

# OPERATIONAL SAFETY AND RELIABILITY ENHANCEMENT OF LARGE-SCALE HYDROSTATIC BEARINGS

**Jan Foltýn, Ing.**

Supervisor: doc. Ing. Petr Svoboda, Ph.D.

Co-supervisor: Ing. Petr Šperka, Ph.D.

Institute of Machine and Industrial Design  
Faculty of Mechanical Engineering  
Brno University of Technology

Brno, 03.06.2026



**INSTITUTE OF MACHINE  
AND INDUSTRIAL DESIGN**



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**Introduction**

**State of the art**

**Aim**

**Scientific questions and hypotheses**

**Material and methods**

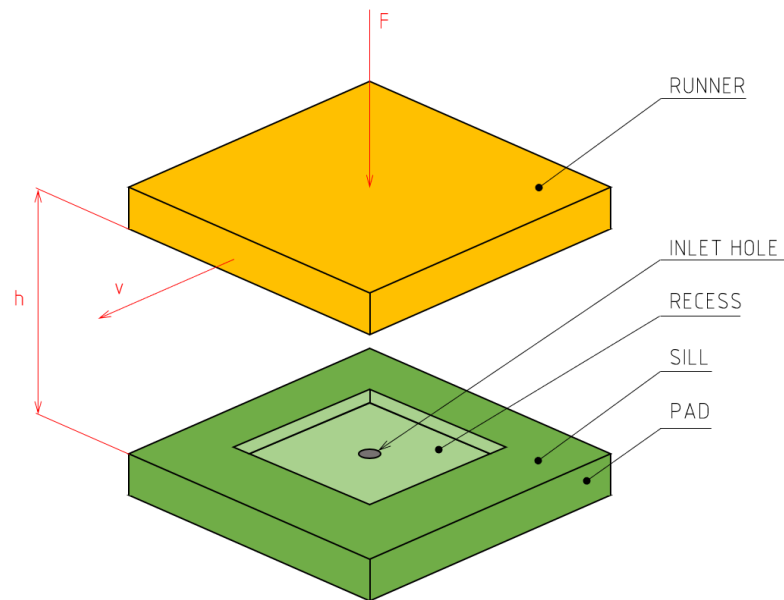
**Results**

**Conclusion**

# INTRODUCTION

## HYDROSTATIC BEARINGS

- Sliding bearings
- Externally pressurized



$$h = \sqrt[3]{\frac{Q \cdot A \cdot \mu}{F \cdot q_f}}$$

## ADVANTAGES

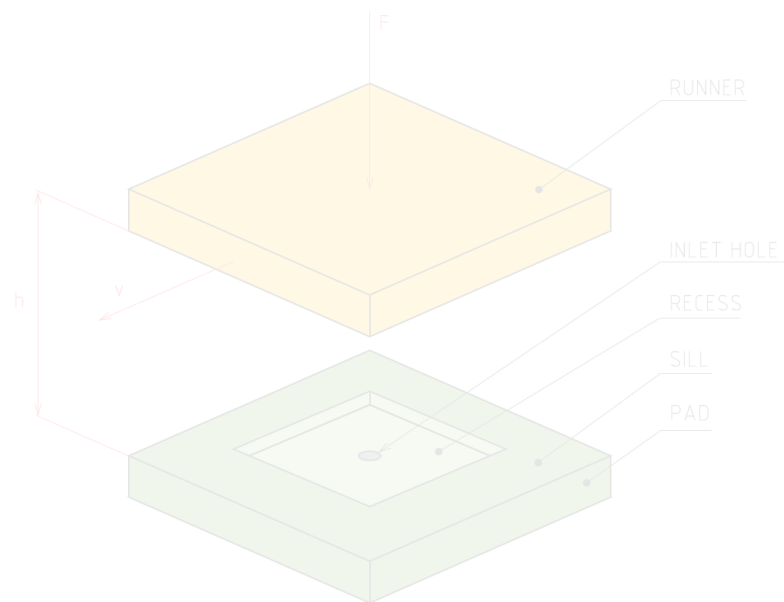
- Zero speed operation
- Large loads
- Low friction



# INTRODUCTION

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## ADVANTAGES

- Zero speed operation
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# MOTIVATION

