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Simulation-based Investigation of Inner Ring Creep at the Wind turbine Main Bearing

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Contents

Motivation

- Bearing Ring Creep identified as one of the failure modes
  - Fretting Corrosion at bearing seats & ring surfaces
- Already investigated in small sized bearings
- Recent trend in ring creep studies of wind turbine bearings
- Focus of thesis: Main shaft bearing

Figure 01: Fretting corrosion observed at shaft and inner ring [1]

[1] Billenstein, "Simulative and Experimental Investigation of the Ring Creeping Damage Mechanism Considering the Training Effect in Large-Sized Bearings," machines, vol. 11, 2023.

Objectives

- Develop a finite element model for inner ring creep
  - Gather qualitative results on a TRB of a wind turbine
  - Gather quantitative results on a smaller sized CRB
- Investigate the influencing factors affecting ring creep

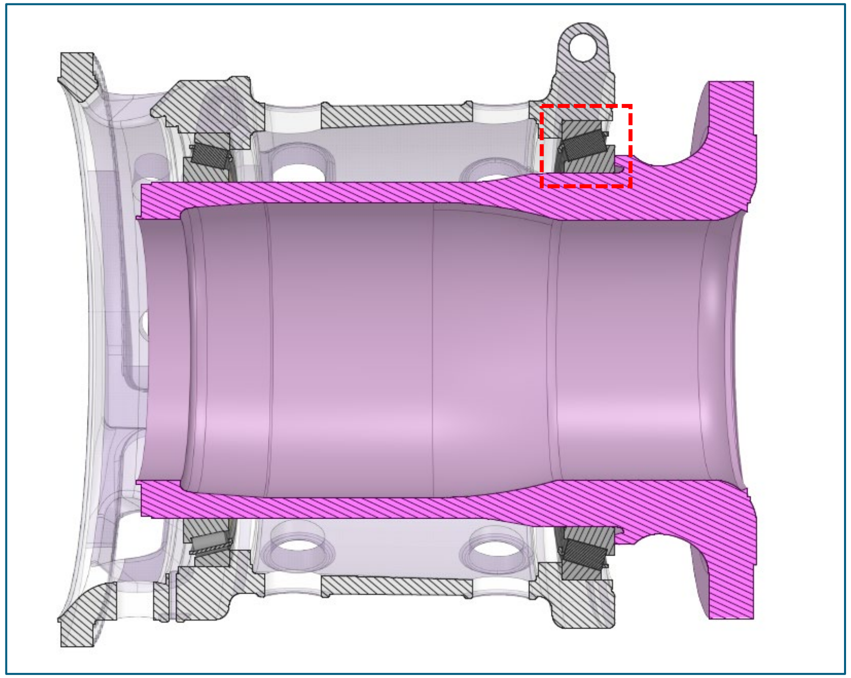


Figure 03: Complete drivetrain assembly with TRB highlighted

Ring Creep

Definition:

- Irreversible micro-movements of bearing ring with respect to its adjacent component
- Traveling wave or caterpillar like movement
- Inner ring – shaft, Outer ring - housing
- Roller induced creep, Structure induced creep

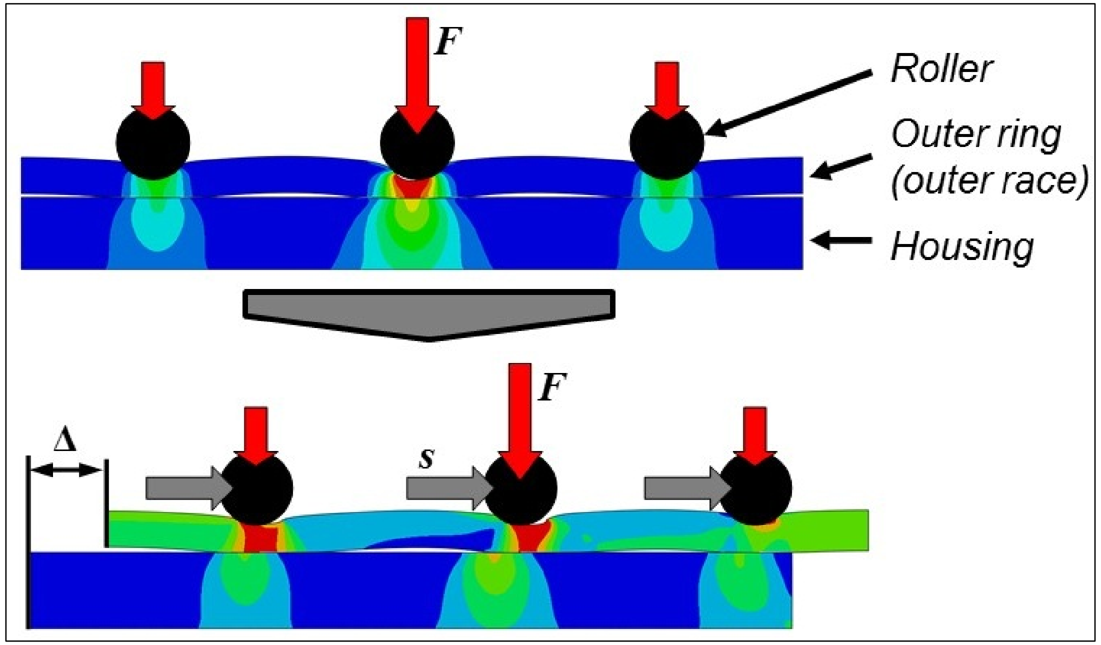


Figure 04: Simple 2-D creep representation [2]

[2] Maiwald, "FE simulations of irreversible relative movements (creeping) in rolling bearing seats--influential parameters and remedies," World Congress on Engineering and Computer Science, vol. 2, 2013. C

Literature review

Modelling of ring creep – state of the art

Year	Author	Title
2005	Murata	Generation Mechanism of Inner Ring Creep
2010	Zhan	Analysis of bearing outer ring creep with FEM
2013	Tsuyoshi Niwa	A creep mechanism of rolling bearings
2013	Maiwald	FE simulations of irreversible relative movements (creeping) in rolling bearing seats - influential parameters and remedies
2023	Billenstein	Simulative and Experimental Investigation of the Ring Creeping Damage Mechanism Considering the Training Effect in Large-Sized Bearings

