Friction and Wear Investigations on Chain Joints of Timing Chains

TRACK OR CATEGORY

Session 3I, Engine & Drive Train I: Engine Tribology, Surface Sciences

AUTHORS AND INSTITUTIONS

Becker, A.*; Meffert, D.; Sauer, B.

Institute of Machine Elements, Gears and Transmissions (MEGT), University of Kaiserslautern

*Corresponding Author: andre.becker@mv.uni-kl.de

INTRODUCTION

In timing chain drives, the chain joint, consisting of bush and pin, is the most critical component regarding wear and energy efficiency. Due to the drive design layout, there are relative motions inside the chain joints. These processes can be found at the in- and outlet of the chain joint on the sprockets, but also induced by vibrations of the slack strand. The contact loads and the relative motions cause wear of bush and pin, so the joint clearance and the chain length increase. The contact loads and relative motions lead to friction losses that influence the energy efficiency of the entire chain [1]. Therefore, an optimization of the wear characteristics is necessary to realize an improvement of the efficiency of the entire combustion engine. By using various materials for bush and pin and also different surface treatments of both components, the tribological system was continuously improved. Surface texturing of the chain components of the joint contact is another possible approach to improve efficiency. Test rigs which allow investigations on entire chains are not suitable for systematic tests of chain components with modified surfaces because of a considerable amount of modified parts needed. To overcome this drawback, a rig for investigations on a single chain joint, called chain joint tribometer, was built at the Institute of Machine Elements, Gears & Transmissions (MEGT). The following chapters present the chain joint tribometer and demonstrate initial results regarding friction and wear.

Chain wear test rig

At the MEGT, two proprietary chain wear test rigs are used to investigate the wear of entire chains. All test parameters of the rigs are adaptable to represent real drive conditions of a timing chain drive. The modular rig setup allows investigation of a wide range of chain sizes, length and structural shapes, such as a bush, roller and silent chains. One test assembly consists of two, parallel installed test chain drives. Both tested chains are tensed up by a proprietary tension clutch, that applies a defined load to the chain drives. By using only one drive motor for investigations of two chains simultaneously, the test rig setup is efficient, especially for endurance tests. The applied torque is measured using resistance strain gauges, that are installed on the bearing support shaft. A telemetry system transmits the data. A linear guided translation stage enables to variation of the center distance of both rotational axes in a wide range, which eases the chain installation and allows for the investigation of different chain lengths. A readjustment device helps to adjust the distance between both bearing blocks while testing. This device is necessary to compensate for high wear rates and thermal elongations by readjusting the tension load during the test. Flat-jet nozzles supply the lubricant and can be freely adapted in position and quantity. A separate oil unit heats the lubricant to 120°C and allows the addition of engine soot. Detailed information about both chain wear test rigs can be found in [2-4].

Chain joint tribometer

The chain joint tribometer (Figure 1) was developed to test a single chain joint under real application loads. A single chain joint, consisting of pin and bush, is installed into specific adapters and impinged with the defined tensioning force by a linear actuator. A highly dynamic electric motor propels the rotation and swivel movement of the test pin. The test rig control system allows a nearly free definition of load collectives with swivel angles and tension load conditions. Besides stationary operations, also complex load collectives with different swivel angle and tension load levels are possible, which reproduce real operations concerning to median load, frictional power, and several load alternations. This opportunity allows defining a load collective by using an MBS simulation model to transfer the dynamic behavior inside a chain joint. Wear of pin and bush increases the clearance inside the chain joint. An online wear measurement using two eddy current sensors determines the wear of pin and bush in an assembled state. This systeminstrumentation enables a closer look at the running-in wear and wear progression over a more extended test period without having to measure the components on an external device. The wear progress can be measured more efficiently, and influences of stop and startup processes are decreased. Both eddy current sensors are stiffly connected to the chain joint installation adapter at the linear actuator and measure the distance to the surface of the drive shaft. Oblique positions or tilting regarding installation are compensated in the analysis by using two sensors. The friction torque, which results from the combination of swivel movement and tensioning force, is induced into a three-axis force sensor. Regarding the kinematic conditions and distance between the force sensor and test chain joint, the logged reaction force is converted to the friction torque inside the chain joint contact area. To achieve nearly realistic driving conditions and the identification of the effect of different lubricants on wear and friction, a proprietary oil supply unit is used to deliver a defined lubricant flow with temperatures up to 120°C. A stirring unit inside the lubricant reservoir keeps added particles like synthetic carbon black in suspension. Several available nozzles supply the test chain joint with lubricant in any positions and with adjustable flow rates. For compensation of manufacturing tolerances, the test-joint position is adjusted to the ideal rotational axis of the drive motor. A vertical and a horizontal adjustment helps to level out precisely the eccentricity between the test joint and the drive shaft axis. Additional information about the chain joint tribometer can be found in [5-7].

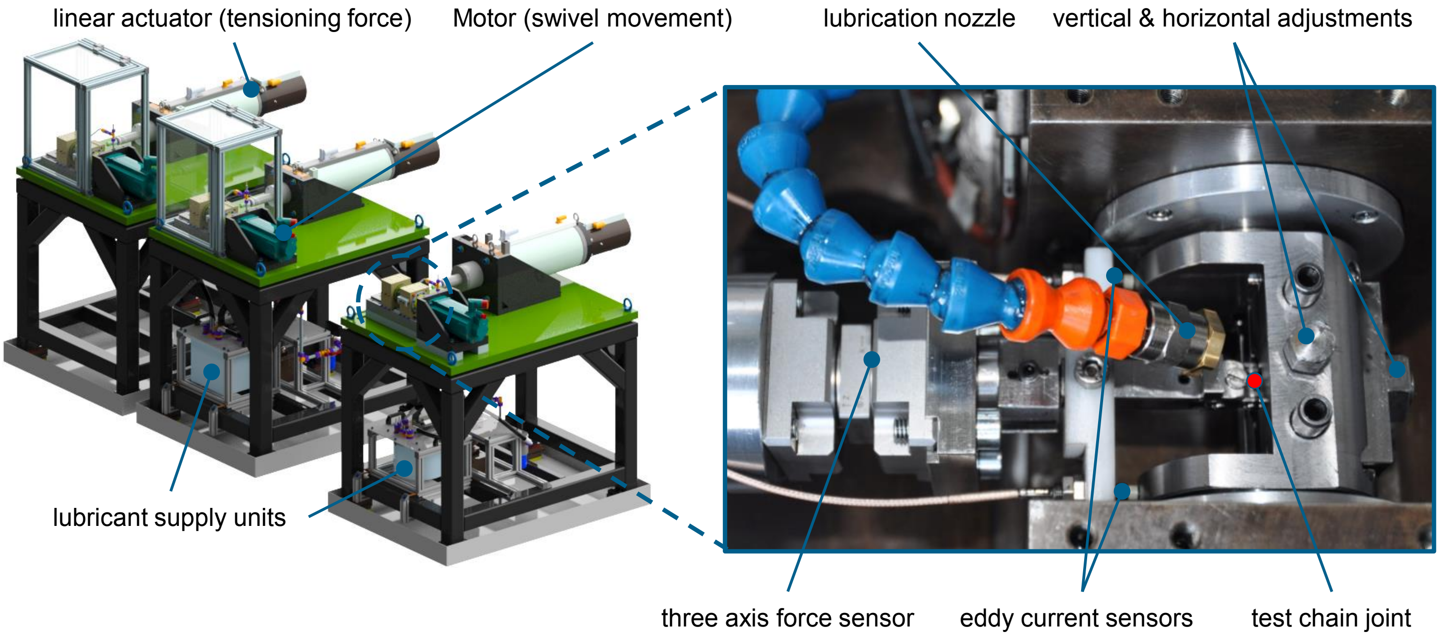


Figure 1: Chain joint tribometer for friction and wear investigations on single chain joints

MULTIBODY SIMULATION

Concurrent to experimental wear investigations, MEGT created a multi-body simulation (MBS) model of the described chain wear test rigs. This model images the real processes and physical parameters inside a chain drive, which cannot (or only with high effort) be monitored during experimental investigations. These parameters are, e.g. relative movement of the chain parts, friction length in a chain joint or progression of the normal force in tensional direction. The results are summarized in load collectives, which can be used as input data for the actuators of the chain joint tribometer. The MBS model was validated by optical chain track measurement, which was recorded during a pre-tensioned test run on the chain wear test rig [2, 8]. The results of such a simulation are shown in Figure 2 a), where all movements, including the negative swivel angle of the slack strand and its contact forces, are evident.

Comparison of chain wear test rig and chain joint tribometer

For the experiments described below, serial state bush chains with a chain pitch of 8mm are used. A case-hardened 16MnCr5 pin is installed to a case-hardened bush made of 10NiCr5-4. To represent real lubrication conditions with a low viscosity oil for modern combustion engines, all test chain joints are lubricated by a fully synthetic poly-alpha-olefin (PAO) of 0W-20 class. Carbon black with a primary particle size of 27nm was added to the oil (1 wt.-%) to emulate the soot entry inside combustion engines. This additive mediates the particle size of gasoline- (30–40nm) and diesel-carbon black (15–25nm).