- Large-scale applications
- Precision of bearing
- High maintenance costs



Ø 34 m



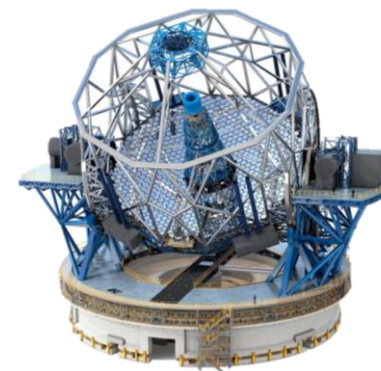
Antenna Goldstone, California  
([www.jpl.nasa.gov](http://www.jpl.nasa.gov))

1,5 year of preparations

7 months realization

10 tuns one HS pad

1,25 mil USD



Ø D

50 m



20 m



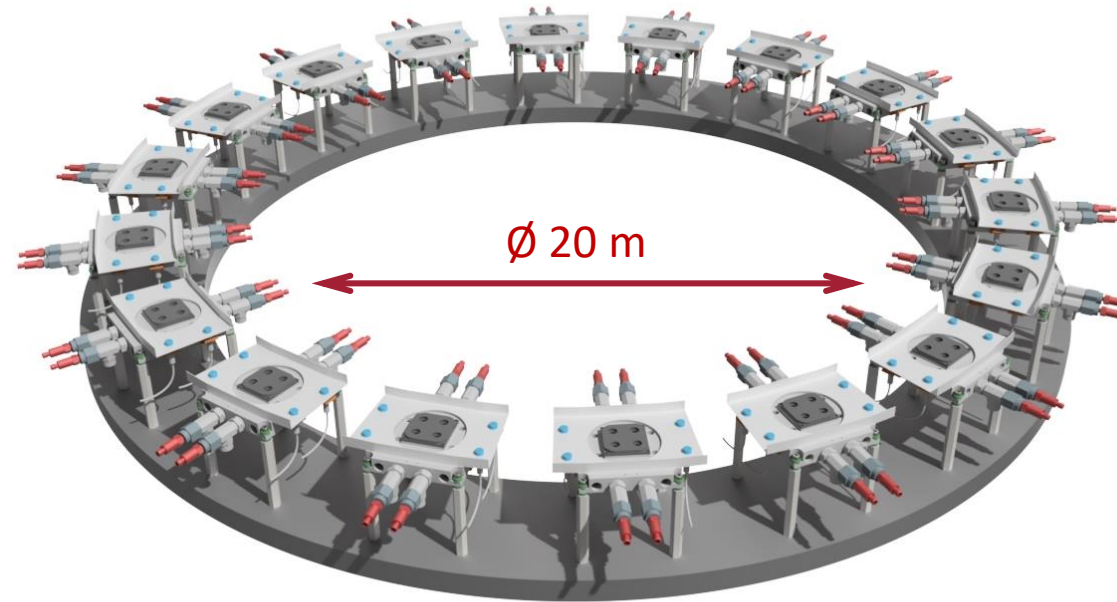
8 m



0,1 m

# STATE OF THE ART

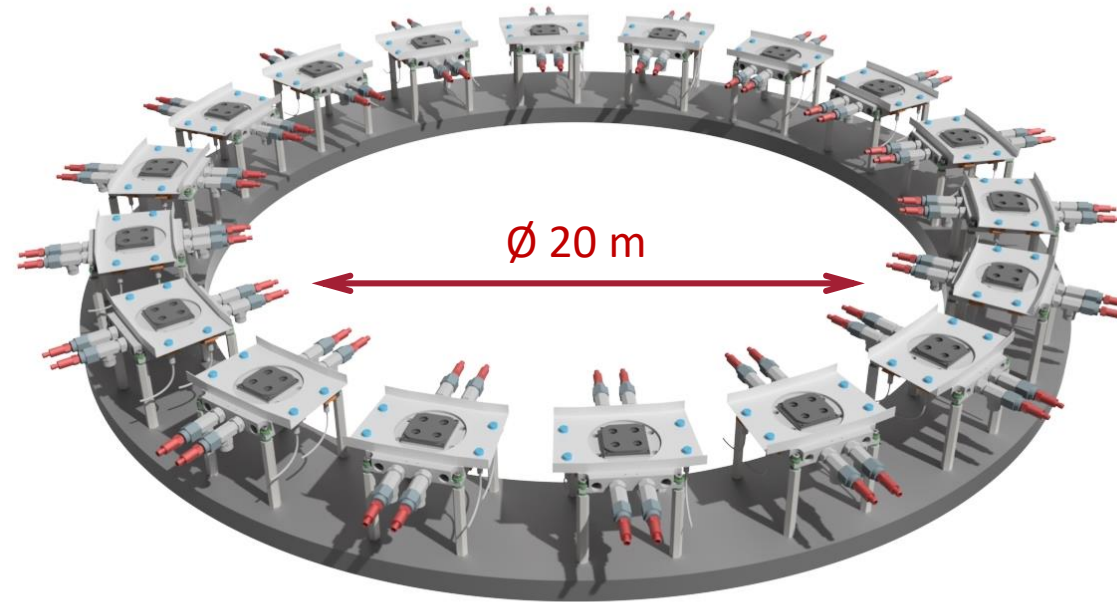
LARGE-  
SCALE  
BEARINGS



SAFETY

# STATE OF THE ART

LARGE-  
SCALE  
BEARINGS



SAFETY

# STATE OF THE ART

## LARGE-SCALE BEARINGS

### DEEP SPACE NETWORK (DSN)

- HS azimuth bearing 34 m diameter
- 3 rectangular pads with 6 recesses
- Supply pressure 28 MPa