Design under study

Wind turbine drivetrain with TRB type main bearing

- Integrated drivetrain with ‘O’ configuration
- Main bearing (TRB) towards hub side
- Reduced number of rollers
- Structural steel for all flexible bodies

w = roller pitch
t = thickness of ring

For wave like deformation:

$t/w < 0.6$

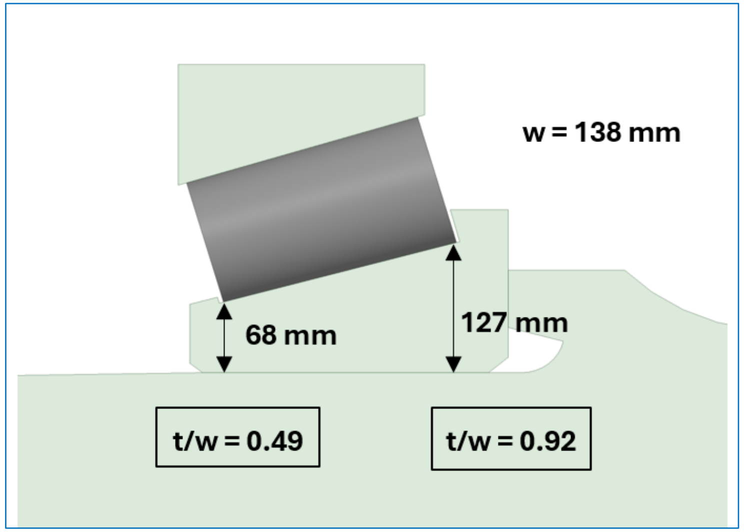


Figure 05 : Creep criteria[3]

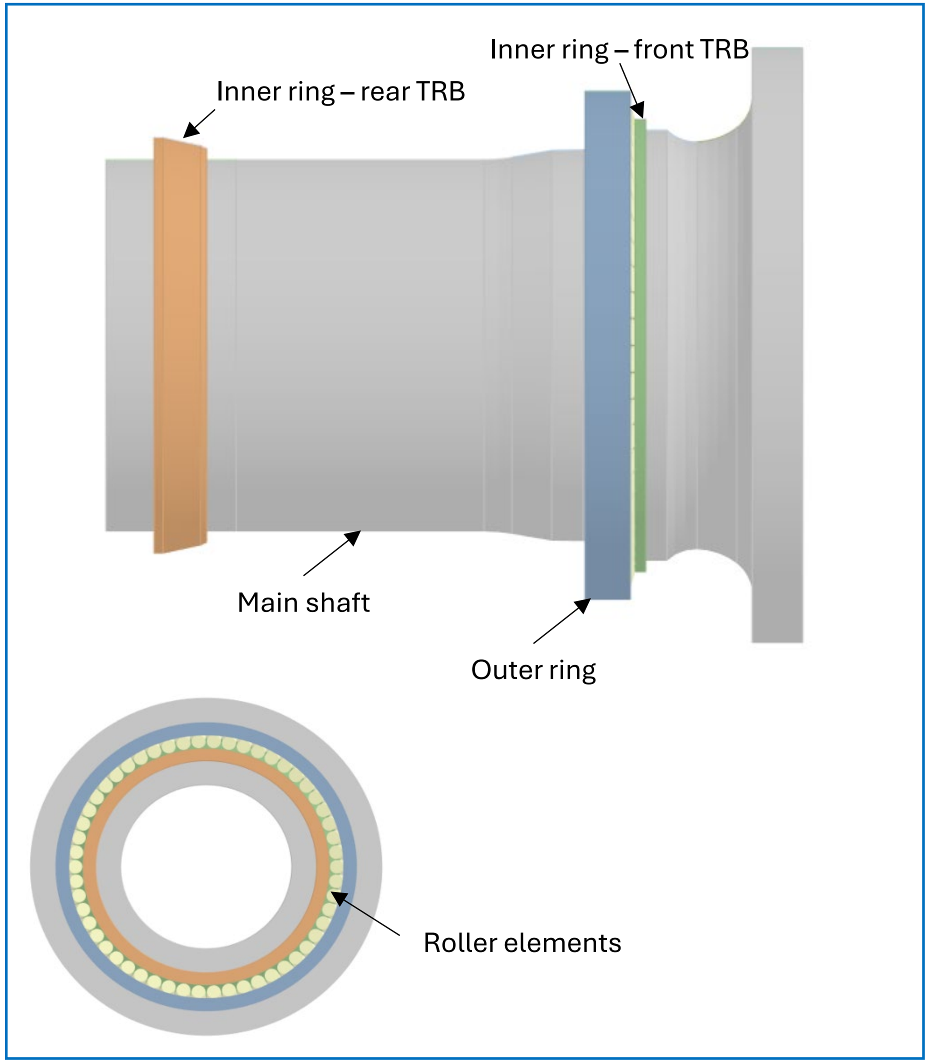


Figure 06 : Model scope

[3] T. Niwa, "A creep mechanism of rolling bearings," NTN Tech. Review, vol. 81, pp. 100-103, 2013.

Modeling approach of ring creep

Full scale model

1. Interference fit

- At inner ring and shaft contact
- Assign positive offset value in frictional contact definitions
- Keep friction off to avoid additional shear stresses
- Additional boundary conditions to avoid rigid body motion

2. Activate friction

- Use APDL commands
- Remove additional boundary conditions

3. Apply loads

- Apply static load
- Solve the model as steady static
- Get qualitative results
- Export contact forces developed between rollers and ring
- Post process the forces and transform into csv format

Reduced model

Reduce the model

- Duplicate the model
- Keep the same mesh
- Remove outer ring and all the roller elements along with corresponding joints and contacts

Apply contact forces

- Include interference fit again in the reduced model
- APDL commands to import contact forces and rotate them around the ring
- Get quantitative results

Modeling approach

Meshing

- SOLID185: 8-noded 3D elements
- Linear elements showing better convergence
- Equally discretized between each roller pair
- Node-to-node