After first tests with different operating conditions, a wear investigation test was implemented on the chain joint tribometer and compared to the results of wear investigations on the chain wear rigs. The chain wear rigs were driven with a drive speed (big sprocket) of 200 and 500 rpm and 40 Nm tensioning torque (load in tensile strand: 800 N). In order to get comparable contact conditions on the chain joint tribometer, the results of the MBS model were used as input data for the two actuators. Thus, the test joint is loaded with the swivel angle and contact force of the left test chain on the chain wear test rig. Figure 2 b) shows the averaged wear elongation curves of tests done on the chain wear rig and the chain joint tribometer over a measurement period of 50 h. The stationary wear rates for both speeds are nearly identically, while the run-in wear behavior on the chain joint tribometer is a bit more pronounced. The outer contour of the pins and the inner contour of the bushes after the experiment for both test rigs is shown in Figure 3. Detailed measurements of the wear on the single components verify a high consistency of wear depth, distribution, and angle.

Friction investigations

In addition to the wear investigation, first tests of the friction measurement in a chain joint were conducted on the chain joint tribometer. In the first experiments, the friction coefficient of the chain-joint contact was investigated in correlation to the lubricant conditions. Before the experiments, all chain-joint parts were cleaned using an ultrasonic bath, installed and driven without any lubrication. The applied load curve was defined as a triangular signal (±10° swivel angle, 4Hz) with a constant tensioning force of 100N. After 30s of dry running, a lubricant supply of 0.5 l/min was applied to the chain joint. Figure 2 c) shows the measured reaction torque during the test period. The addition of lubricant to the friction contact leads to a significant reduction of the friction torque. In correlation to the geometric relations of the test configuration, the friction coefficient is determined. A coefficient of 0.61 for a dry run and 0.12 for lubricated conditions was measured. These results are in a good agreement with results of SAPPOK et al. [3] and COENEN [9] on a pin-disc tribometer, which correlates concerning material pairing, lubrication, and contact forces.

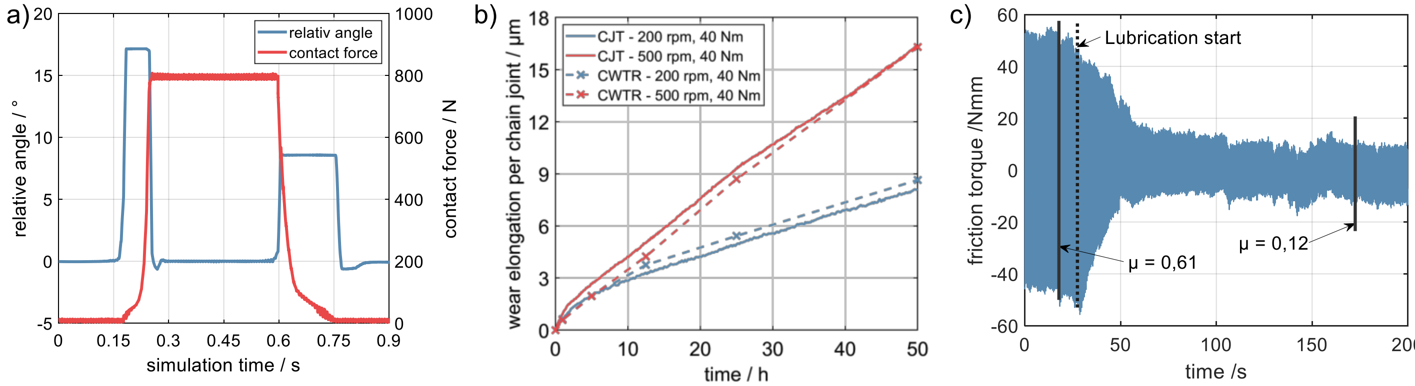


Figure 2: a) MBS Results: Load collective consisting of relative angle and contact force for a single chain joint on the chain wear test rig (left chain, n = 200 rpm, T = 40 Nm); b) Comparison of tests on the chain joint tribometer (CJT) and the chain wear test rig (CWTR): Wear progress during a test period of 50 h with suitable load conditions (PAO +1 wt.-% soot, 70°C oil temperature); c) Friction torque measurement on the chain joint tribometer: Comparison between dry running and lubricated chain joint contact (PAO +1 wt.-% soot, 70°C oil temperature)

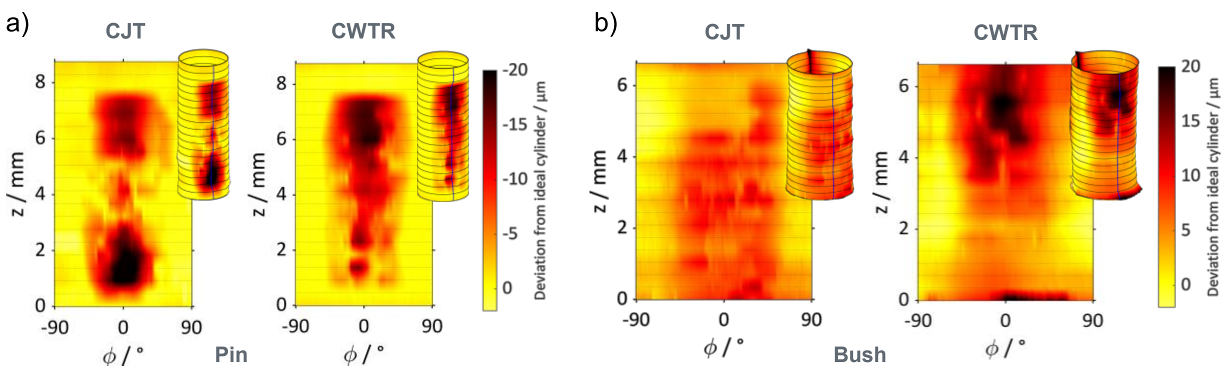


Figure 3: Results of roundness measurement of pin (left) and bush (right) of chain wear test rig (CWTR) and chain joint tribometer (CJT) after 50h runtime

ACKNOWLEDGMENTS

All presented results were thankfully funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation)—Project number 172116086—SFB 926, subproject CO2.

REFERENCES

[1] Fink, T., Bodenstein, H., 2011, “Möglichkeiten der Reibungsreduktion in Kettentrieben“, MTZ – Motortechnische Zeitschrift, 72 (7–8), pp. 582–587.
[2] Sappok, D., 2016, “Experiment und simulative Methoden zur Untersuchung der Verschleißvorgänge im Kettengelenk von Antriebs- und Steuerketten”, Ph.D. Thesis, TU Kaiserslautern.
[3] Sappok, D., Merz, R., Sauer, B., Kopnarski, M., 2015 “Surface analysis of chain joint components after tribological load and usage of anti-wear additives”, Conference Papers in Science - European Symposium on Friction, Wear and Wear Protection, London.
[4] Sappok, D., Sauer, B., 2015, “Wear Measurement on Chain Joint Components Using a Roundness Instrument”, Periodica Polytechnica Mechanical Engineering 59(2), pp. 51–59.
[5] Becker, A., Sauer, B., 2018, “Wear investigations on timing chains using a chain joint tribometer”, 73th STLE Annual Meeting, Minneapolis.
[6] Becker, A., Sauer, B., 2018, “Verschleiß- und Reibungsuntersuchungen am Bolzen-Hülsen-Kontakt von Steuerketten mit einem Einzelgelenkprüfstand“, 59. Tribologie-Fachtagung (GfT): 18/1–18/10
[7] Becker, A., Meffert, D., Sauer, B., 2019. “Friction and wear investigations on single chain joints”, Forschung im Ingenieurwesen 83 (1), pp 53–63.
[8] Becker, A., Krupp, F., Sauer, B., 2017, “Systematische Verschleißuntersuchungen an Kettenkomponenten“, 58. Tribologie-Fachtagung (GfT): 11/1–11/10.
[9] Coenen, W., 1984, “Einfluss der Schmierung auf das Verschleißverhalten von Rollenketten,. Ph.D. Thesis, RWTH Aachen University.