- Expected thickness 127 – 254  $\mu\text{m}$



NASA, *DSN antennas*

### VERY LARGE TELESCOPE (VLT)

- 2 azimuthal rings: 8 m and 20 m
- 16 square pads with 4 recesses
- Supply pressure 8.5 MPa
- Thickness measured 2x a year
- Expected thickness 40 – 60  $\mu\text{m}$



### GIANT MAGELLAN TELESCOPE (GMT)

- HS azimuth bearing 21 m diameter
- Recess pressure 3.5 MPa
- Expected thickness 65 – 70  $\mu\text{m}$



Giantmagellan.org

# STATE OF THE ART

## LARGE-SCALE BEARINGS

### DEEP SPACE NETWORK (DSN)

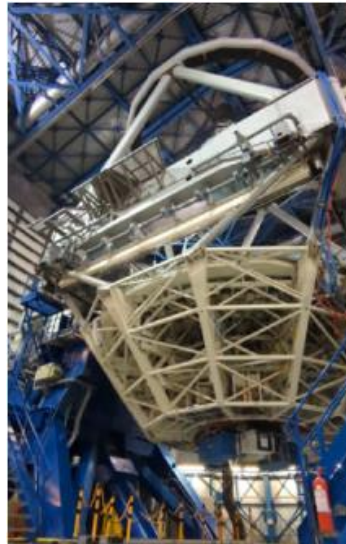
- HS azimuth bearing 64 m diameter
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- Supply pressure 28 MPa
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NASA, DSN antennas