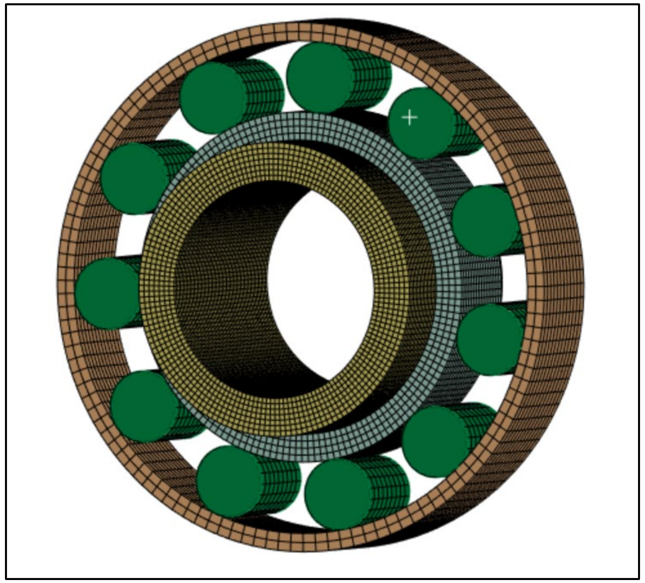


Figure 07: Mesh of simple CRB

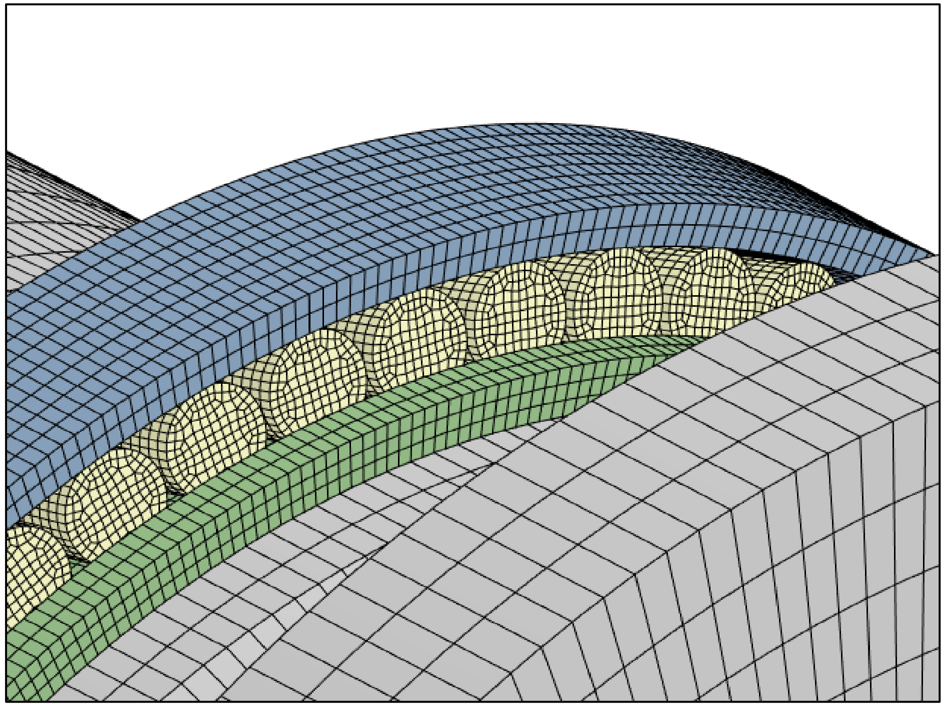


Figure 08 : Mesh of full scale TRB

Modeling approach
Contact definition

Inner ring and shaft:

- Frictional: friction deactivated in 1st loadstep
- Normal Lagrange: better accuracy
- Detection method: Nodal projection
- Elastic slip tolerance
- Small sliding
- Offset: (Diametrical overfit) / 2

Inner ring and rollers:

- Frictionless
- Augmented Lagrange

Outer ring and rollers:

