical assessments with INARA

→ INARA (Integrity Assessment for Railway Axles)

→Analytical assessment of remaining service life (calculation starts with crack front after crack initiation stage)



→ Implementation of material database and material laws

→ Evaluation of accuracy and optimisation

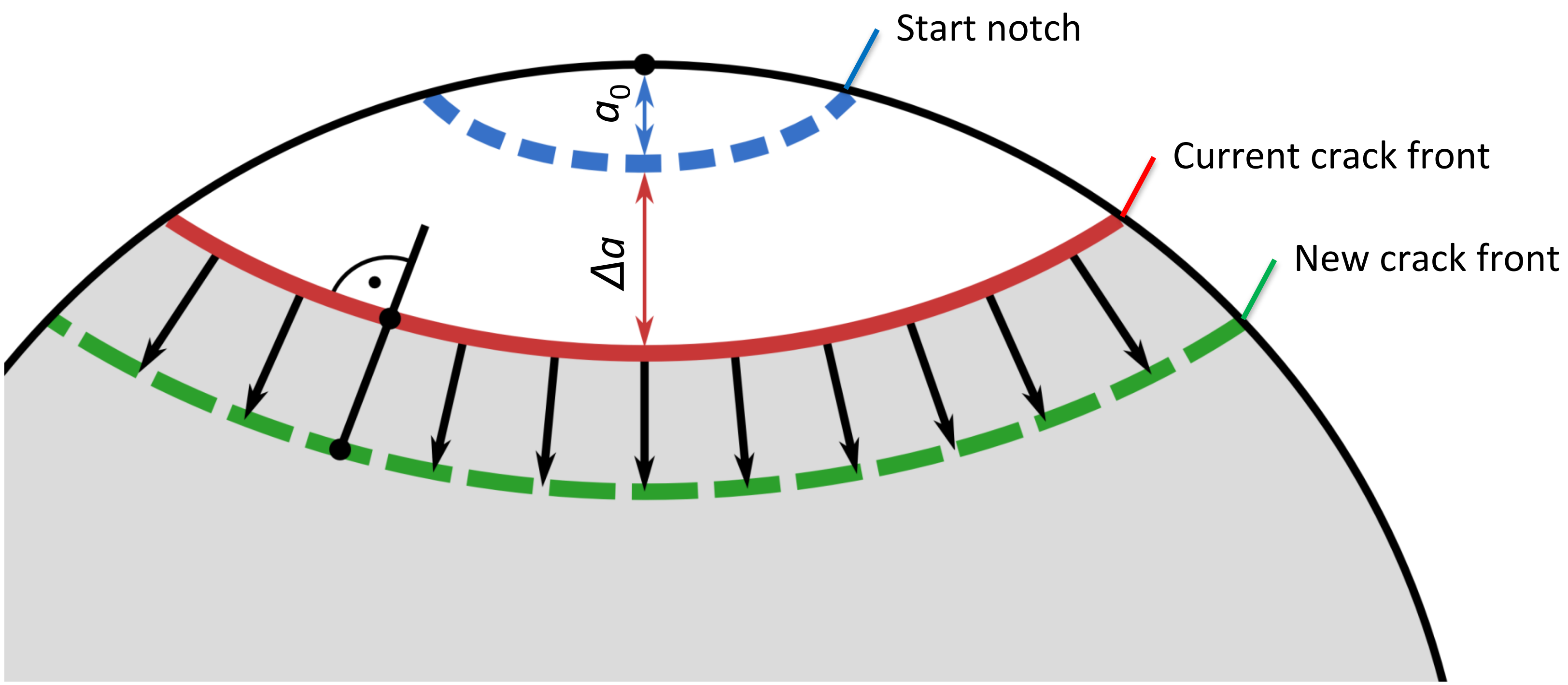
→Industrial application for assessment of inspection intervals

→ Comparison with experimental investigations

→ Outlook:
Validation of results with numerical *3D*-analysis

Outlook: Numerical analysis of crack propagation

→ Based on preliminary work at MCL
→ Crack propagation with automatic re-meshing
→ Evaluation of stress intensity factors for every node at the crack front
→ Crack propagation analysis with modified NASGRO-equation
→ Evaluation and comparison of numerical and experimental crack growth for *1:3* and full-scale specimens



Conclusion & Outlook

- Test rig for *1:3* scale specimens

→ Functionality and calibration of the test rig
→ Geometry for cylindrical *1:3* scale specimens
→ Optical crack length measurement

- Experimental investigations

→ Crack propagation in *1:3* scale specimens
→ Fracture surface analysis

- Analytical and numerical assessments

→ Analytical assessments with INARA
→ Assessments with numerical methods

Thank you very much for your attention!

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