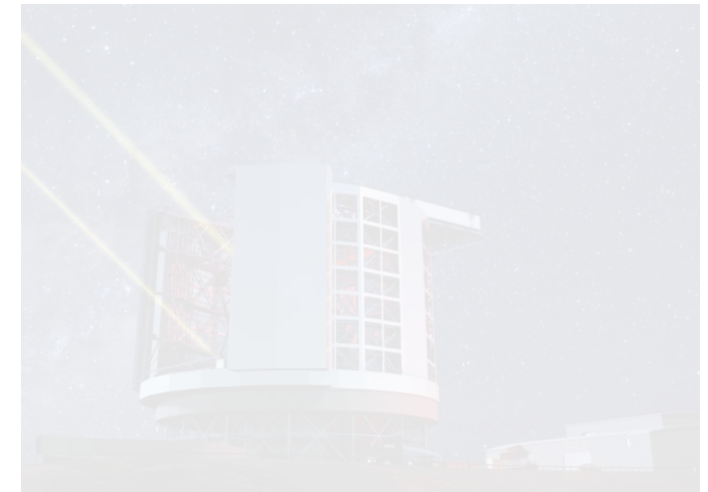
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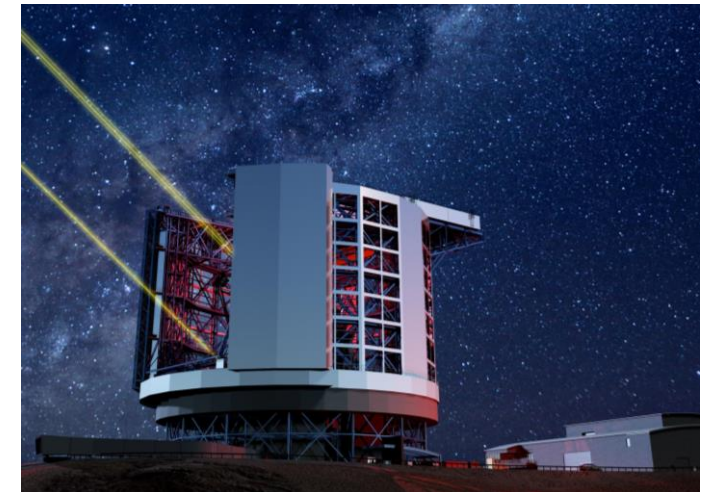
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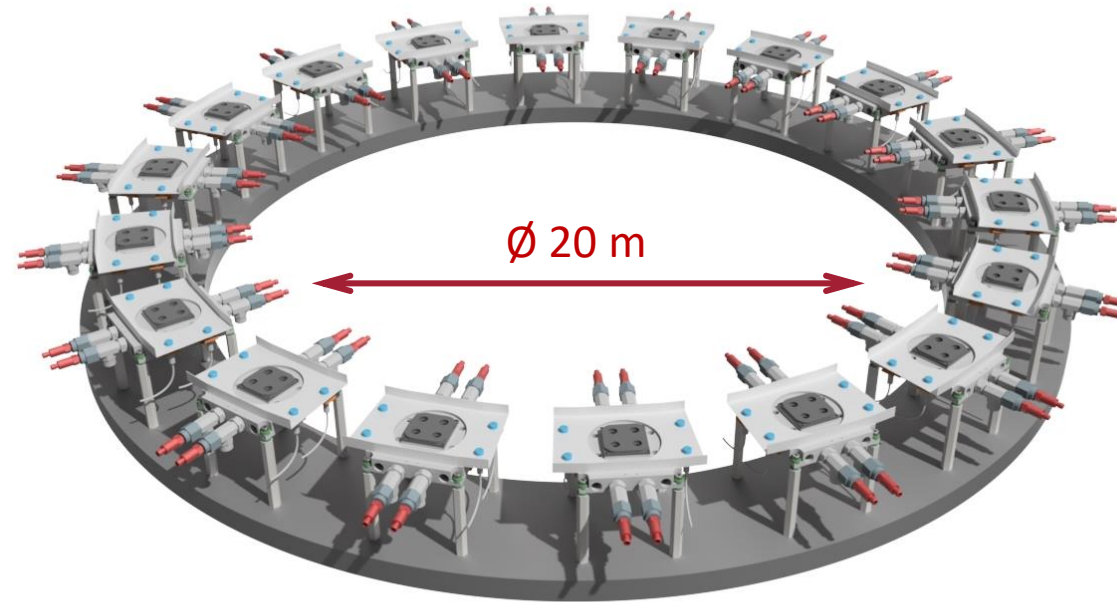
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# STATE OF THE ART