- Bonded: to simplify the model
- Augmented Lagrange

Modeling approach

Friction model

Coulomb friction model

$$\tau_{lim} = \mu P + b$$

where,

τ_{lim} = limiting frictional stress

$||\tau||$ = equivalent shear stress at the surface

μ = coefficient of friction

P = contact normal pressure

b = contact cohesion

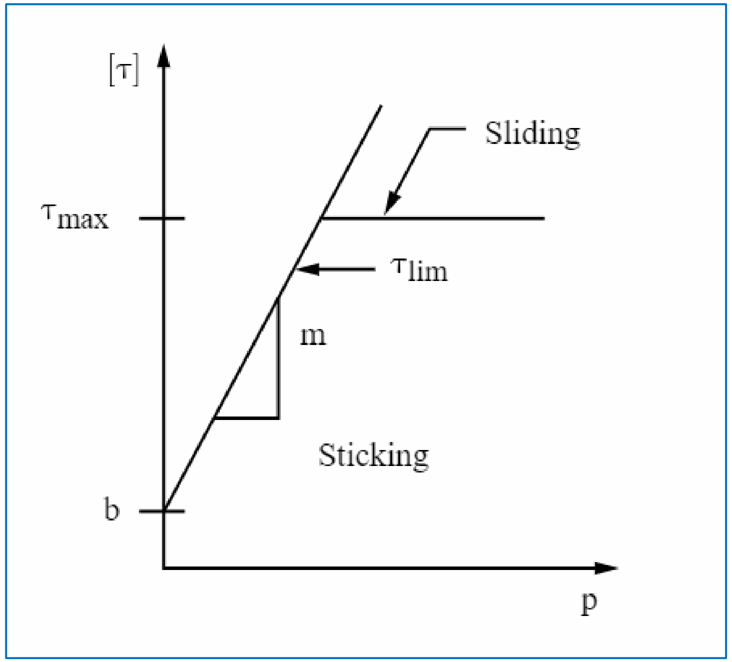


Figure 09 : Coulomb friction

Modeling approach

Modeling of cage & rollers

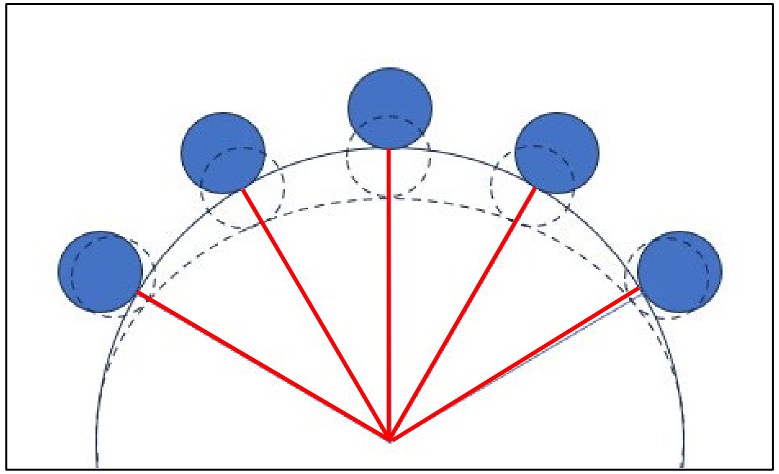


Figure 10 : Cage modeling

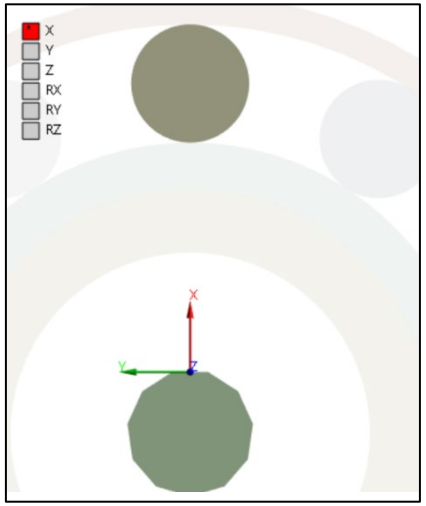


Figure 11 : Translational joint

Cage and roller:

- ➢ Cage not modeled as flexible body
- ➢ Rigid polygonal prism for reference surfaces
- ➢ Translational joints between each roller and respective reference surface (CRB)
- ➢ Modification for TRB

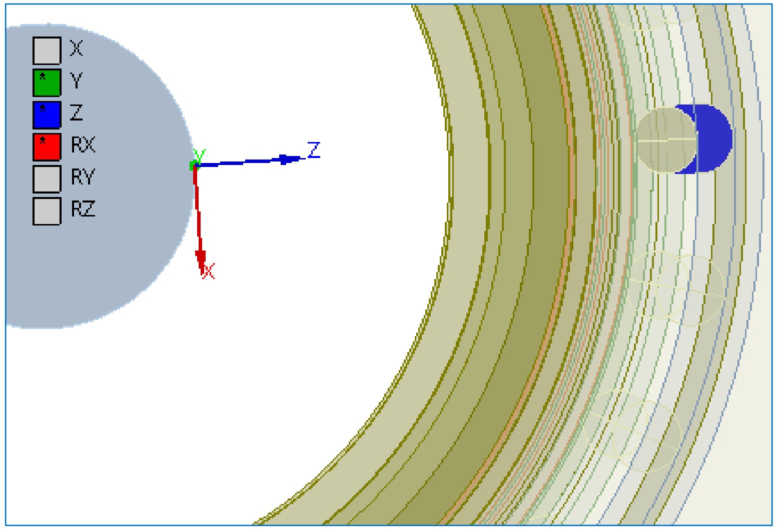
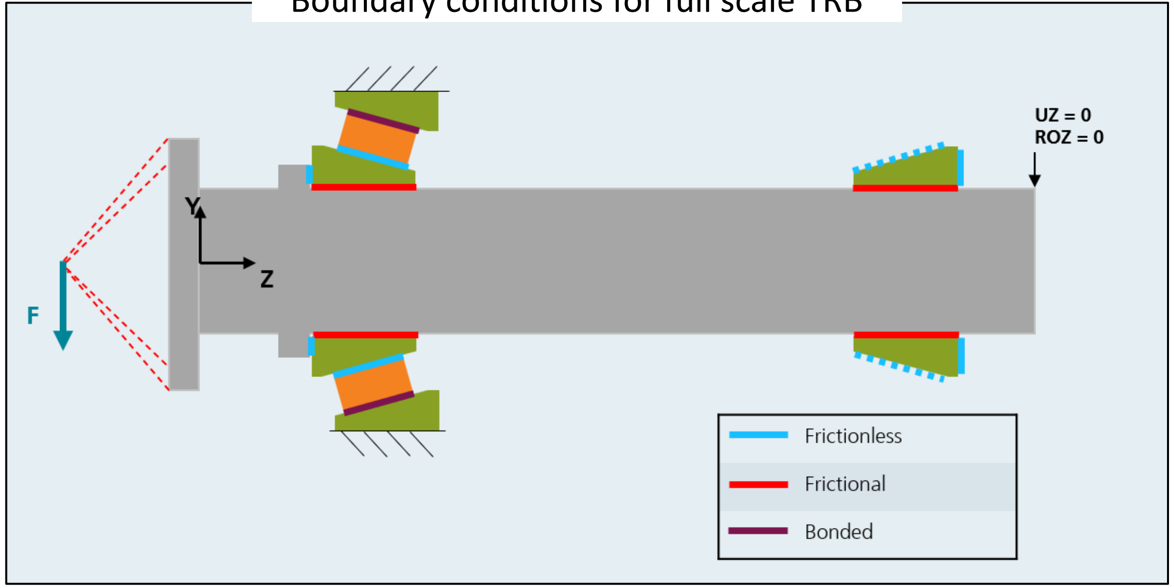


Figure 12 : General joint

Modeling approach

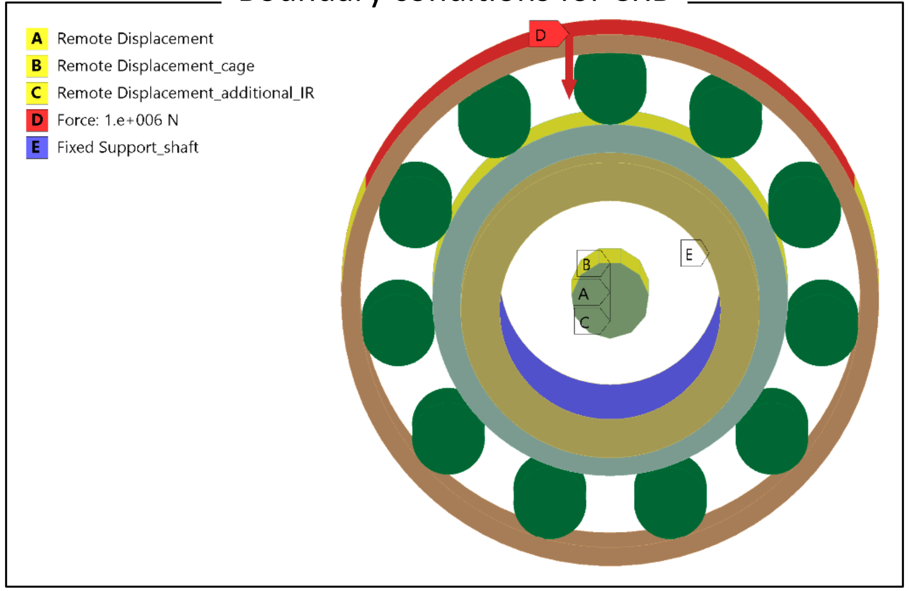
Boundary conditions

Boundary conditions for full scale TRB



- Outer ring – Fixed
- Additional boundary conditions to Inner rings
- Inner ring 2 - Compression only support
- Shaft end Generator – Remote displacement