KEYWORDS

Chain Drives, Wear Mechanisms, Wear/Failure Testing Devices

MASCHINENBAU UND
VERFAHRENSTECHNIK

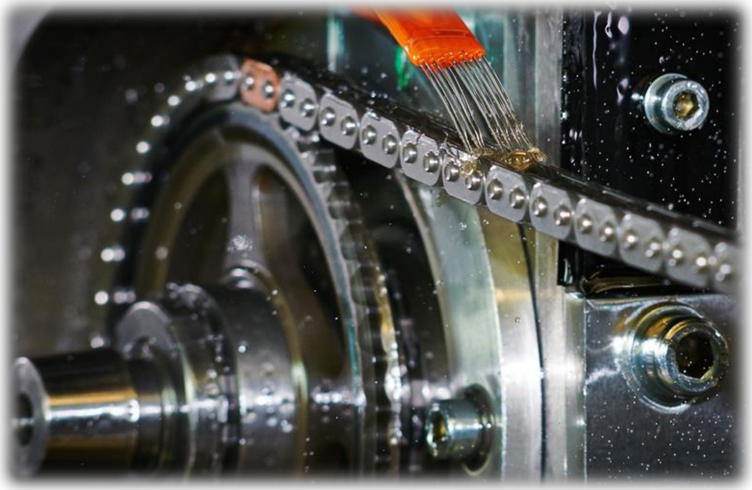
MEGT

Institute of Machine Elements, Gears & Transmissions
Prof. Dr.-Ing. B. Sauer

TECHNISCHE UNIVERSITÄT
KAISERSLAUTERN

2019 STLE Annual Meeting

Friction and Wear Investigations on Chain Joints of Timing Chains



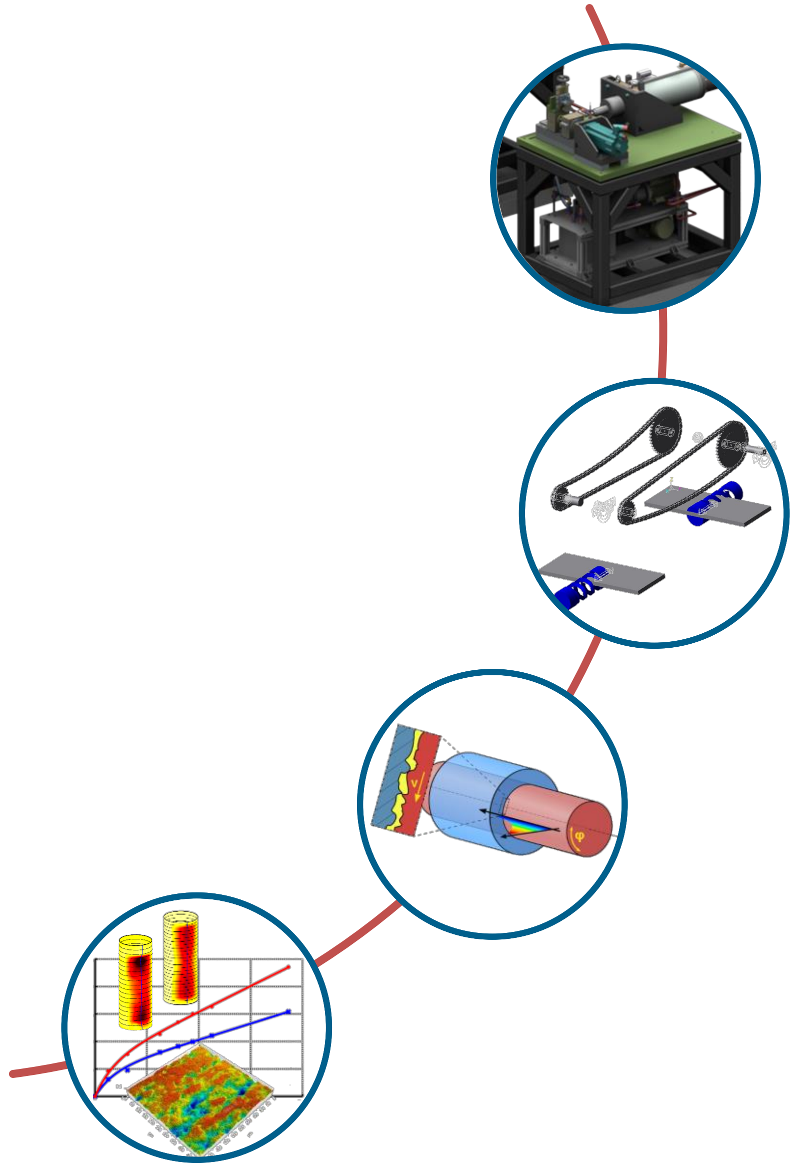
May 21th, 2019

Dipl.-Ing. A. Becker

Prof. Dr.-Ing. B. Sauer

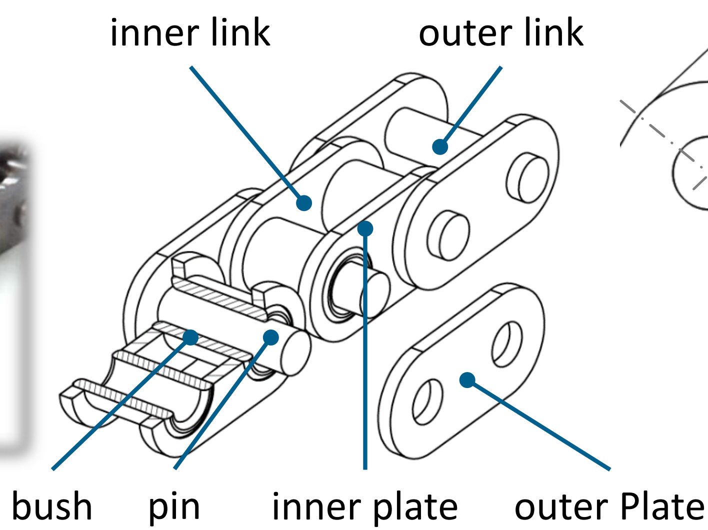
Content

- **Introduction**
- **Experimental methods**
- **Analytical methods**
- **Results**
- **Conclusion & Outlook**

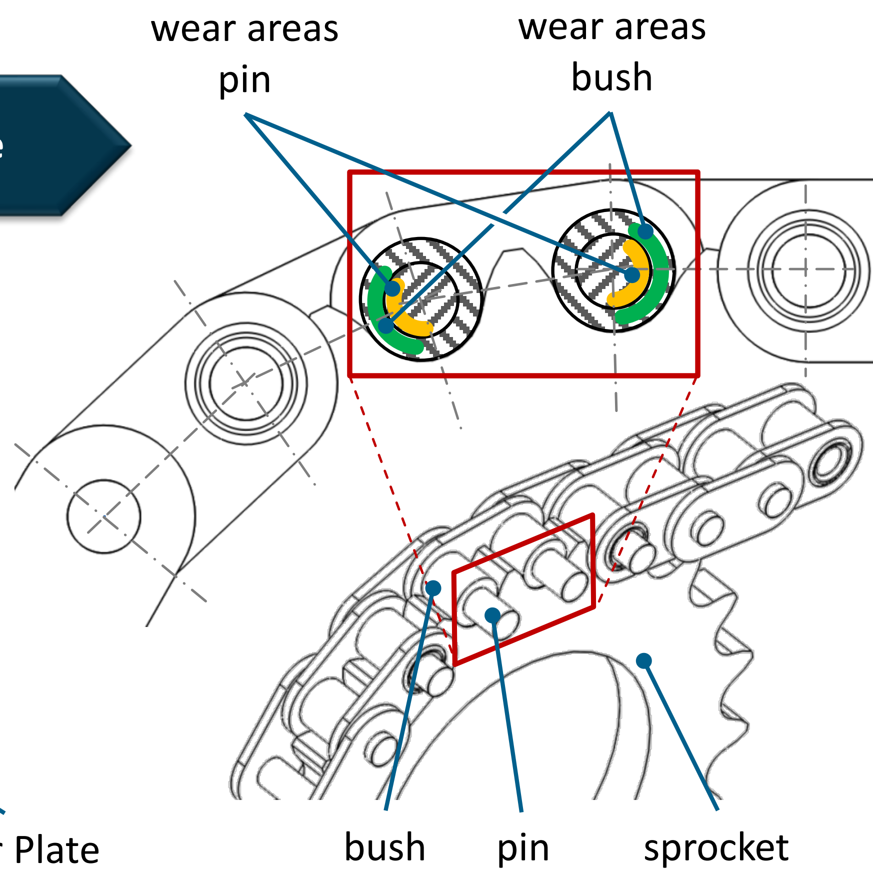


Introduction – Chain Joint Wear

Bush chain



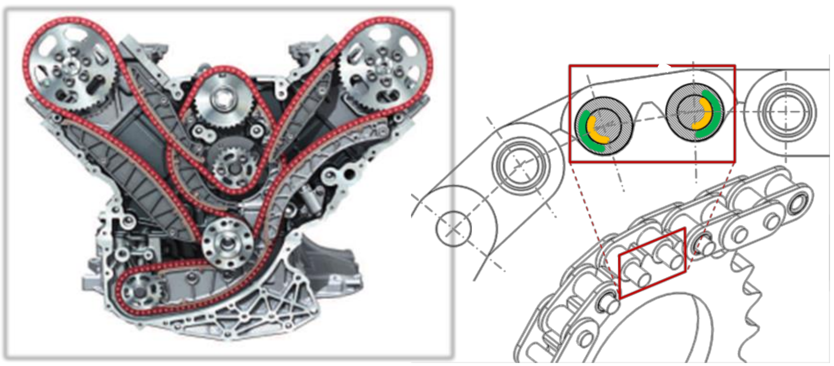
Components of bush chain

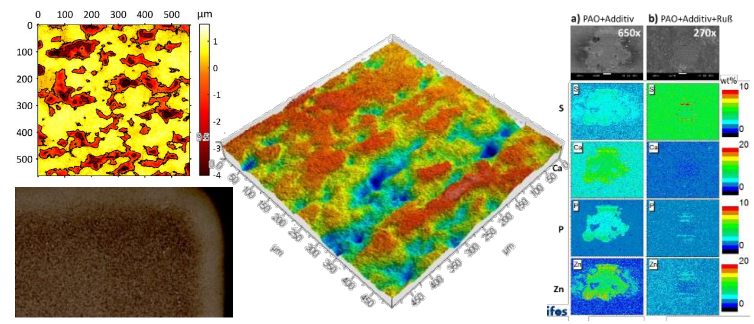


Wear areas in bush chain joint

Introduction – Chain Joint Wear

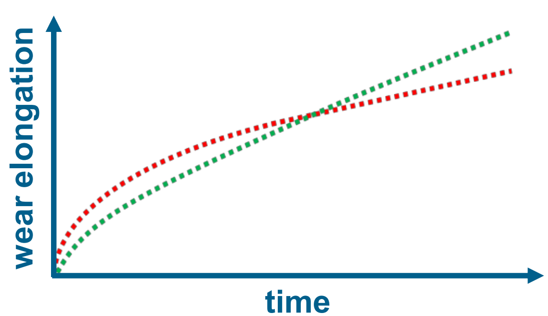
- Wear in chain joints determines the lifetime of the entire chain
- Understanding wear mechanisms is essential for reducing wear
- Tribological contact is influenced by various parameters





