# Effects of unevenly worn cage pockets on the service life of a solid lubricated rolling bearing

**TRACK OR CATEGORY**
Session 4D, Wear II

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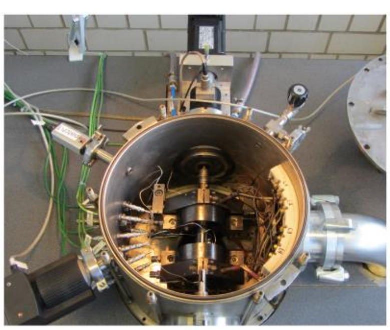
**INTRODUCTION**

Solid lubricated rolling bearings are used in many technical systems where conventional lubrication, such as oil or grease, fail due to the critical conditions like vacuum or high temperatures. Molybdenum Disulfide ($MoS_2$) and Silver (Ag) has proven itself as a dry lubricant that has excellent tribological characteristics and therefore is also used in rolling bearings. Solid lubricated rolling bearings use a polymeric cage endowed with Molybdenum Disulfide ($MoS_2$) particles as a reservoir of lubricant, increasing their service life significantly [1]. During the bearing's operation, solid lubricant from the cage is transferred onto the raceways replenishing the initial lubricant coating of the raceways. Preliminary investigation has shown that uneven wear of the individual cage pockets can occur that causes the pockets to possess different diameters. This results in an effect on the bearing's service life. Therefore, it is necessary to study these effects of unevenly worn cage pockets on the service life of such rolling bearings. This will help in the future to develop a general life estimation model for the solid lubricated rolling bearings. To analyze the real wear process, a four-bearing-vacuum-test-rig is used. Cage pockets with intentionally enlarged pocket diameters of solid-lubricating material are considered. In order to understand the effects of enlarged pocket geometries on the bearing's dynamic, a multi-body simulation model (MBS) is utilized.

**EXPERIMENTAL INVESTIGATION**

In order to gain a sufficient understanding of the description of the phenomenon of the different cage pocket wear, component tests are necessary. These tests are performed on the test setup with a four-bearing-test rig shown in Figure 1 (left). In this test setup, four test bearings (spindle bearing Type 7205) is in operation at the same time in vacuum at a maximum operating temperature of 200°C. Each bearing is loaded combined radially (250 N) and axially (80 N). The shaft system (see Figure 1 right) is installed in a vacuum chamber for this purpose. All the experiments take place under identical boundary conditions, and thus, unwanted environmental influences can be avoided as best as possible. The focus of performing the tests is to consider the intentionally enlarged pocket diameters and analyze their effects on the wear of individual cage pockets and overall frictional moment.



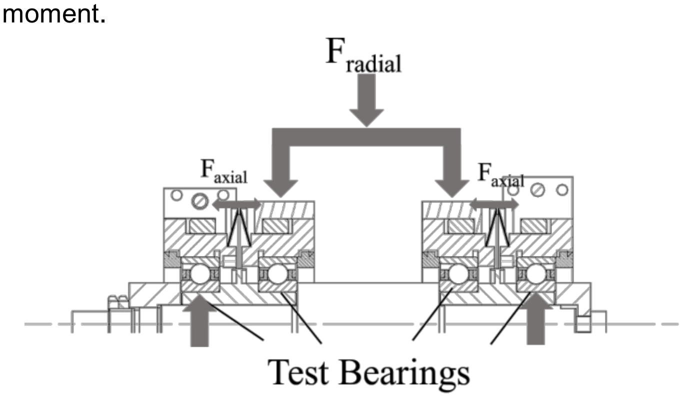



**Figure 1: Four-bearing-test rig at MEGT; Left: Vacuum chamber with shaft system; Right: Schematic of the shaft system carrying four test bearings under axial and radial load.**

**Table 1: Details of the tests performed**

| Test | Run-Time | Initial cage pocket diameter |
|---|---|---|
| Test 1 | 10 million revolutions | 8.0 mm |
| Test 2 | 10 million revolutions | 8.1 mm |
| Test 3 | 10 million revolutions | 8.3 mm |
| Test 4 | 7 million revolutions | 8.5 mm |

Tests mentioned in Table 1 were performed for this research work. From the first initial results, it can be seen from the Figure 2 (left) that average cage pocket wear of the bearings differs from each other within the same test. However, the general tendency shows that increase in the cage pocket diameter causes a substantial reduction in pocket wear. It can also be interpreted that an increase in the cage pocket diameter causes the reduction in the lubrication interval. However, it cannot be said that large cage pocket diameter produces the best results when it wears less because this might affect cage dynamics. Similarly, Figure 2 (right) shows that increase in the cage pocket diameter causes the significant drop in the overall frictional moment because frictional energy dissipation at the cage pocket has a considerable influence on the overall frictional energy dissipation within the bearing. It can be seen that the increase in cage pocket diameter from 8.0 mm to 8.5 mm causes the frictional moment to drop around by 45%.

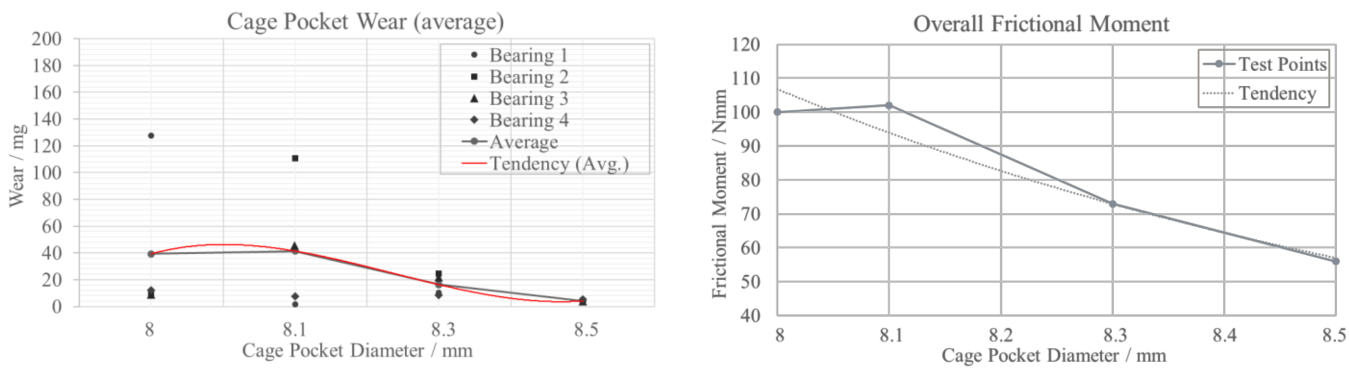



**Figure 2: Effects of enlarged cage pocket diameters on the pocket wear (left) and the overall frictional moment of the bearings (right)**

## MULTIBODY SIMULATION

Dynamic simulations are intended to observe the dynamic responses of a system in motion. MEGT has developed its dynamic models of bearings with the commercially available software MSC. Adams and self-written user routines [2, 3]. The MBS model describes the dynamic behavior of a bearing through the numerical simulation. The calculation of all contacts in the rolling bearing takes place within self-programmed calculation routines, which receive input data as state variables and parameters from the MBS tool and return the forces and moments as output variables acting in the respective contact.