LARGE-  
SCALE  
BEARINGS



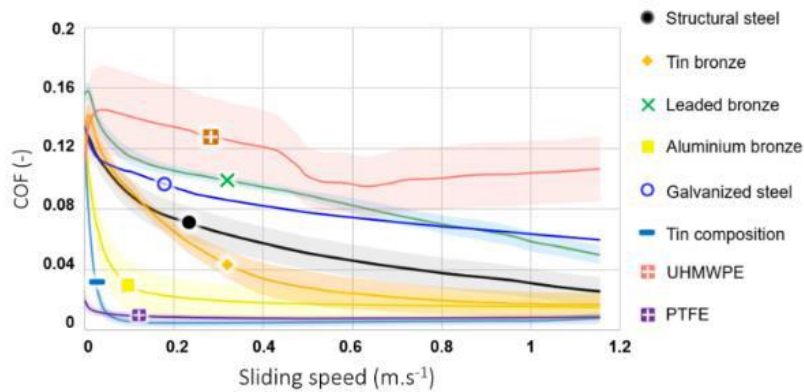
SAFETY

# STATE OF THE ART

## SAFETY OF OIL FILM

### MATERIAL INFLUANCE

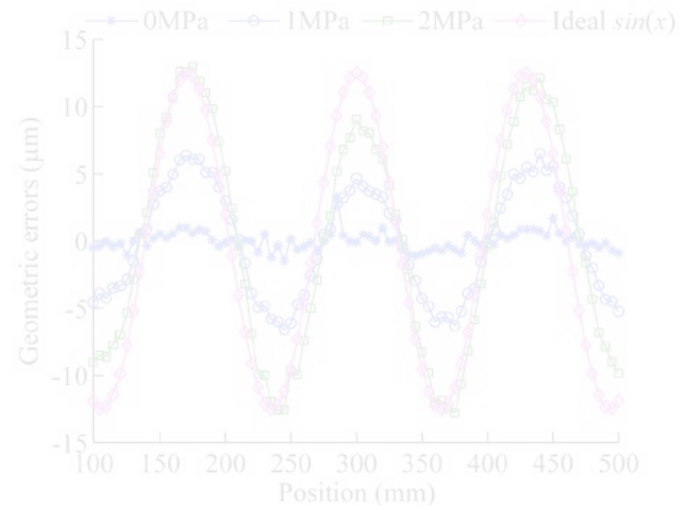
- Risk of abrasive particles
- Beneficial material combinations



MICHALEC, M. et. al. *Adv Eng Mater* (2024)

### GEOMETRIC ERRORS

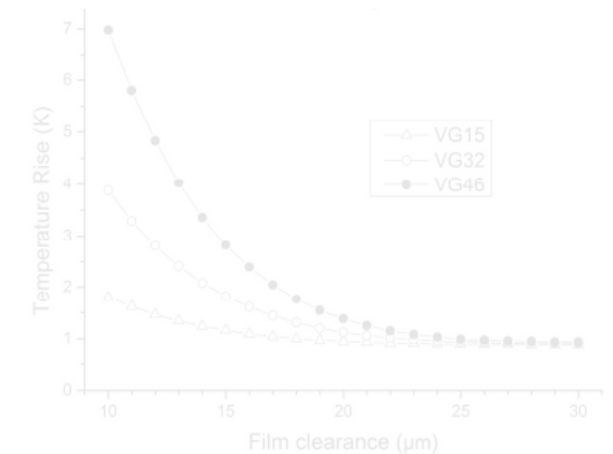
- Influence of manufacturing on pressure distribution
- Decrease of stiffness and precision



Zhang, P. et. al. *Int J Mach Tools Manuf* (2018)

### TEMPERATURE CHANGES

- Shear in small clearances
- Changes during night and day



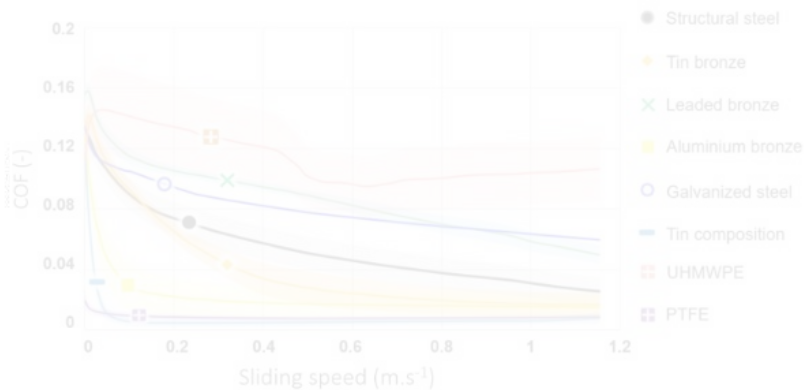
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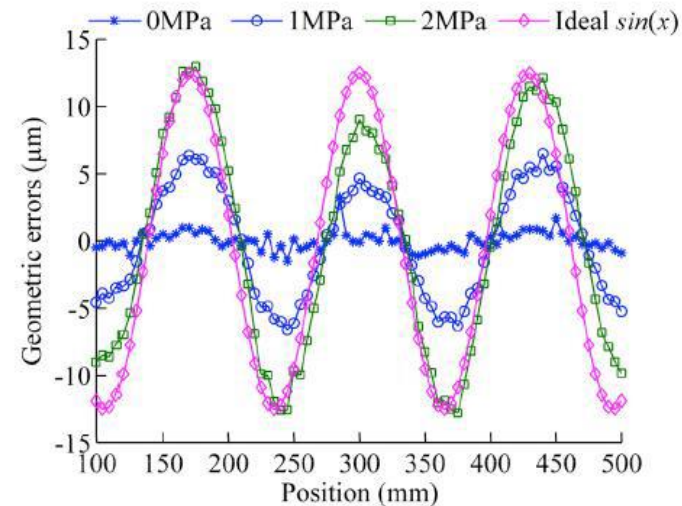
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MICHALEC, M. et. al. *Adv Eng Mater* (2024)