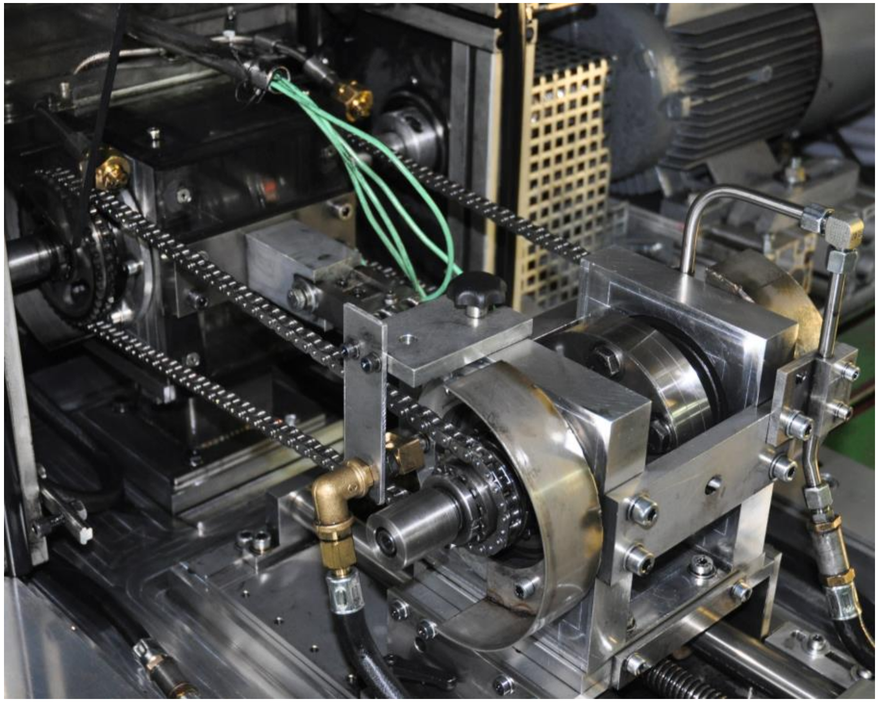
Material, surface structure & chemical composition