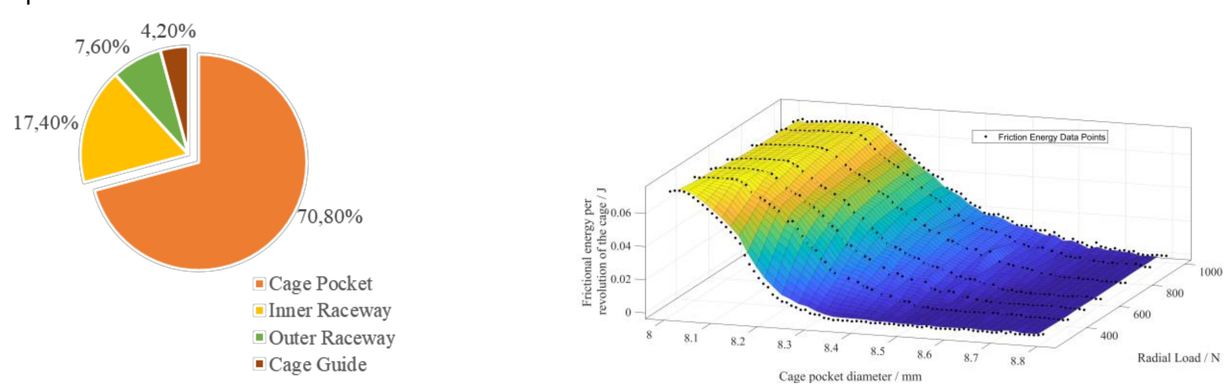



**Figure 3: Left: Share of frictional energy at individual contacts; Right: Influence of cage pocket diameters and radial load on frictional energy at the cage pocket contact for one revolution of the cage**

In this contribution, an angular contact ball bearing model is employed to fulfill the purpose and adapted accordingly. The focus of the MBS model of bearing is to investigate the interaction between the ball-cage pocket contact and the estimation of the functional characteristic like frictional energy at the contact.

Figure 3 (left) shows the exemplary results of the contribution of cage pocket frictional energy out of the total frictional energy [4]. The effects of cage pocket diameters and radial load on the frictional energy per revolution of the cage can be seen from Figure 3 (right). Results are self-explanatory. Figure 4 (left) shows the effects of worn-out cage pockets on the frictional energy at contact. Cage pocket diameters shown in the figure are the resulting diameters (worn-out) from the test and are assigned into the simulation model. It can be seen that pocket wear is uneven and pocket possess different diameters. This cause the pocket clearance to change and shows a substantial effect on the frictional energy at individual contacts. Similarly, it also affects the cage dynamic to a great extent making the cage unstable (Figure 4 right).

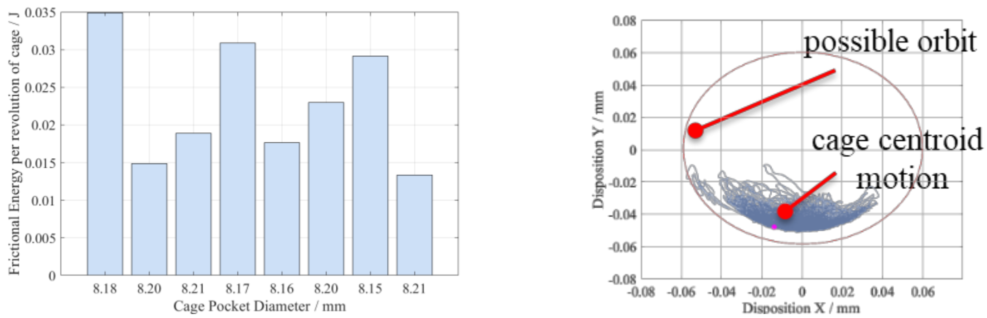



**Figure 4: Effects of worn-out cage pockets on frictional energy at the pocket contacts (left) and the cage dynamic (right)**

## CONCLUSIONS

On the basis of experimental results, it is concluded that increase in the cage pocket diameters cause the overall reduction in the pocket wear and thus the lubrication interval. Enlarged cage pocket diameters tend to reduce the frictional moment. Ambiguous effect on the service life of the bearings has been observed. From the simulation point of view, it can be concluded that increase in cage pocket diameters affect the cage dynamic to a great extent.

## OUTLOOK

More tests need to be performed under various operating conditions in order to analyze the effects of different loads and speeds on the wear behavior of the cage pockets and to validate the simulation model to a certain extent in this case. Simulation model must be developed further in order to consider the flexibility of the cage. Wear model must also be implemented to reproduce the evolution of the cage pocket geometry in the simulation.

## ACKNOWLEDGMENTS

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[1] Marquart, M., Wahl, M., Emrich, S., Zhang, G., Sauer, B., Kopnarski, M., and Wetzel, B., 2013, "Enhancing the lifetime of $MoS_2$-lubricated ball bearings," Wear, 303 (1-2), pp 169–177.

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[3] Teutsch, R., 2005, "Kontaktmodelle und Strategien zur Simulation von Wälzlagern und Wälzführungen", Ph.D. Thesis, TU Kaiserslautern, MEGT.

[4] Pörsch, S., 2019, "Ansätze zur erweiterten Lebensdauerberechnung feststoffgeschmierter Wälzlager", Ph.D. Thesis, TU Kaiserslautern, MEGT.