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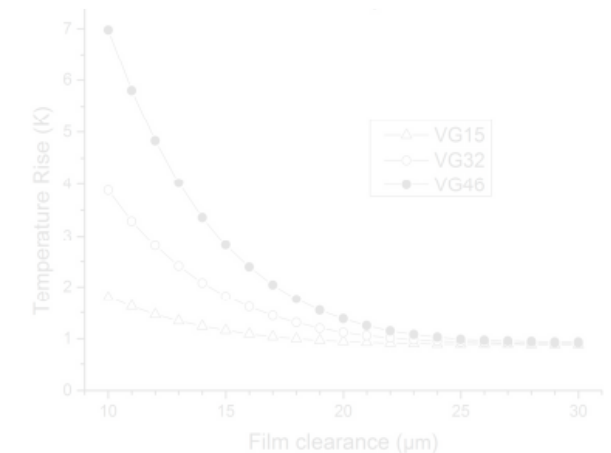
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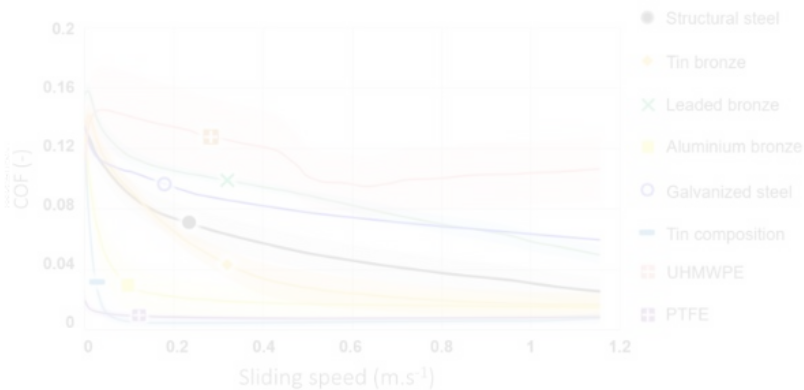
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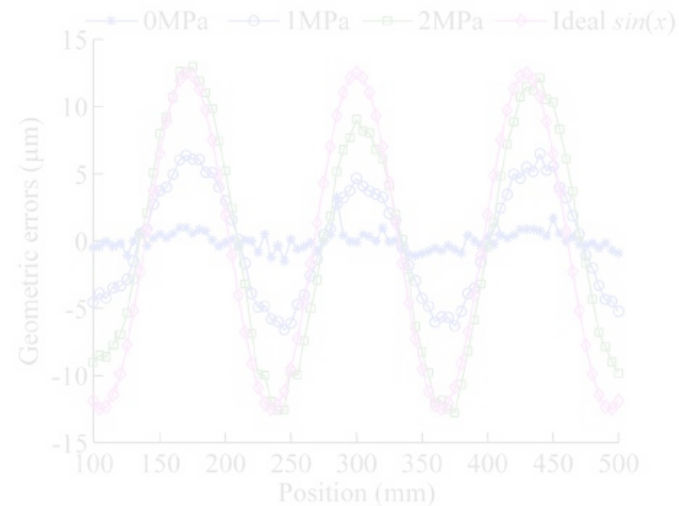
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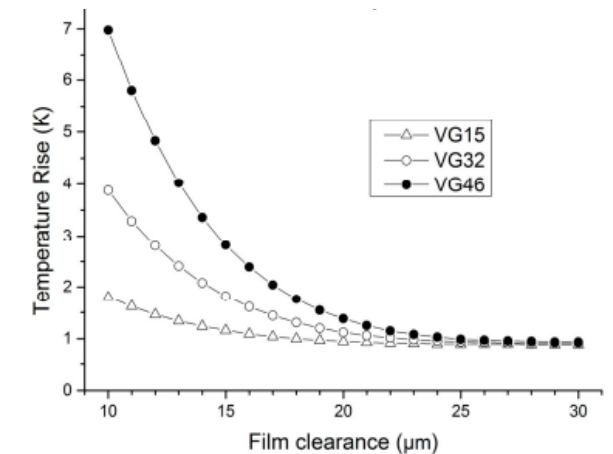
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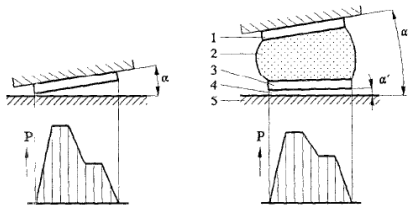
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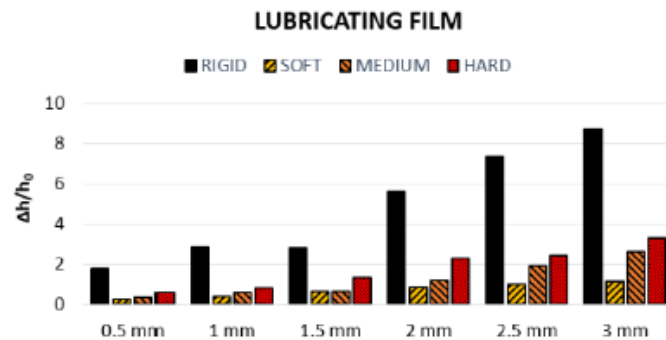
## SAFETY OF OIL FILM