Operating conditions

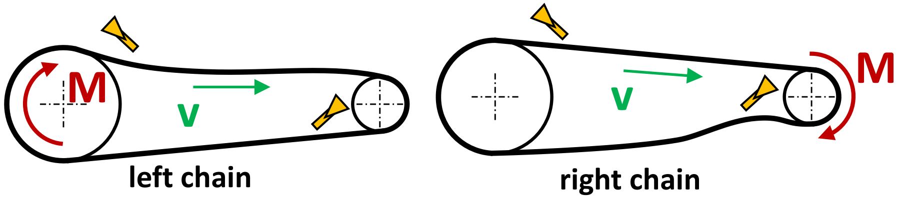


Modifications

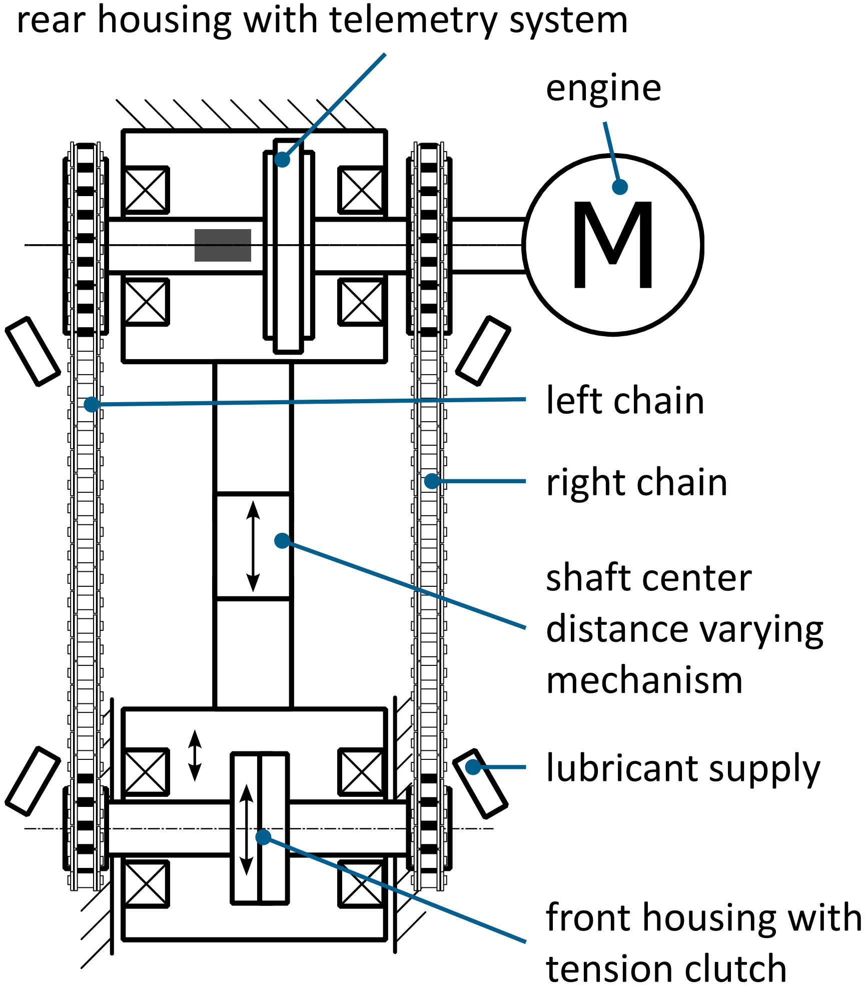
Chain Wear Test Rig



Modular chain wear test rig



Drive Layout

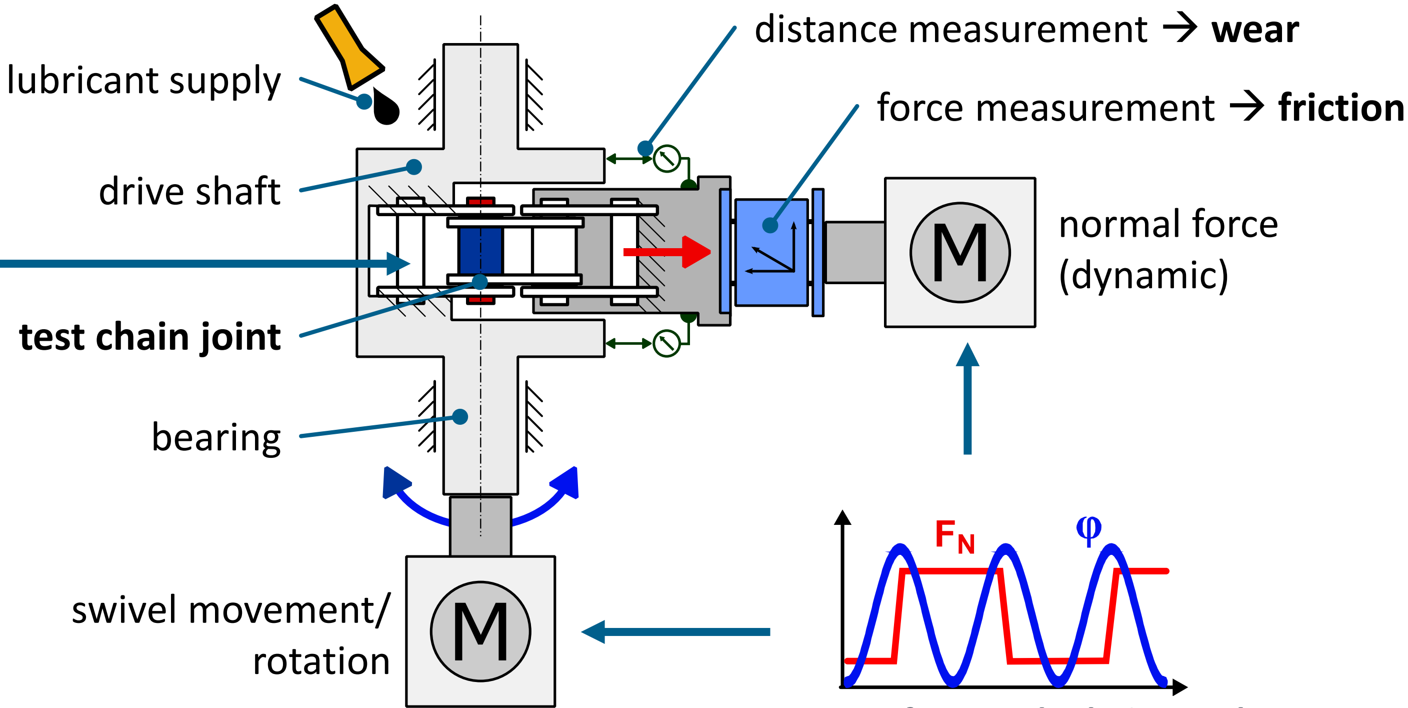


Schematic representation

Chain Joint Tribometer

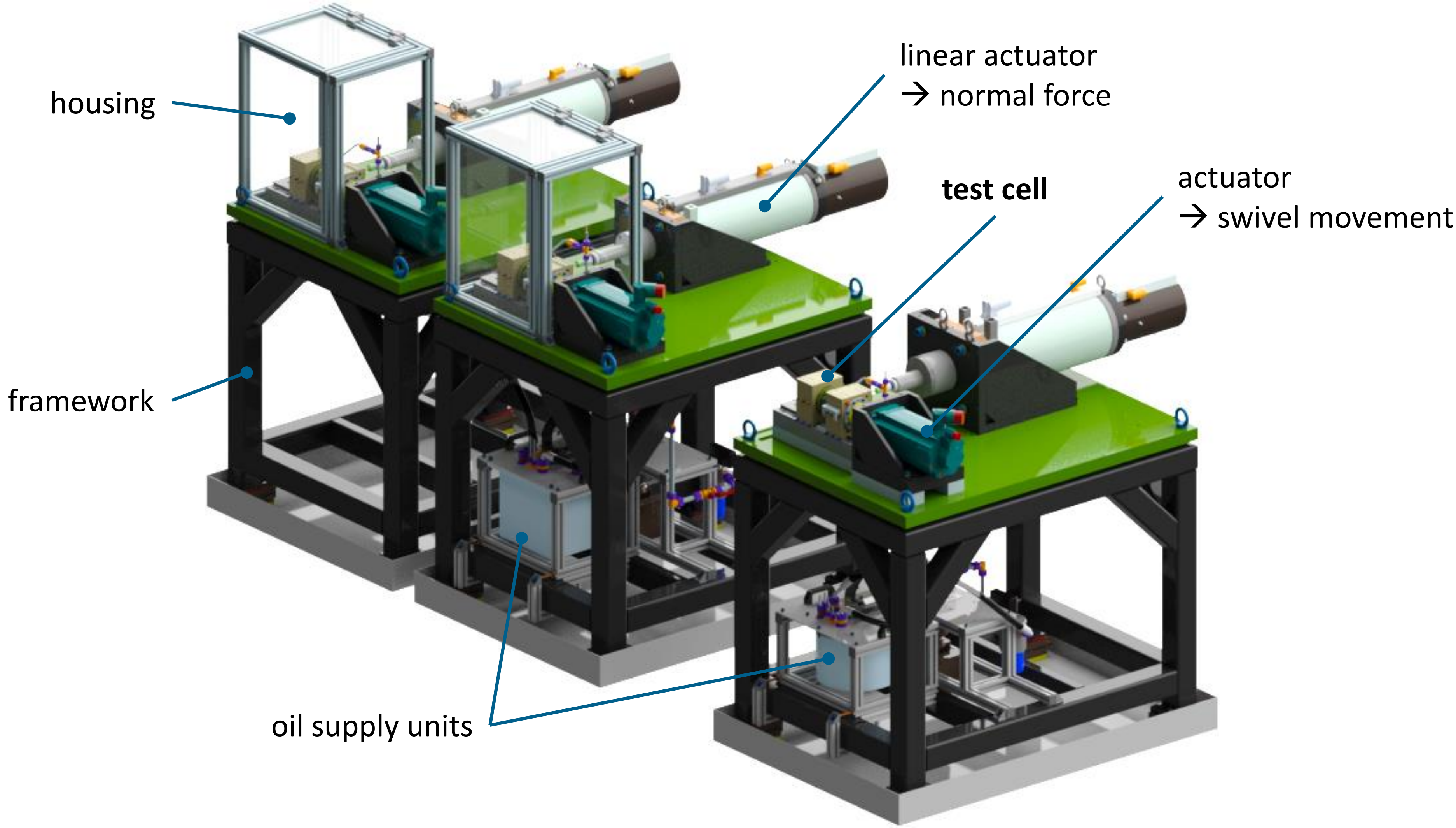
- Friction and wear investigations on single chain joint
- Real contact situation with batch production components
- Load curves from Multi-Body simulation

Chain section on chain wear test rig

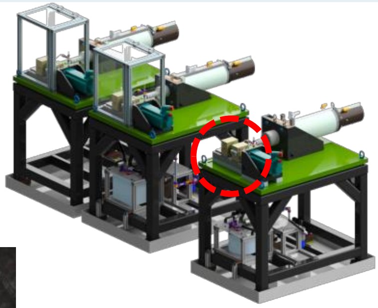


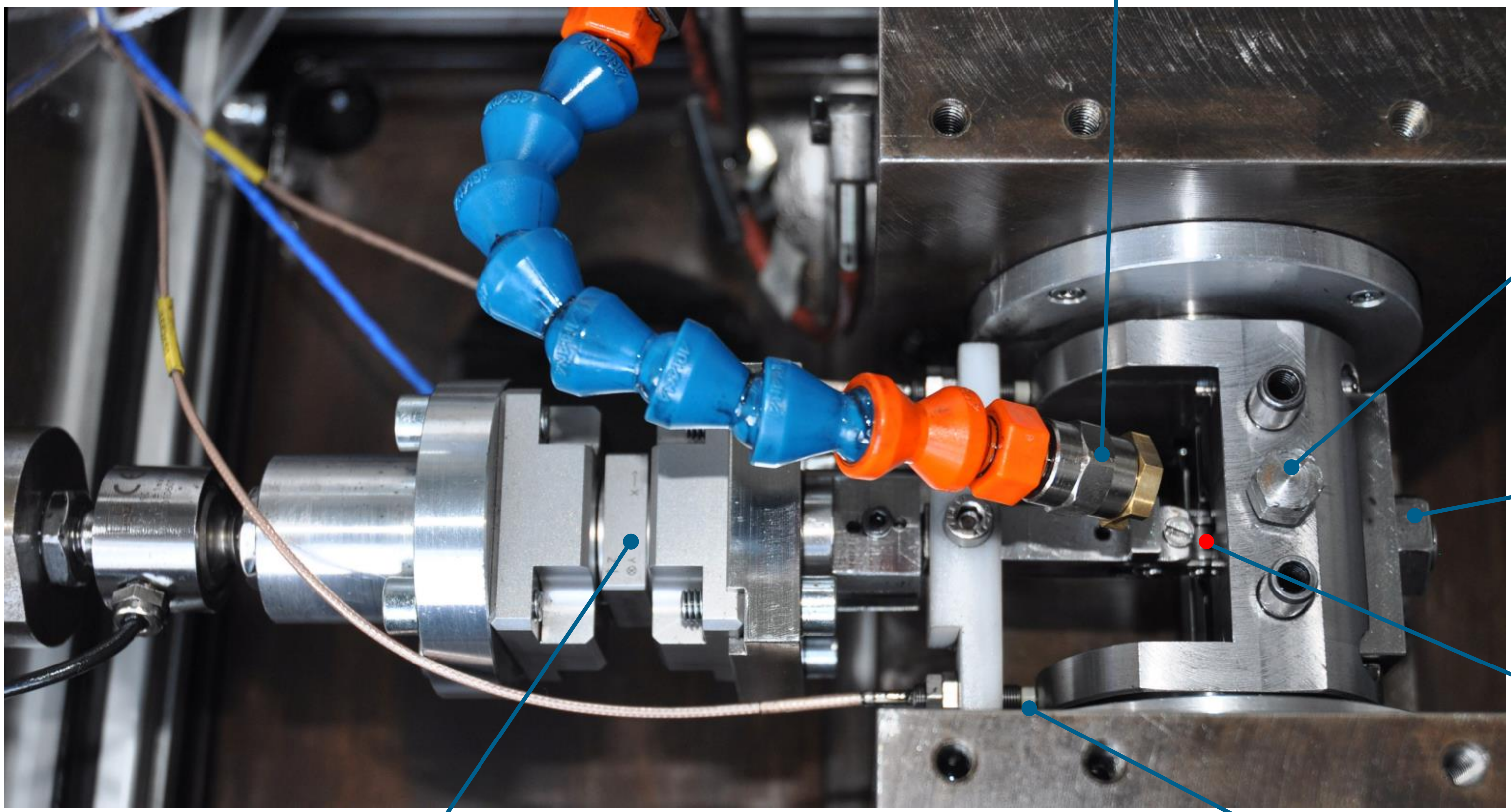
Contact force and relative angle

Chain Joint Tribometer



Chain Joint Tribometer



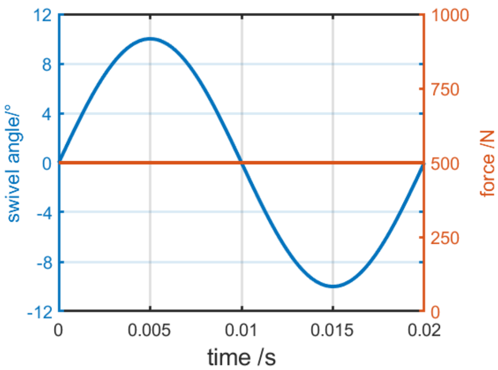


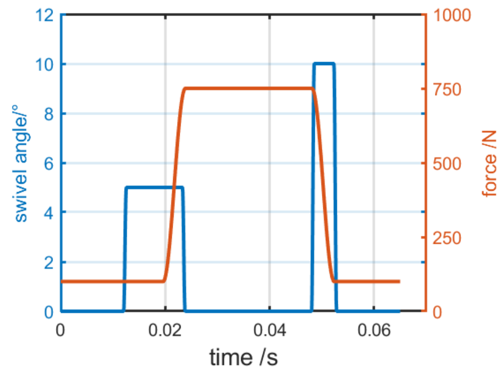
Chain Joint Tribometer

Operating conditions

- Normal force: 1 … 11.000 N
- Swivel angle: 0 … 360°
- Oil temperatur: 20 … 125°
- Oil flow rate: 0 … 1 l/min