## KEYWORDS

Solid lubricated bearings, Molybdenum disulfide, Polymeric cage, Cage pocket wear, Multibody simulation, Service life

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74th STLE Annual Meeting & Exhibition


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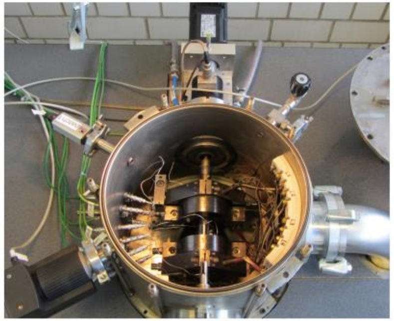
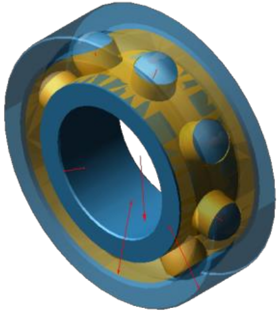
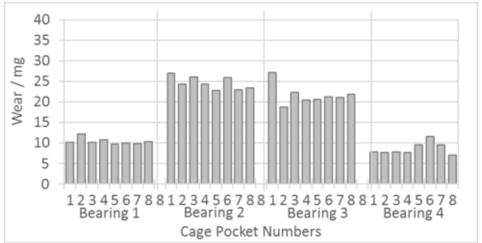
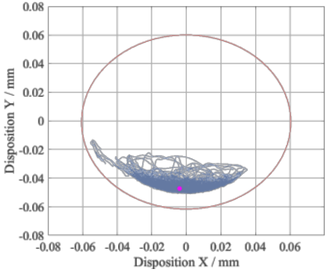


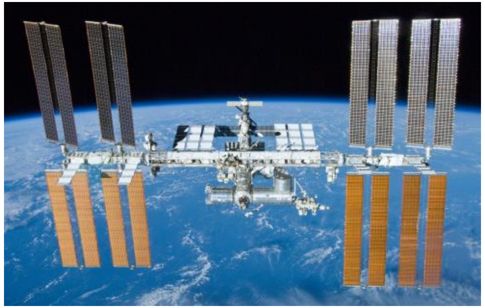


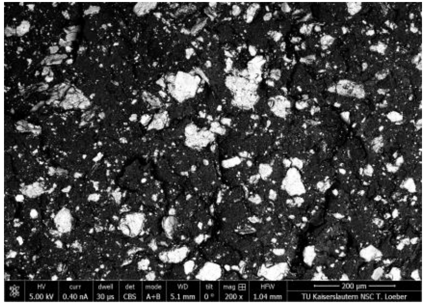


# Introduction

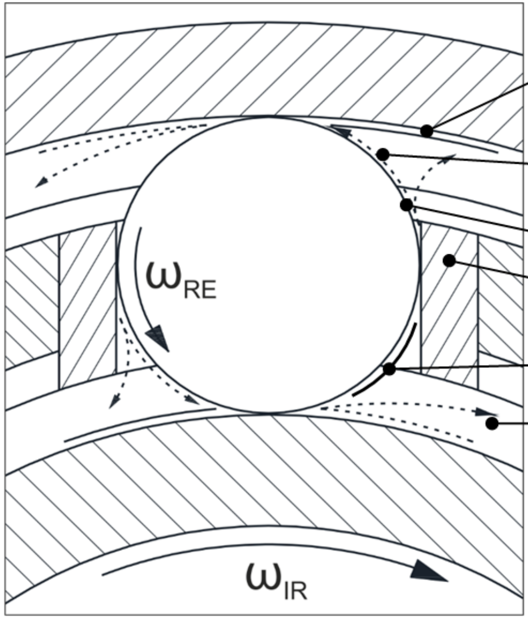
- **Solid lubricated rolling bearings**
  - ➢ conventional lubrication fails
- **Special applications**
  - High & Low temperature
  - Vacuum
  - Space
  - Medical
- **Molybdenum Disulfide ($MoS_2$)**
- **Silver (Ag)**





# Introduction

## *Service life of solid lubricated rolling bearings*

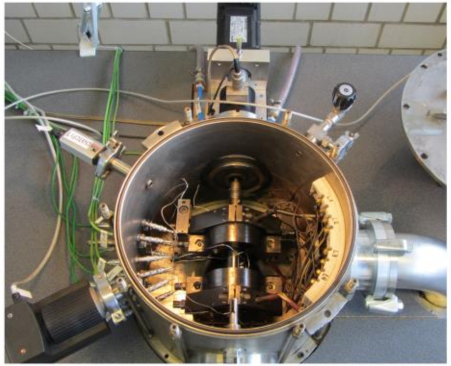


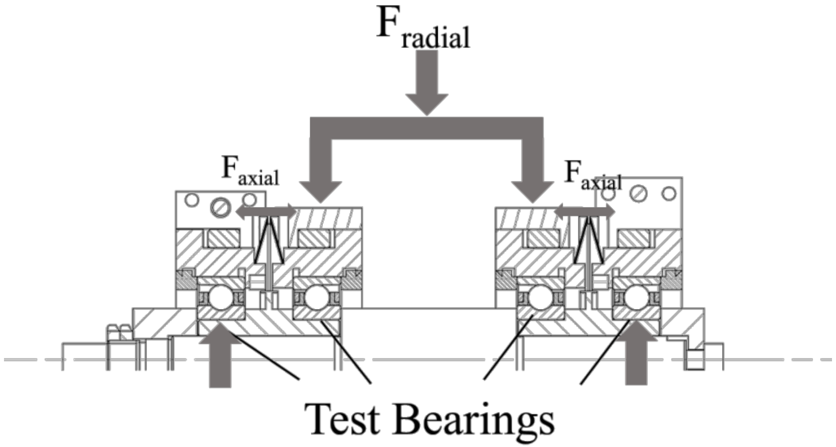
# Motivation

- **Minimal cage pocket wear → Lubrication requirement**
- **Preliminary investigation**
  - **Uneven cage pocket wear - due to various reasons**
  - **Exhibit different pocket diameters**
- **Influences cage dynamic (acoustic) and service life**
- **Effects of unevenly worn cage pockets on the service life**
- **General Life Estimation Model for solid lubricated rolling bearings**