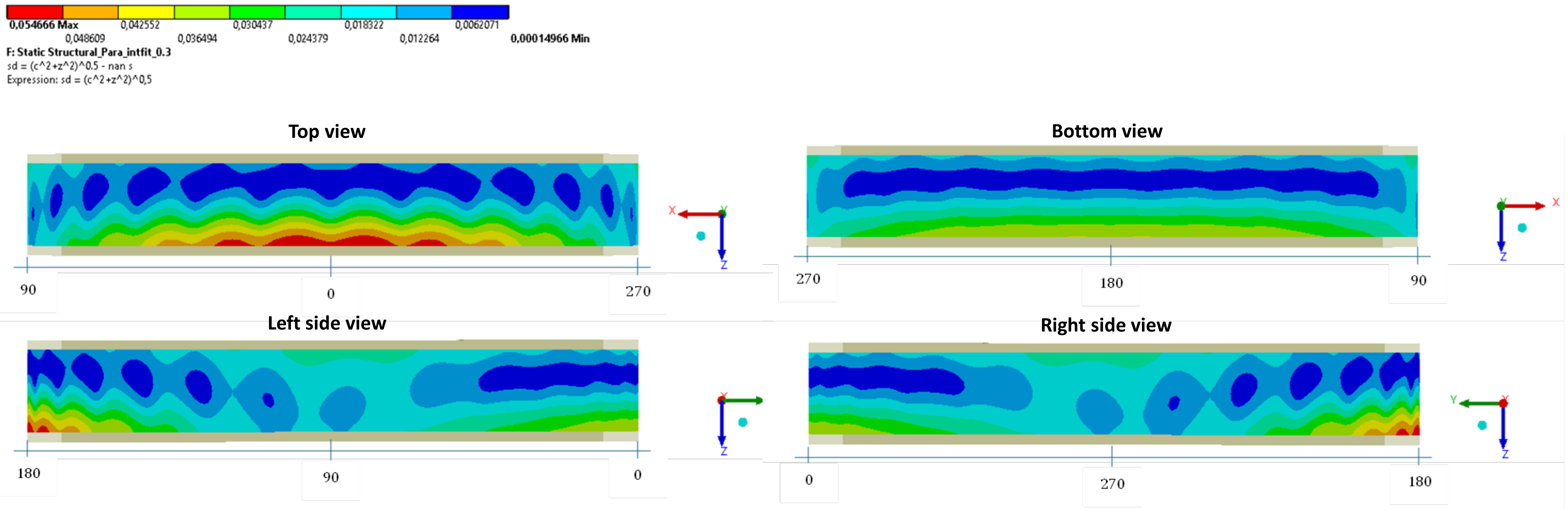
Boundary conditions for CRB



- Outer ring – Partially fixed and loaded
- Additional boundary conditions to Inner ring
- Shaft - Fixed

Results

Sliding distance in full scale TRB model



Load step 1 : Sliding -> Load step 2 : Sticking -> Load step 3 : Stick-slip

Results

Contact status in full scale TRB model

Side view

Load step 1 : Sliding

Load step 2 : Sticking

Load step 3 : “Stick-slip”