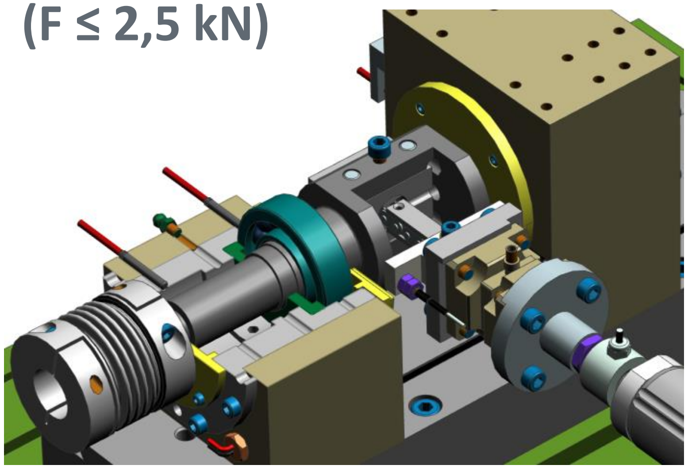
Test cycles



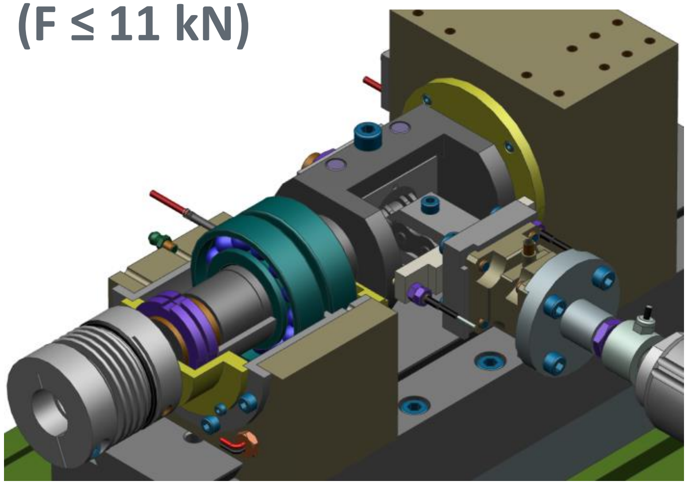


Modular design

- Configuration for timing chains (F ≤ 2,5 kN)



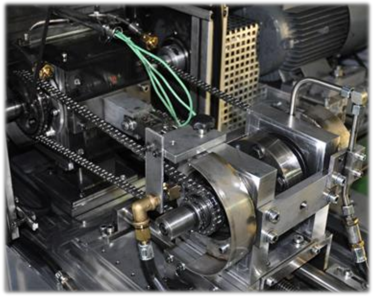
- Configuration for drive chains (F ≤ 11 kN)



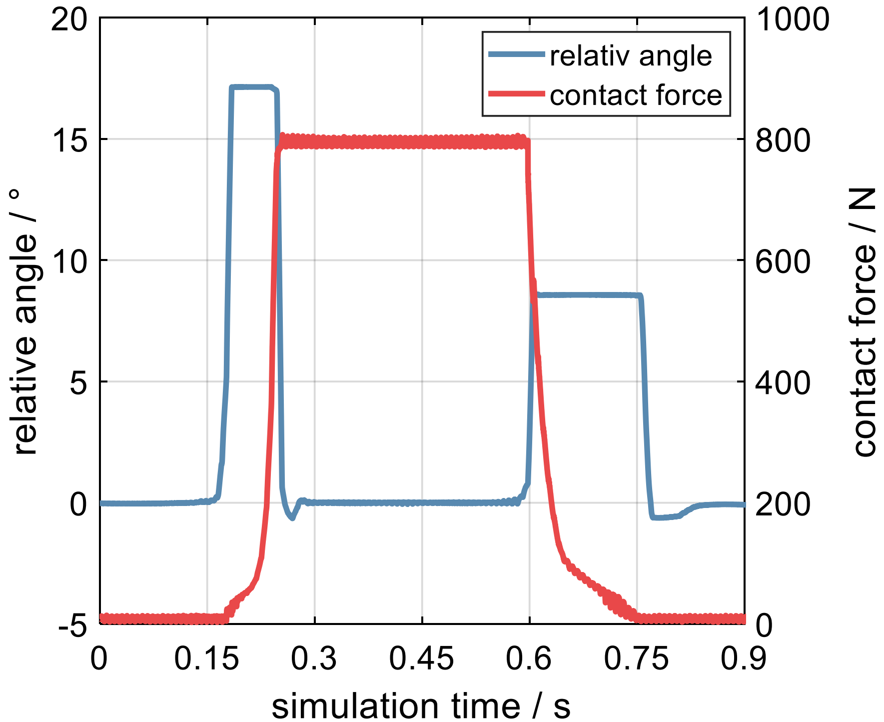
Multi-Body Simulation

MBS-Model Chain Wear Test Rig

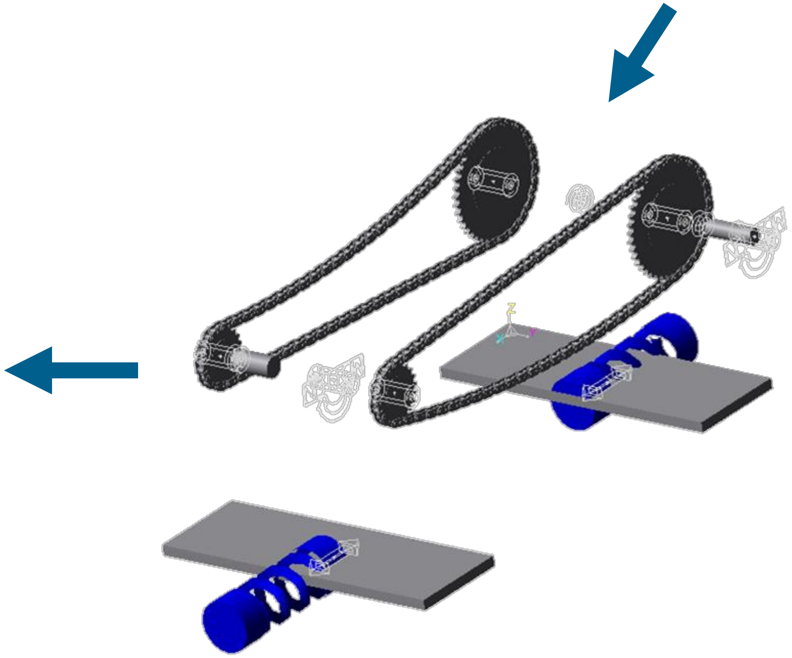
- **Calculation of inner loads in the chain joint**
- **Input data for the chain joint tribometer**



Chain wear test rig



Results

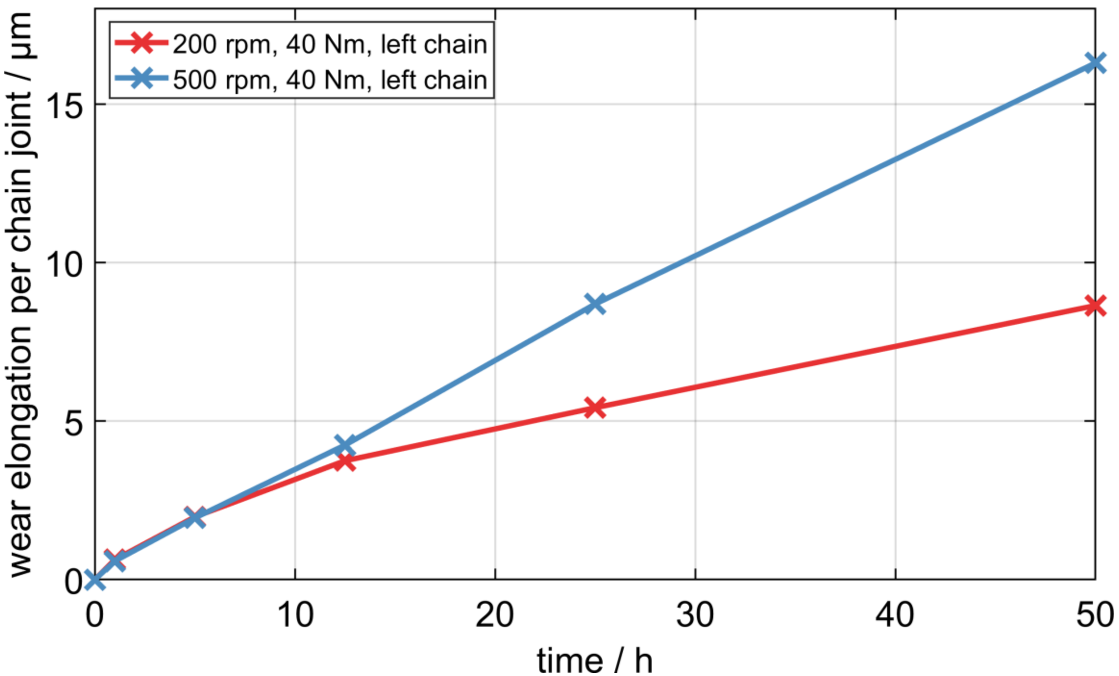


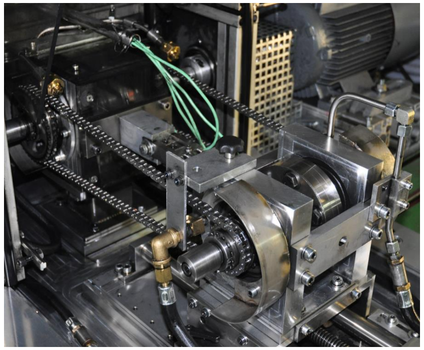
MBS-Model

Results

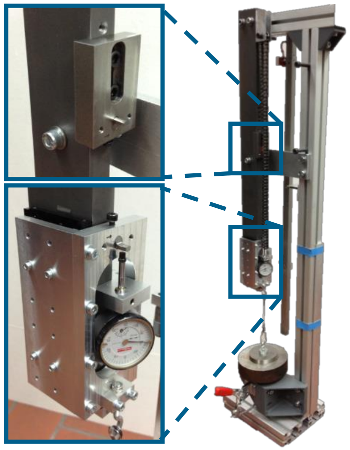
Comparison: Chain Wear Test Rig ↔ Chain Joint Tribometer