# Investigation Approach

## *4-Bearing-tests*





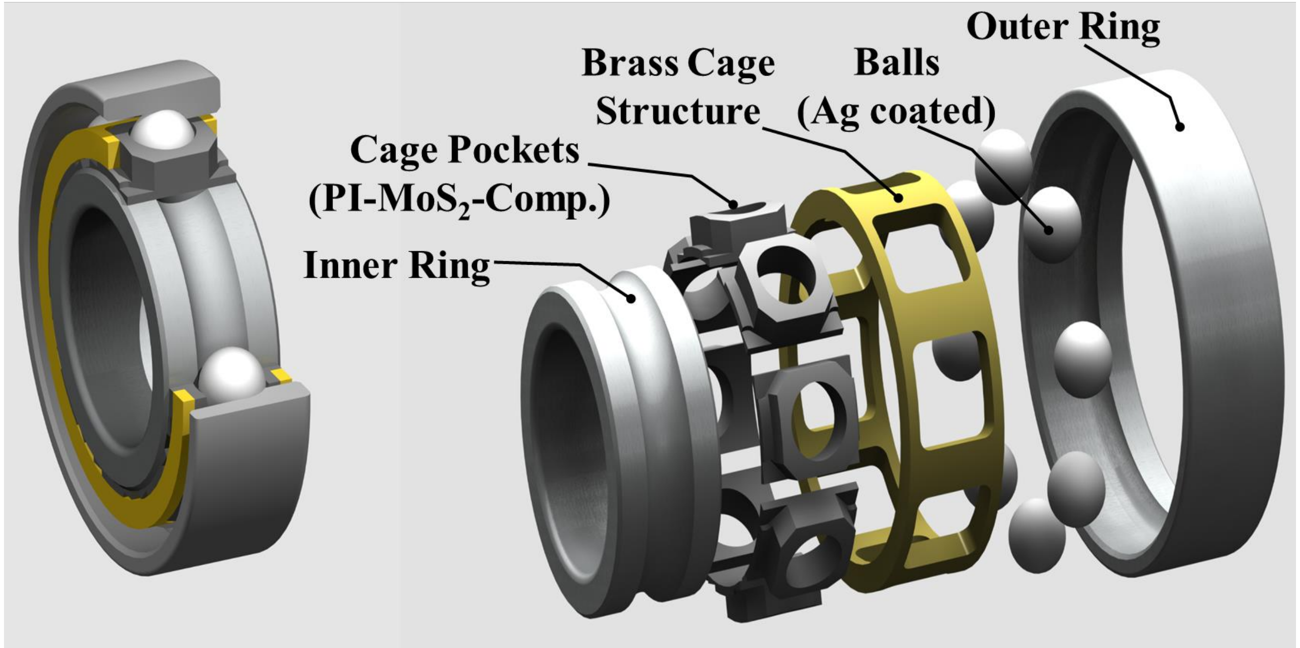

| Test | Run-time | Cage pocket diameter |
|---|---|---|
| Test 1 | 10 Million rev. | 8.0 mm |
| Test 2 | 10 Million rev. | 8.1 mm |
| Test 3 | 10 Million rev. | 8.3 mm |
| Test 4 | 7 Million rev. | 8.5 mm |

**Operating Conditions:**
- Vacuum (< $10^{-4}$ mbar)
- Radial Load = 250 N
- Axial Load = 80 N
- Shaft Speed = 1500 rpm
- Temperature = 200°C

**Measurands:**
- Wear mass
- Frictional Moment

# Investigation Approach

## *Modified cage design*

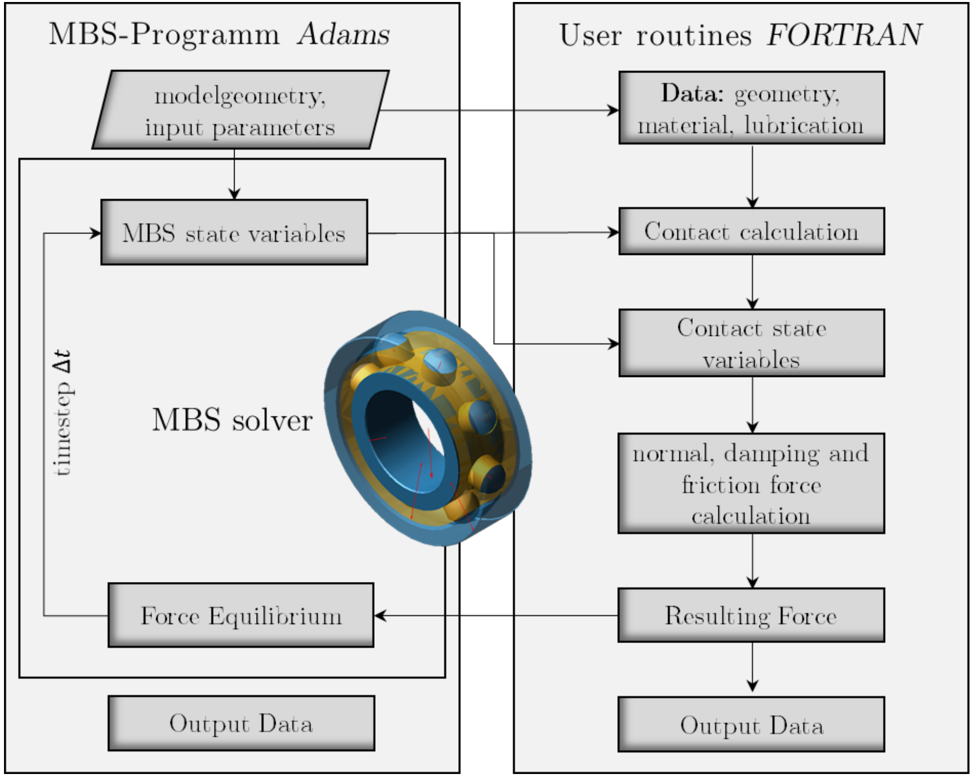


# Investigation Approach

## *Multibody Simulation*

**Simulation parameters:**

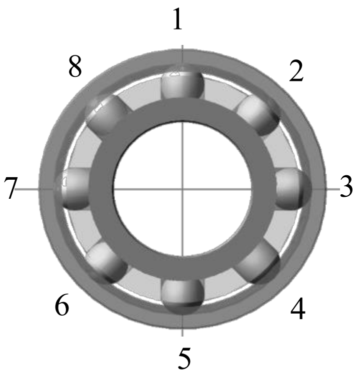
- Radial Load = 250 N
- Axial Load = 80 N
- Rotational Speed = 1500 rpm
- Dynamic Load Rating = 6.2 kN
- Combined Cage density = 4906 kg/m$^3$
- Ball-Raceway Friction Coefficient = 0.15
- Ball-Cage Friction Coeffcient = 0.08