### COMPLIANT SUPPORT

- Stiffness is not key parameter
- Can adapt to imperfections



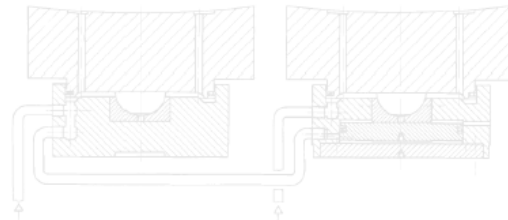
VAN BEEK, A. et. al. *Tribology International* (1997)



MICHALEC, M. et. al. *Precision Engineering* (2022)

### TILTING SUPPORT

- Demanding for manufacturing
- Angular and height adjustments



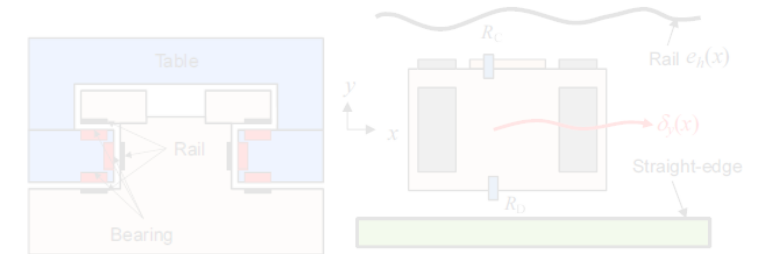
BASSANI, R. et. al. *Hydrostatic lubrication* (1992)



MARCHIORI, G. et. al. *SPIE* (2018)

### ALIGNMENT

- Linear HS guideway
- Probe with negative shape of HS support
- Precision  $\pm 0,001$  mm



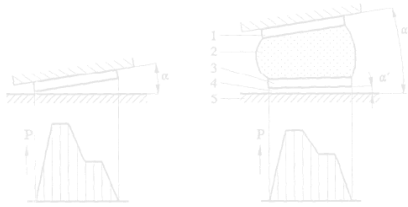
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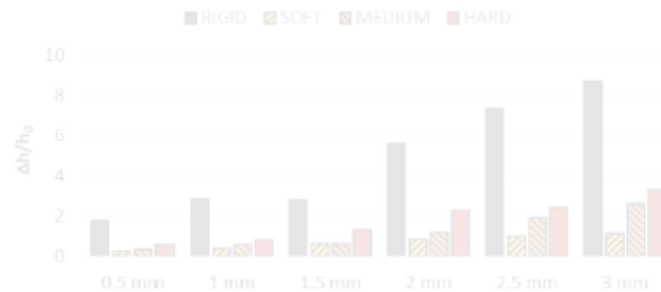
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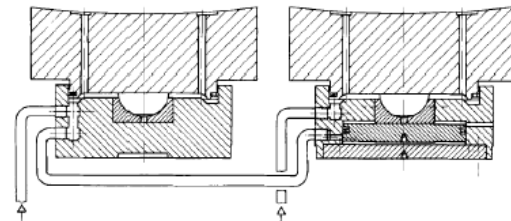
### LUBRICATING FILM