- **Test run on chain wear test**
  - Speed: 200 rpm & 500 rpm
  - Load: 40 Nm → 800 N
  - Oil: PAO with Additive & Soot, 80°C , 0,55 l/min





Chain wear test rig

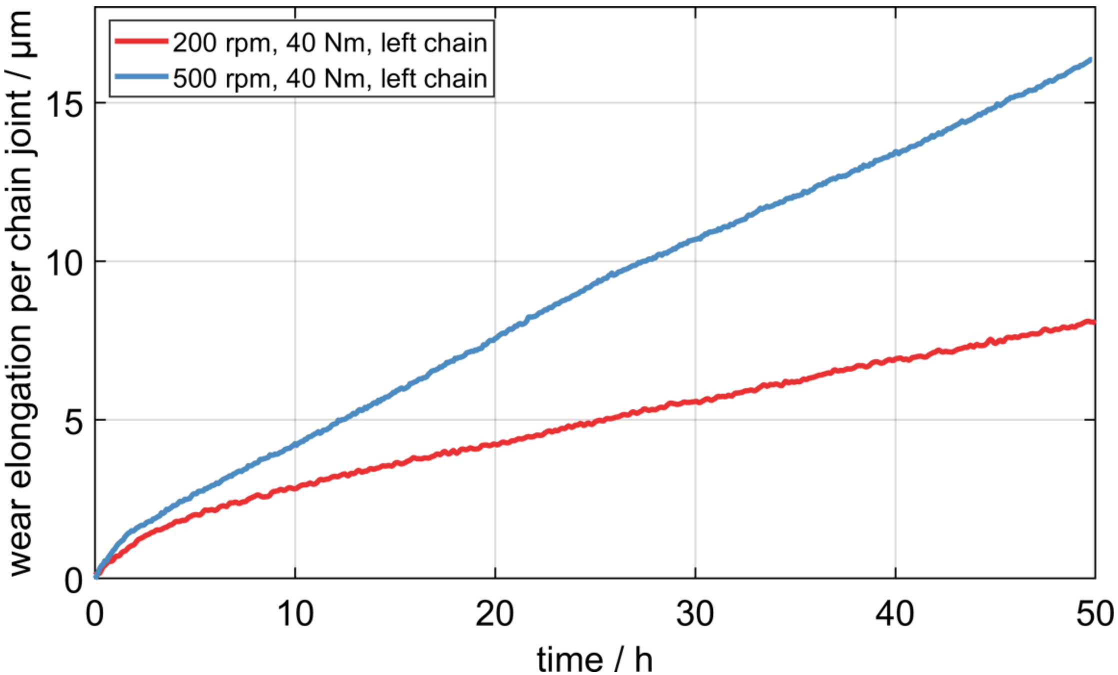


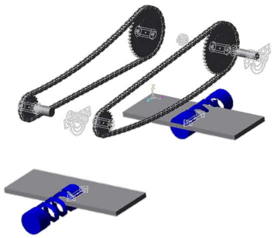
Length measuring device

Results

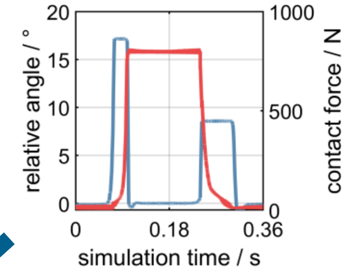
Comparison: Chain Wear Test Rig ↔ Chain Joint Tribometer

- **Test run on chain joint tribometer**
  - Load curves from MBS-Model of chain wear test rig
  - Oil: PAO with additive & soot, 80°C , 0,55 l/min