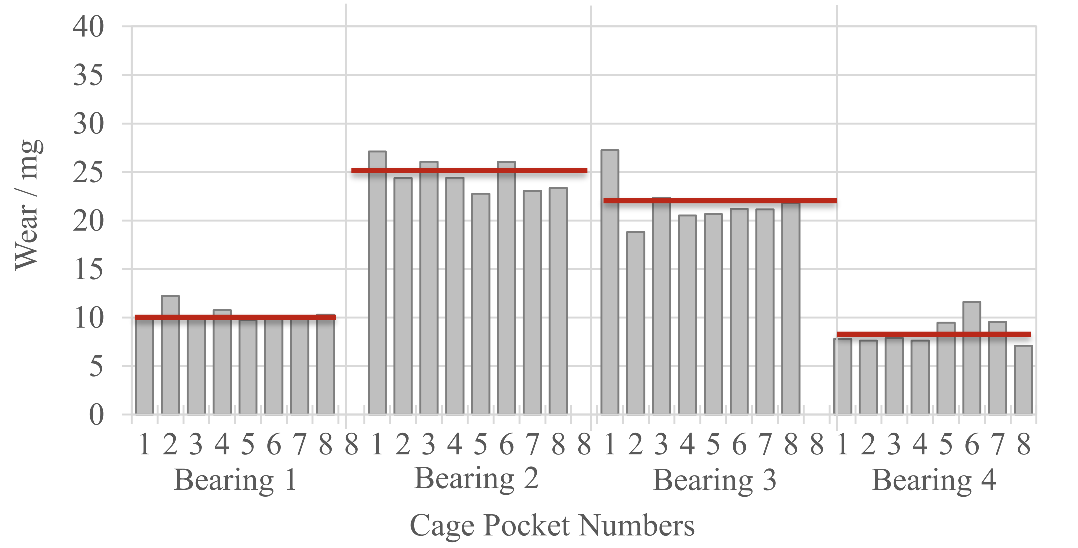


# Results

## *4-Bearing-tests*

- Exemplary result – Cage pocket wear – Test 3 (8.3 mm)



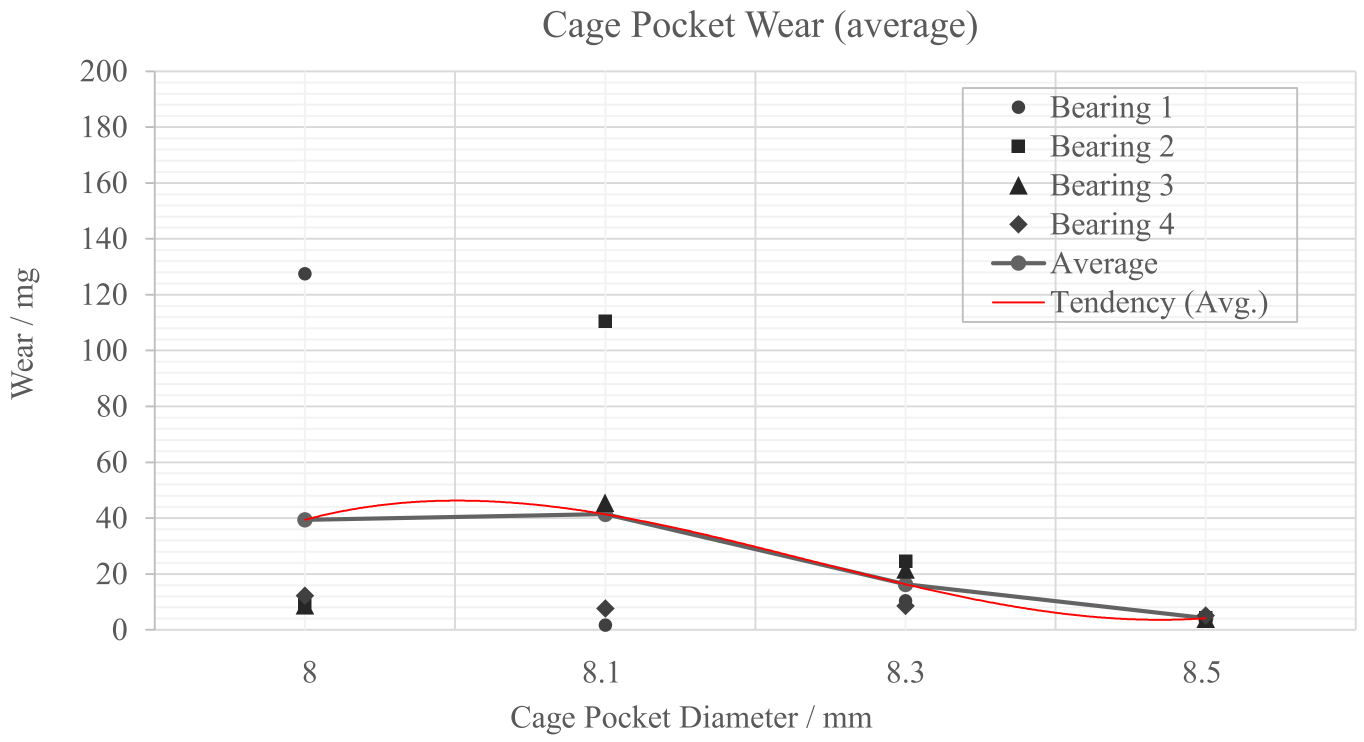

**Operating Conditions:**

- Vacuum (< $10^{-4}$ mbar)
- Radial Load = 250 N
- Axial Load = 80 N
- Shaft Speed = 1500 rpm
- Temperature = 200°C