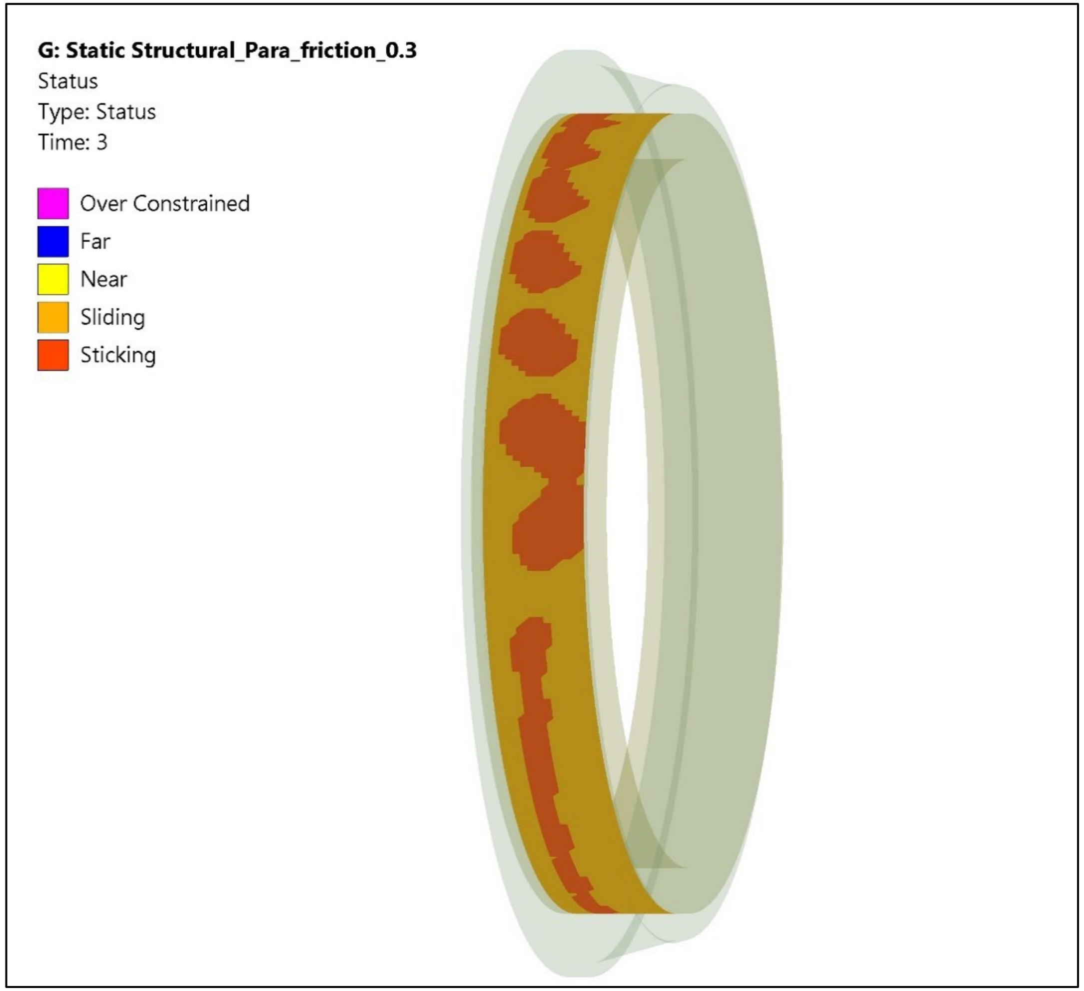
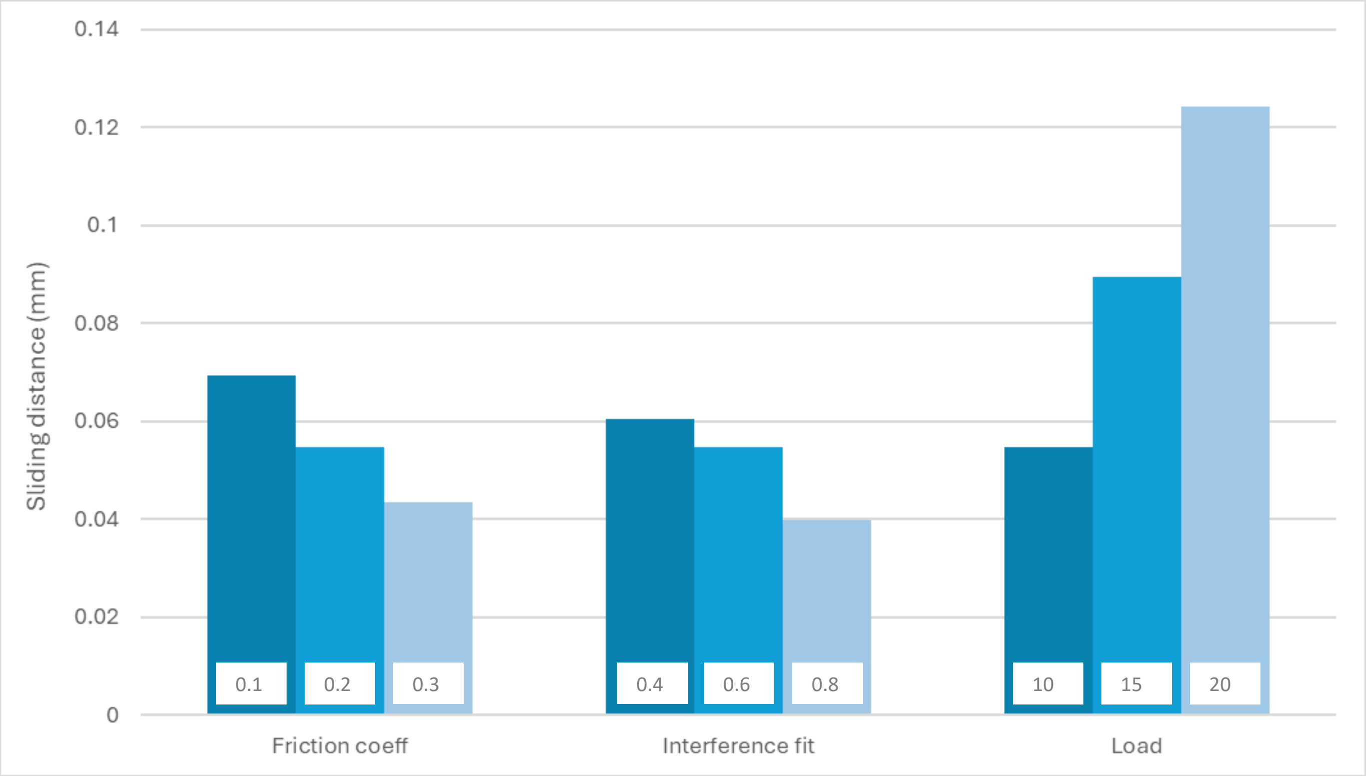


Figure 16 : Contact status

Results

Parametric study for full scale TRB model



	Coefficient of friction	max. Sliding distance (mm)
1	0.1	0.069476
2	0.2	0.054666
3	0.3	0.04349

	Interference fit (mm)	max. Sliding distance (mm)
1	0.4	0.060436
2	0.6	0.054666
3	0.8	0.039756