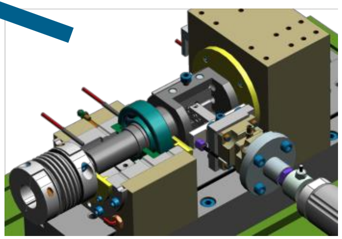




MBS-Model



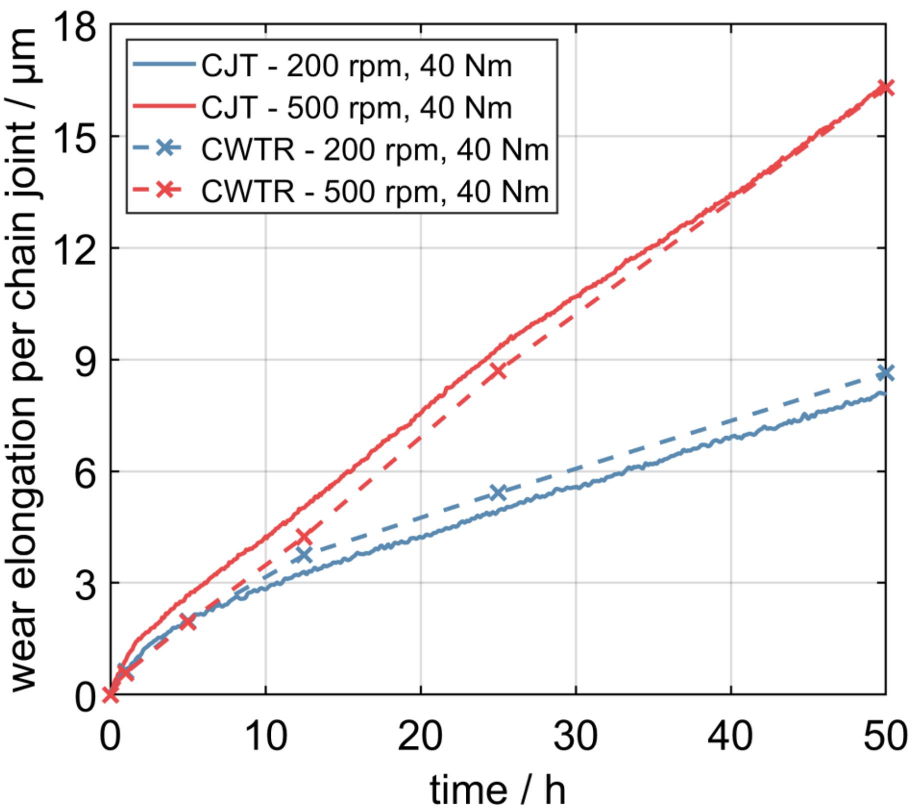
Load curves

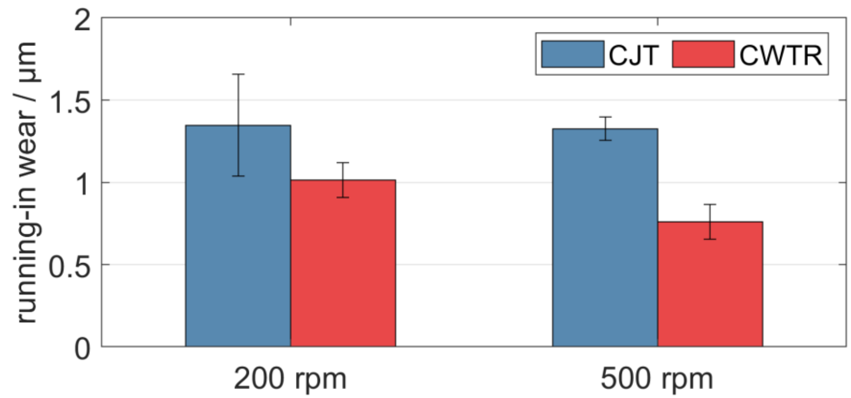


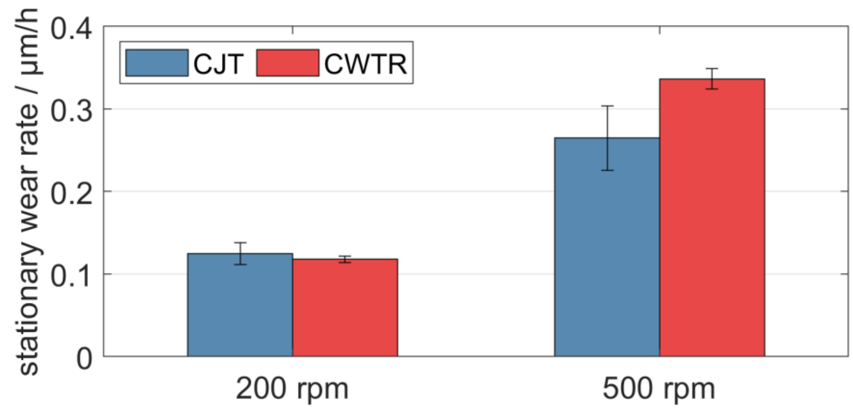
Chain joint tribometer

Results

Comparison: Chain Wear Test Rig ↔ Chain Joint Tribometer

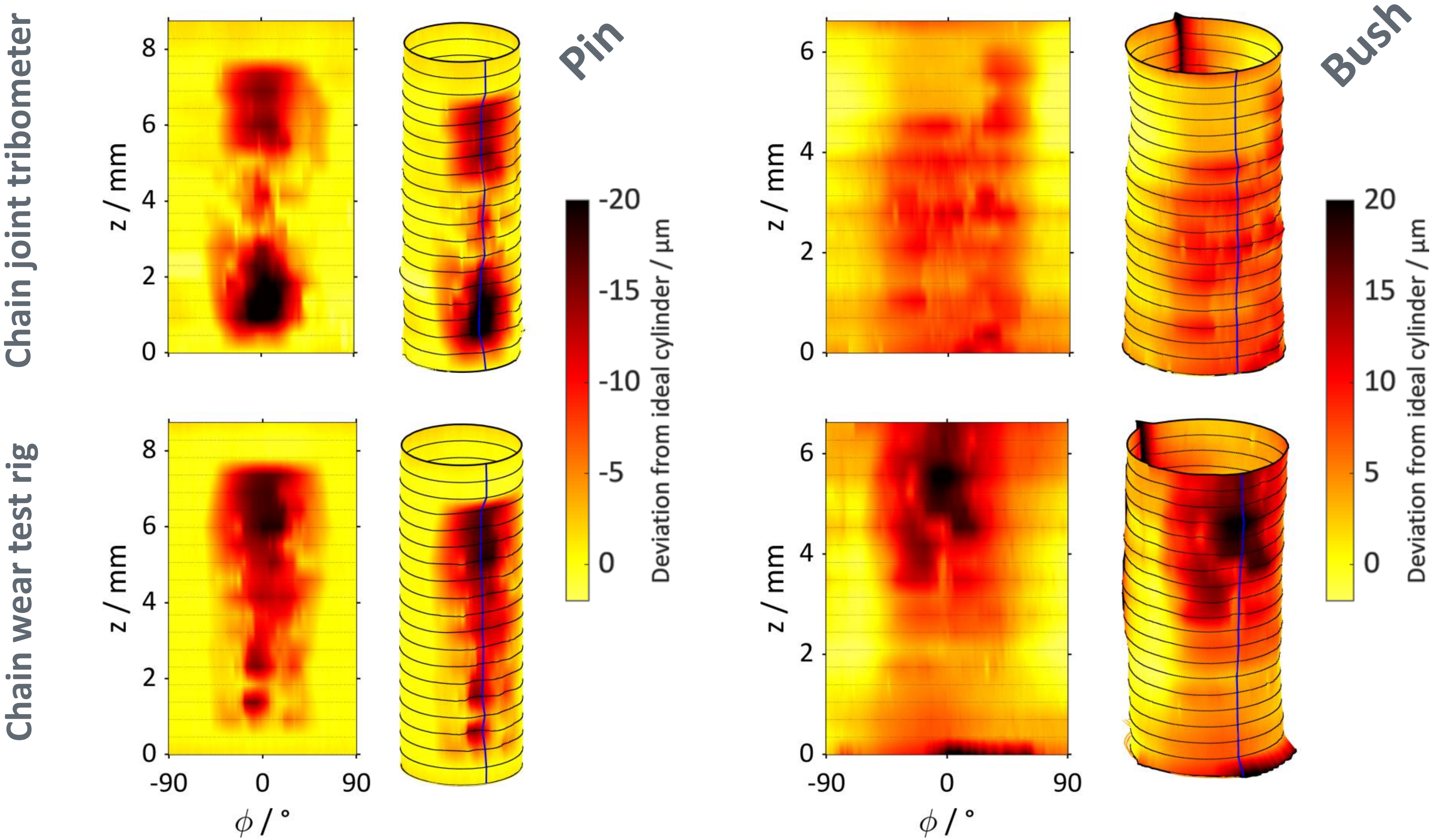




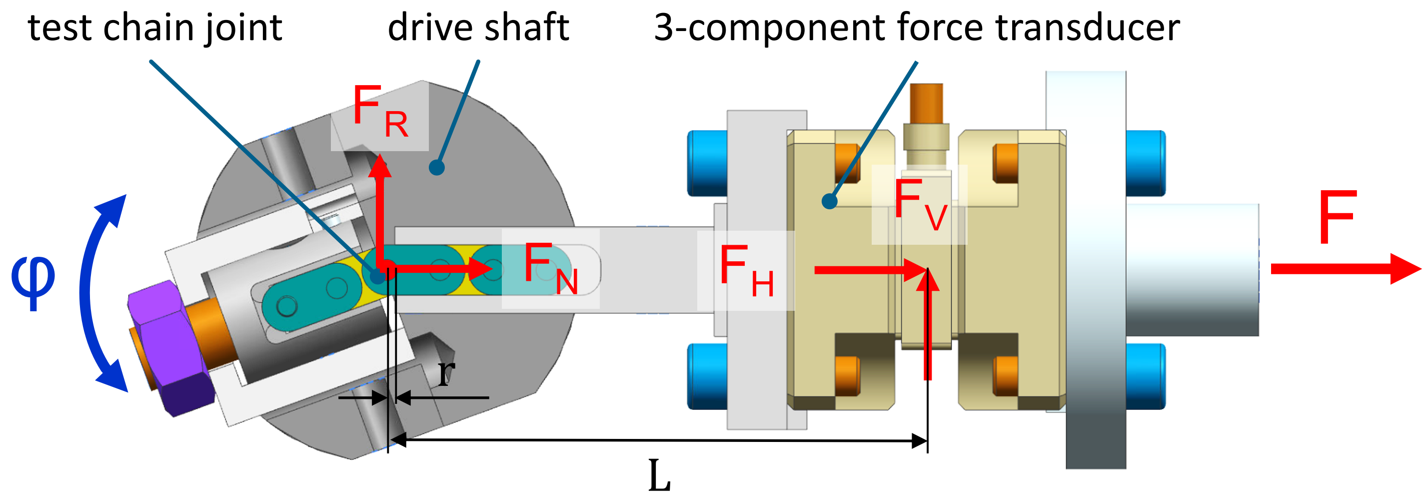


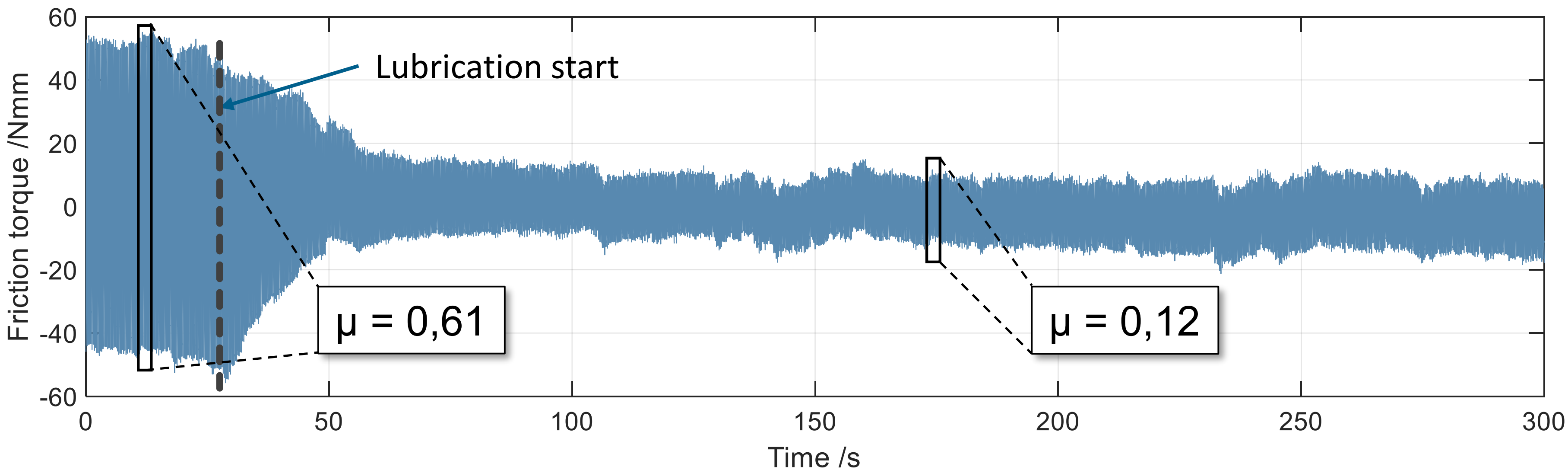
CJT = Chain joint tribometer CWTR = Chain wear test rig

Results – Form Measurement



Results – Friction Investigations





Conclusion & Outlook

- **Conclusion**
  - Experimental and simulative methods for wear and friction investigations on timing chains
  - Chain joint tribometer as a supplement to the chain wear test rig
  - Results:
    - Comparison between chain wear test rig and chain joint tribometer
    - Good correlation between the two test rigs
    - First results of friction investigations

- **Outlook**
  - Investigation of chain pins with modified surfaces

Thank you for your kind attention!

Dipl.-Ing. Andre Becker

Mail: andre.becker@mv.uni-kl.de

Tel.: +49 631 205-2858

The authors would like to thank the German Research Foundation (DFG) for the support of the research within the Collaborative Research Centre 926 “Microscale Morphology of Component Surfaces” (MICOS), subproject C02.