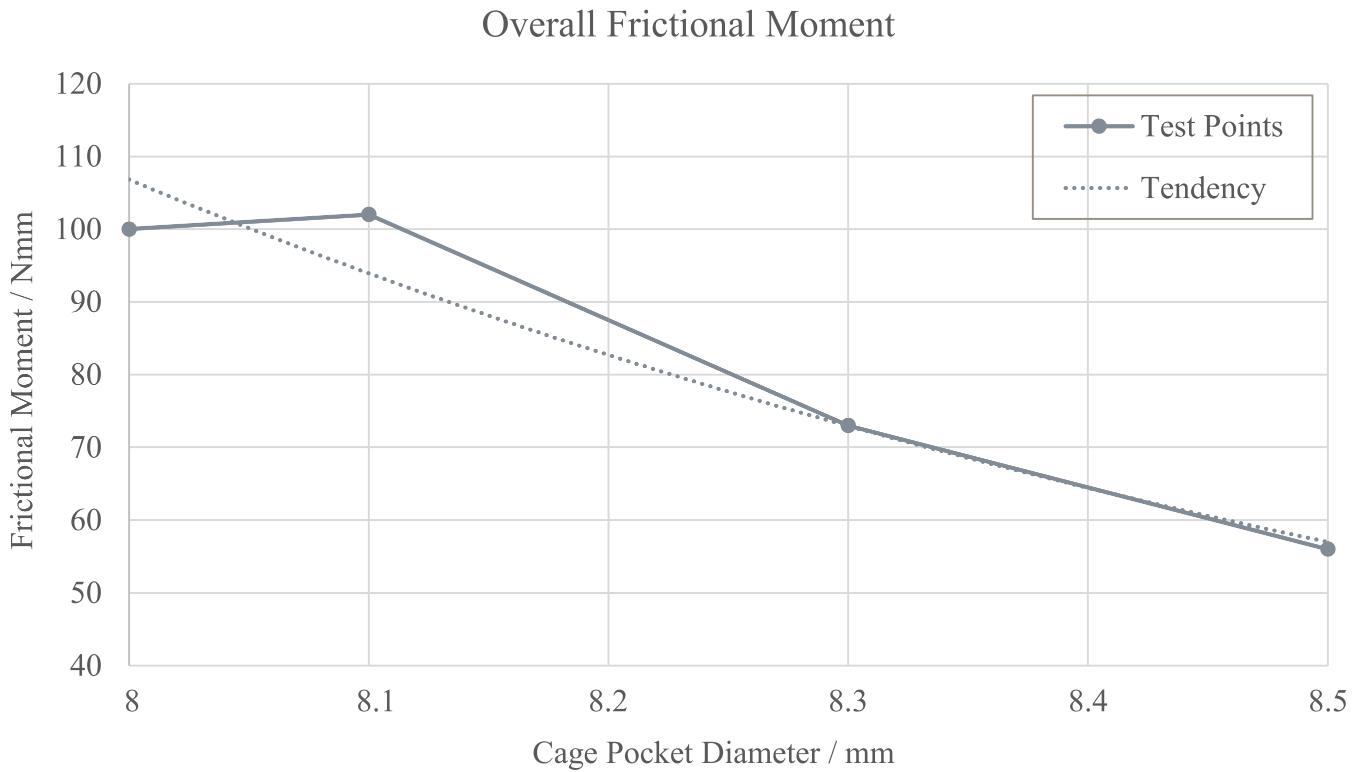
**Measurands:**

- Wear Volumes
- Frictional Moment

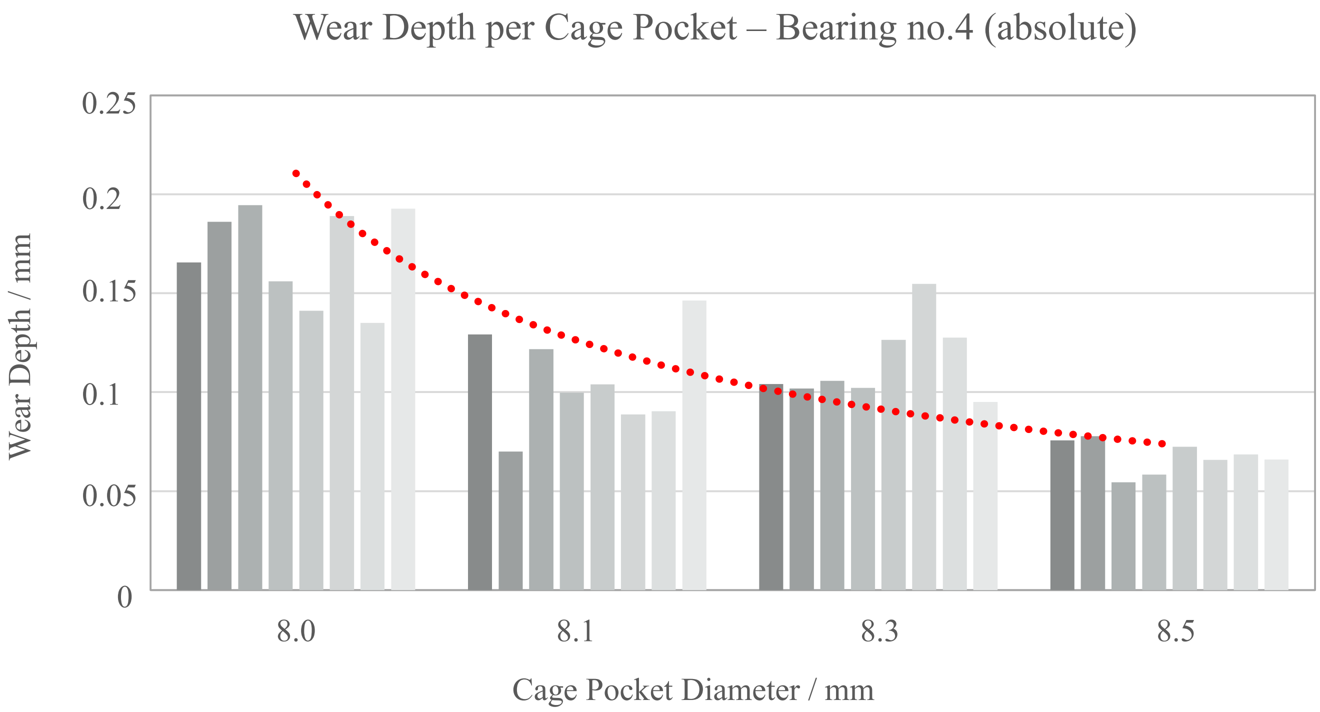
# Results


Cage Pocket Wear (average)
Wear / mg
200
180
160
140
120
100
80
60
40
20
0
8
8.1
8.3
8.5
Cage Pocket Diameter / mm
Bearing 1
Bearing 2
Bearing 3
Bearing 4
Average
Tendency (Avg.)

# Results


Overall Frictional Moment
Frictional Moment / Nmm
120
110
100
90
80
70
60
50
40
8
8.1
8.2
8.3
8.4
8.5
Cage Pocket Diameter / mm
Test Points
Tendency