	Load (MN)	max. Sliding distance (mm)
1	10	0.054666
2	15	0.089608
3	20	0.1242

Results

Ring creep in CRB reduced model

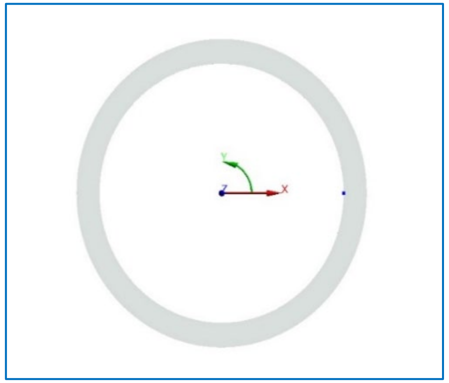
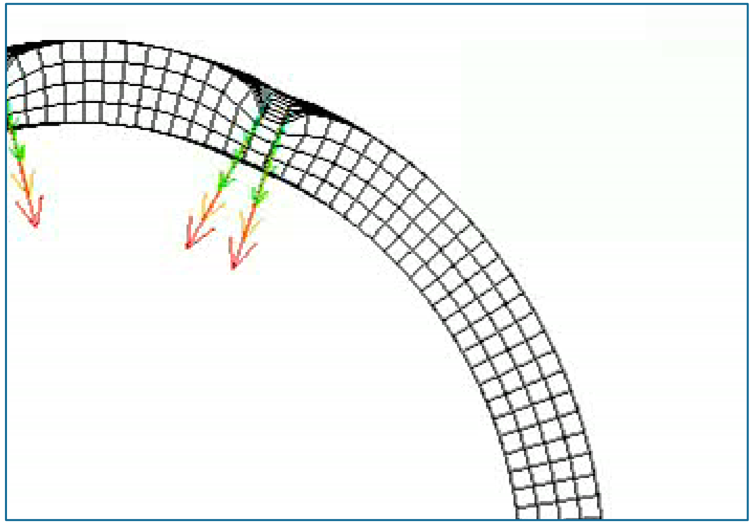
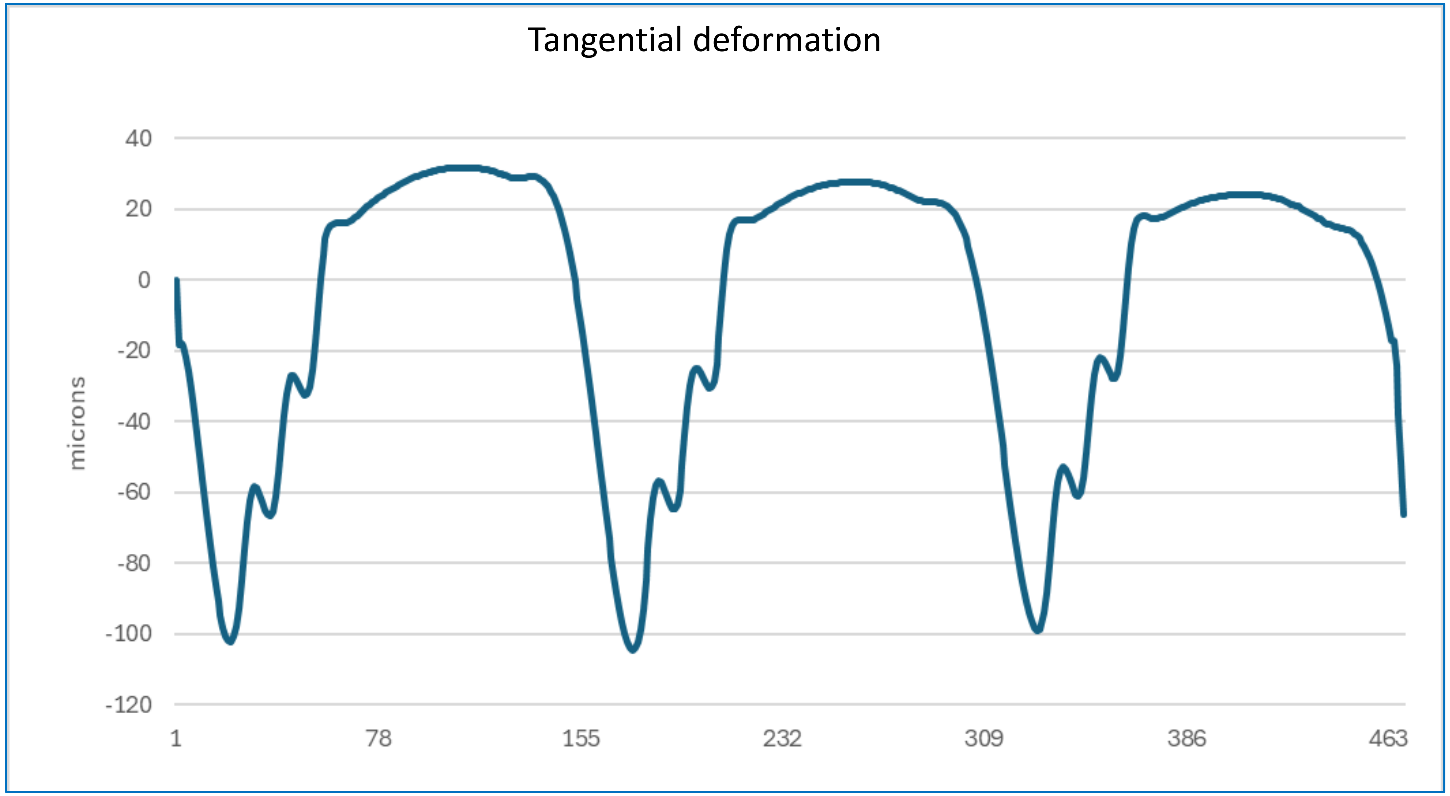
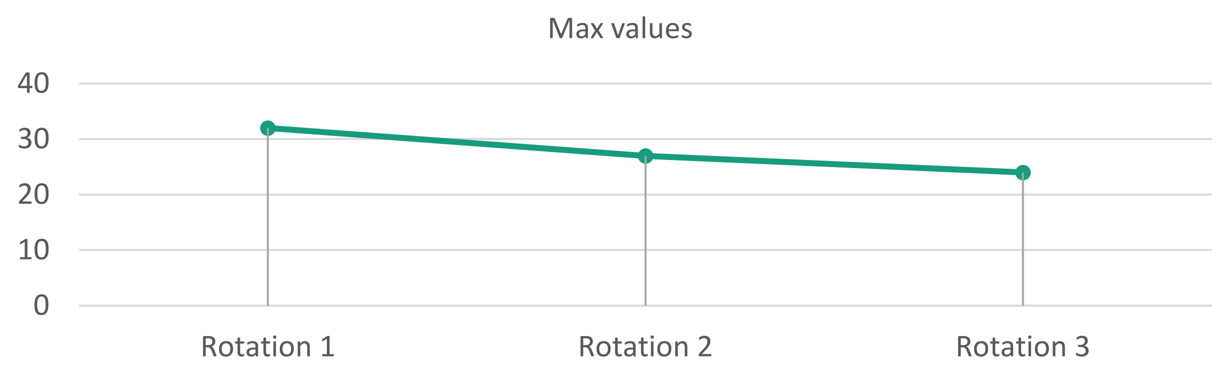


Figure 17 : Node used for measurement







Further findings

- Meshing:
  - Quadratic vs Linear - Linear showed better convergence; Quadratic elements got highly distorted
  - Node to node contact - Consistency in results
- Elastic limit: quantitative results highly sensitive

Conclusion

- Dependence of inner ring creep on Friction, interference fit and load
- Parametric study results in accordance with previous studies
- Developed an APDL script for applying forces and get quantitative results
- Observed slip in tangential deformation plot

Further scope and improvements

- Validate contact definitions
- Friction models
- Include kinematics of roller bearing
- Study on other parameters (Housing deformation, materials, etc)

Thanks a lot for your attention!