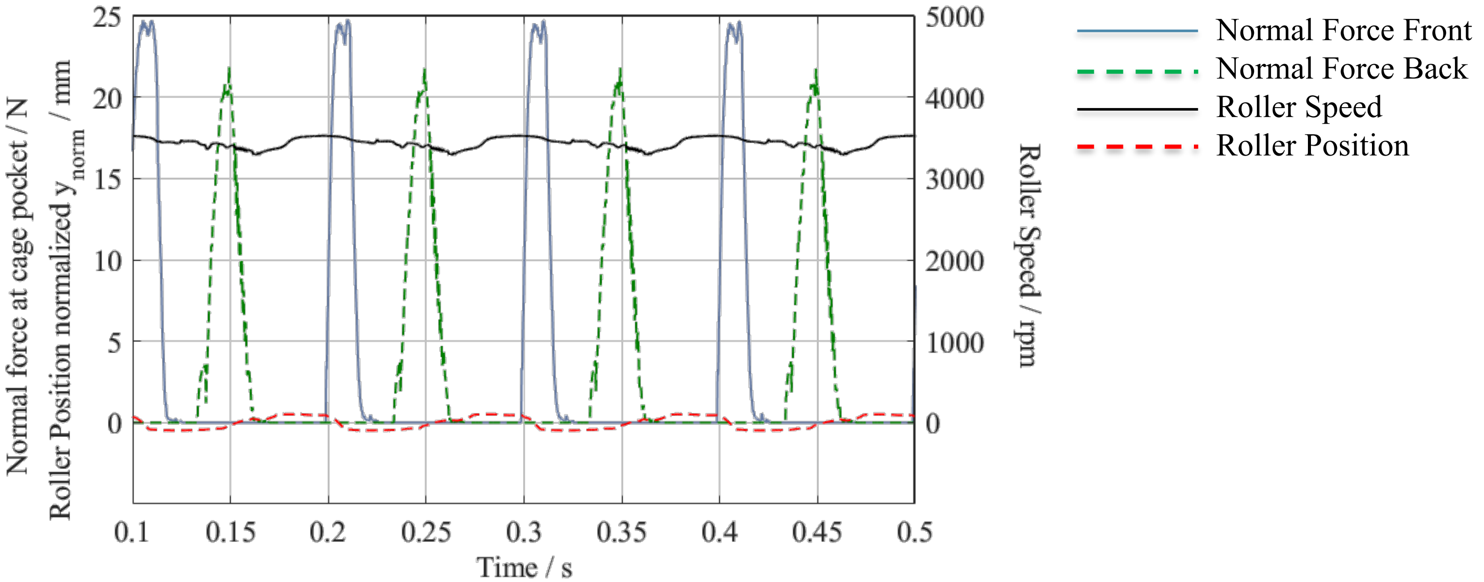
# Results


Wear Depth per Cage Pocket – Bearing no.4 (absolute)
Wear Depth / mm
0.25
0.2
0.15
0.1
0.05
0
8.0
8.1
8.3
8.5
Cage Pocket Diameter / mm

# Results

## *Multibody Simulation*

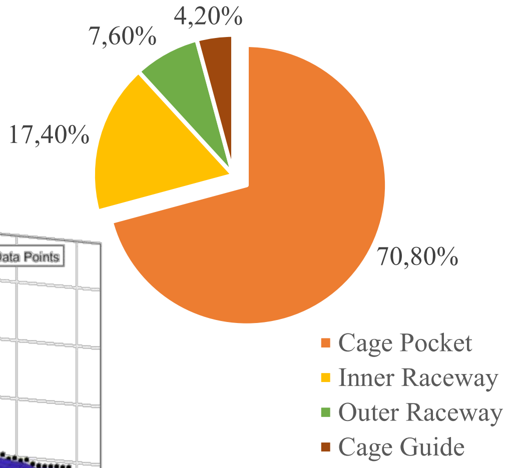
- Interaction ball-cage pocket interface (new cage pocket)

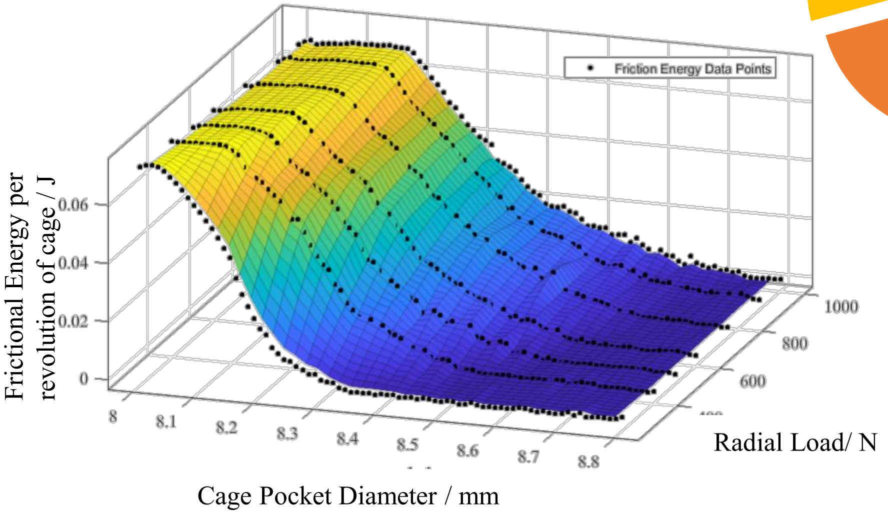


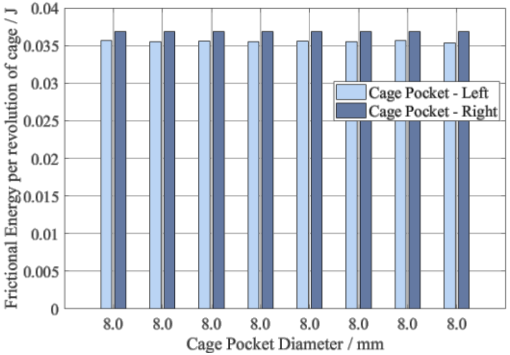
# Results

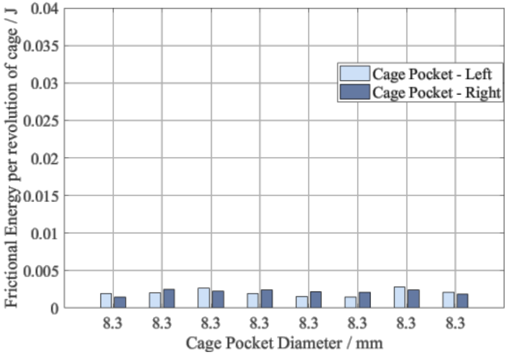
- Frictional Energy at roller-cage pocket interface (new cage pocket)

Indication of the proportion of the fritional energy at individual contacts out of the total frictional energy



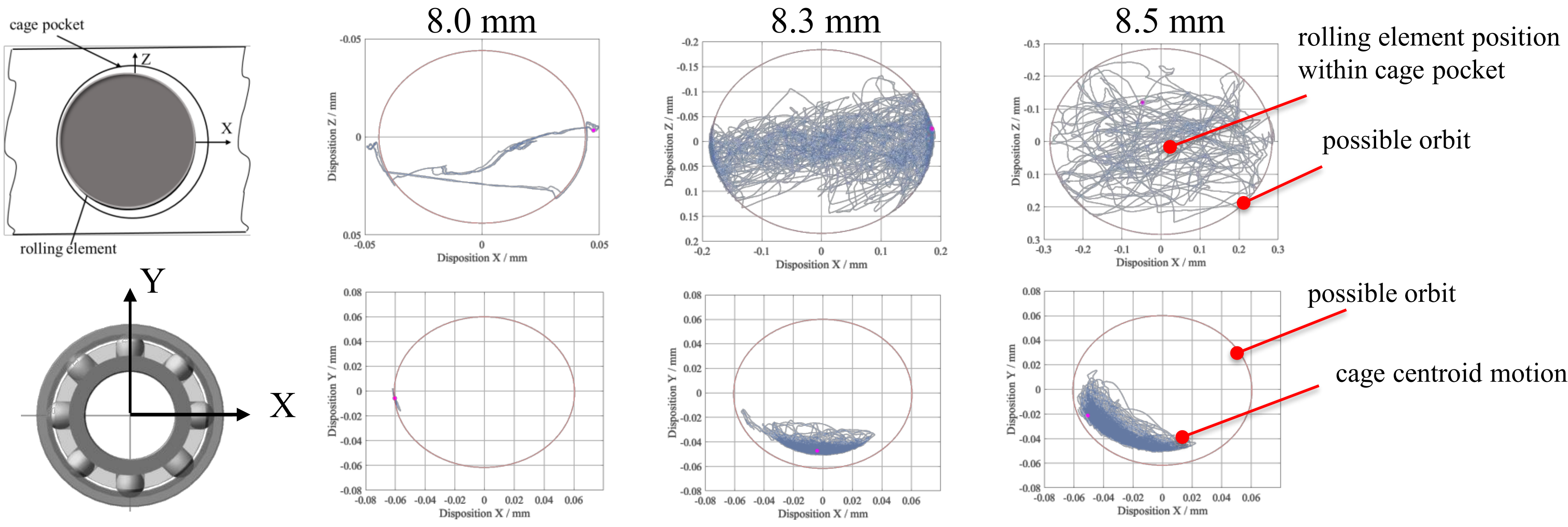



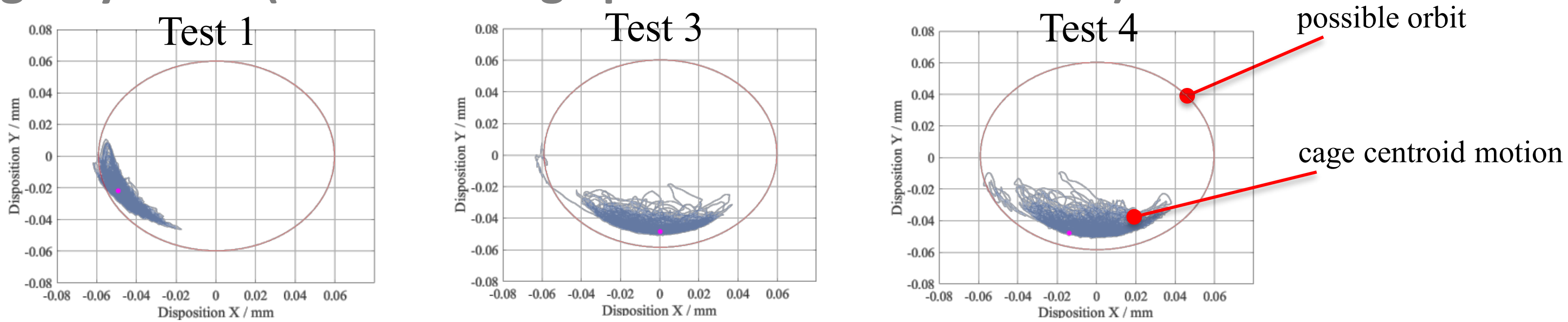
# Results

- Rolling Element and Cage Dynamic (new cage pockets)

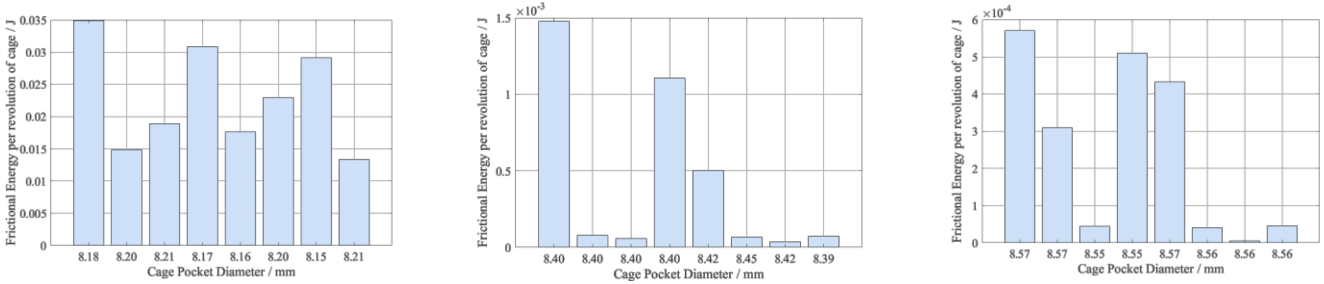


# Results

- Cage Dynamic (worn-out cage pockets - 10 million rev.)




- Frictional Energy (worn-out cage pockets - 10 million rev.)

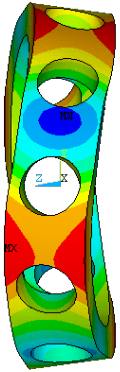


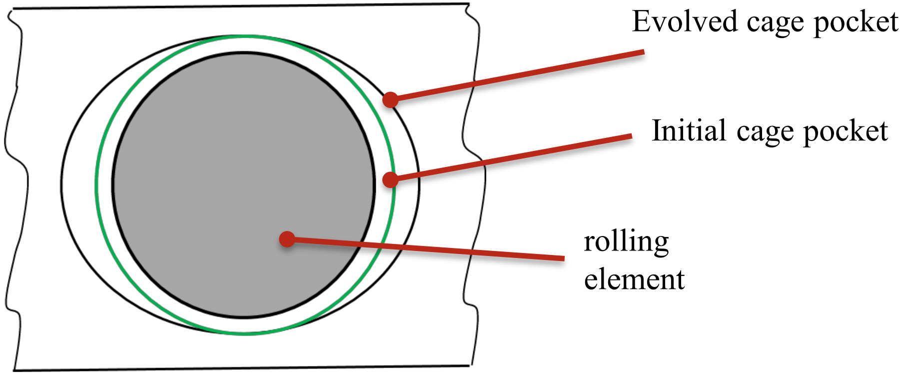
# Conclusions

- **Experiment**
  - ➢ ↑ cage pocket diameter
    - ↓ Wear
    - ↓ Lubrication
    - ↓ Overall friction moment
    - Ambiguous effect on service life
- **Simulation**
  - Substantial effect on friction energy
  - Rolling element and cage become very unstable

# Outlook

- **Further component tests with various operating conditions**
- **Further development of simulation model**
  - Flexibility of cage
  - Evolution of cage pocket diameter (wear model)





# Thank you for your kind attention!

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