Questions

Appendix

Ring Creep

Mechanism:

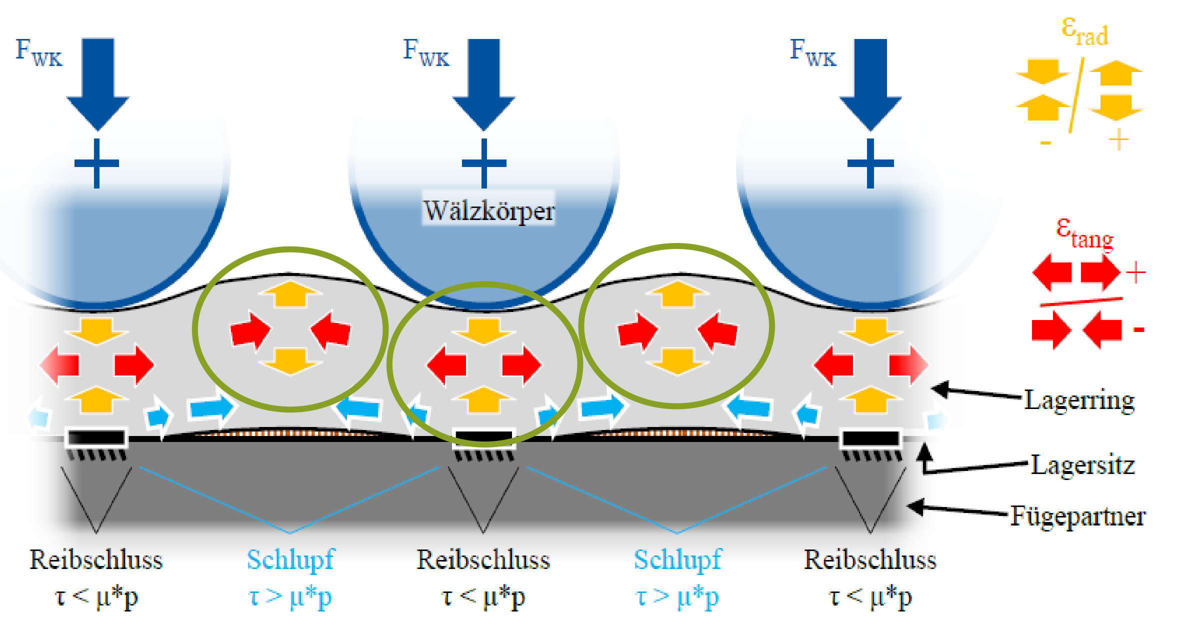


Figure 03: Static Loading

- Static loading of rollers
- Radial compression under rollers
- Tangential compression between rollers
- Wave like deformation
- Increase in local joint pressure under rollers
- Decrease in local joint pressure between rollers
- Shear stresses (τ) developed
- Frictional stresses ($\mu * p$) developed
- Corresponding stick-slip regions formed

Ring Creep

Mechanism:

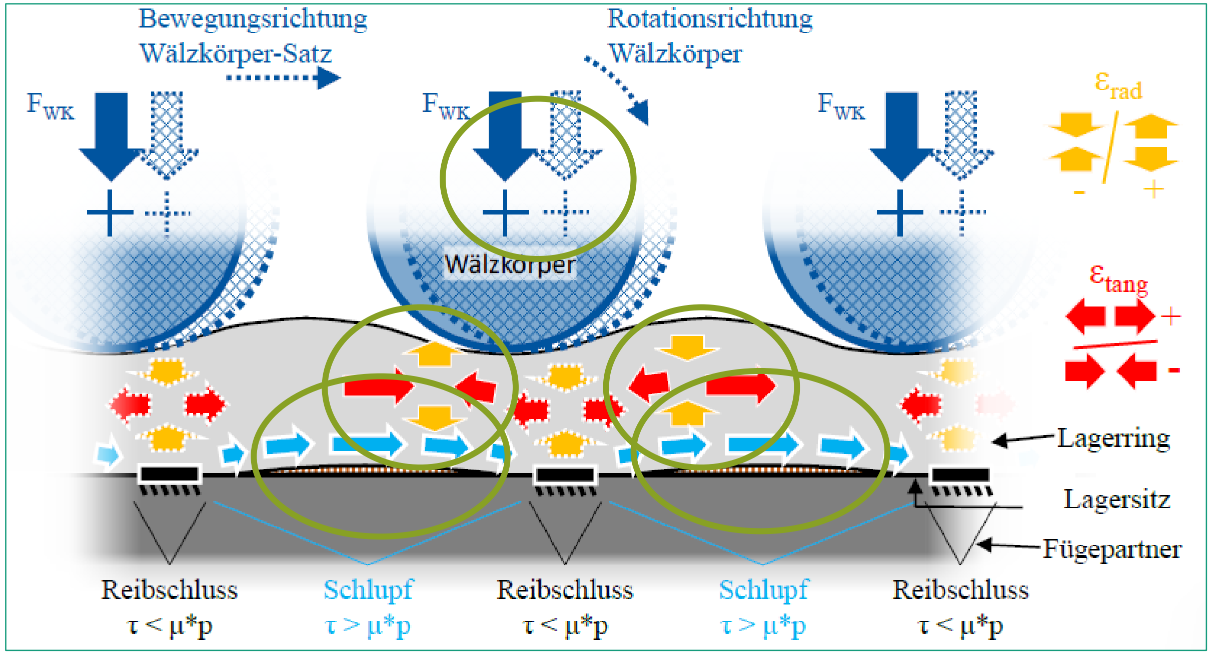


Figure 04 : Roller movements

- Movement of rollers (right direction)
- Shifting of material
- Shifted material on right cannot return back due to stick region
- Material on left expands radially back to original shape
- Consequently, must shrink tangentially
- Shifted material on left cannot return back due to stick region
- Net shift of material in right direction
- Irreversible creep movement