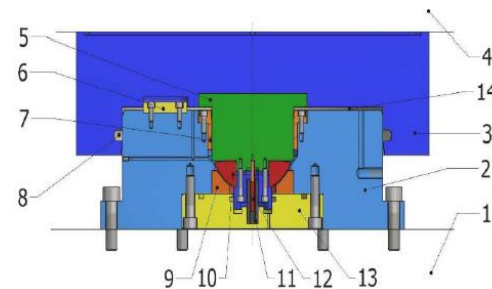
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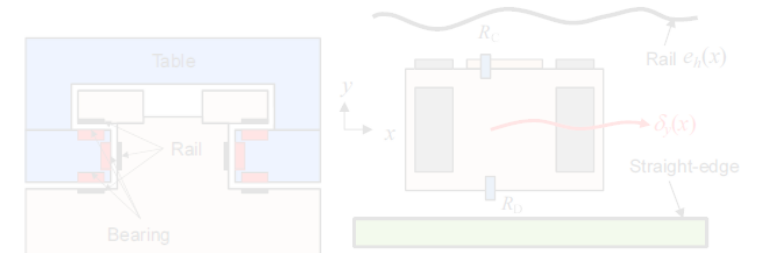
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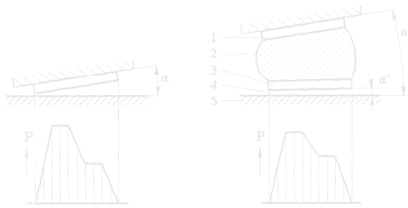
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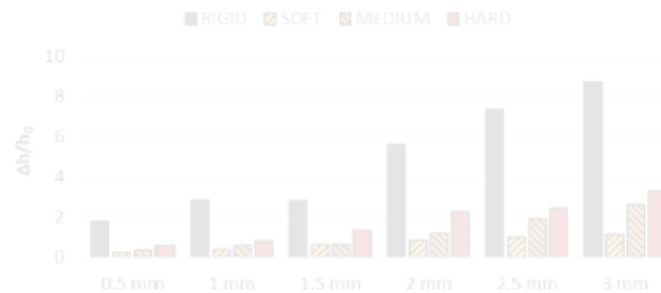
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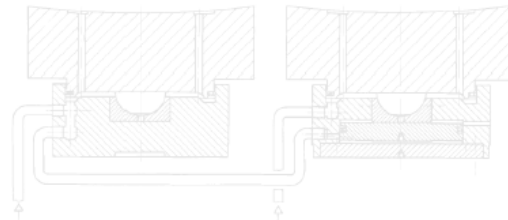
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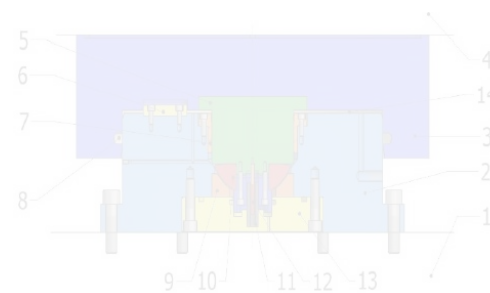
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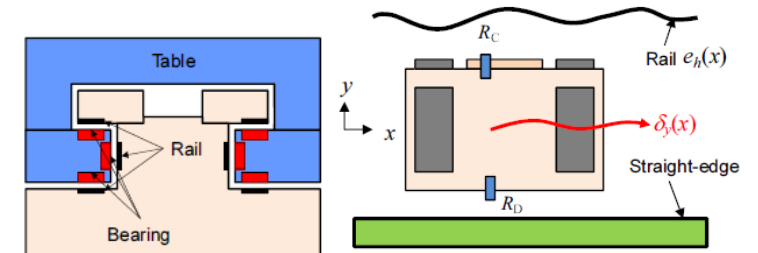
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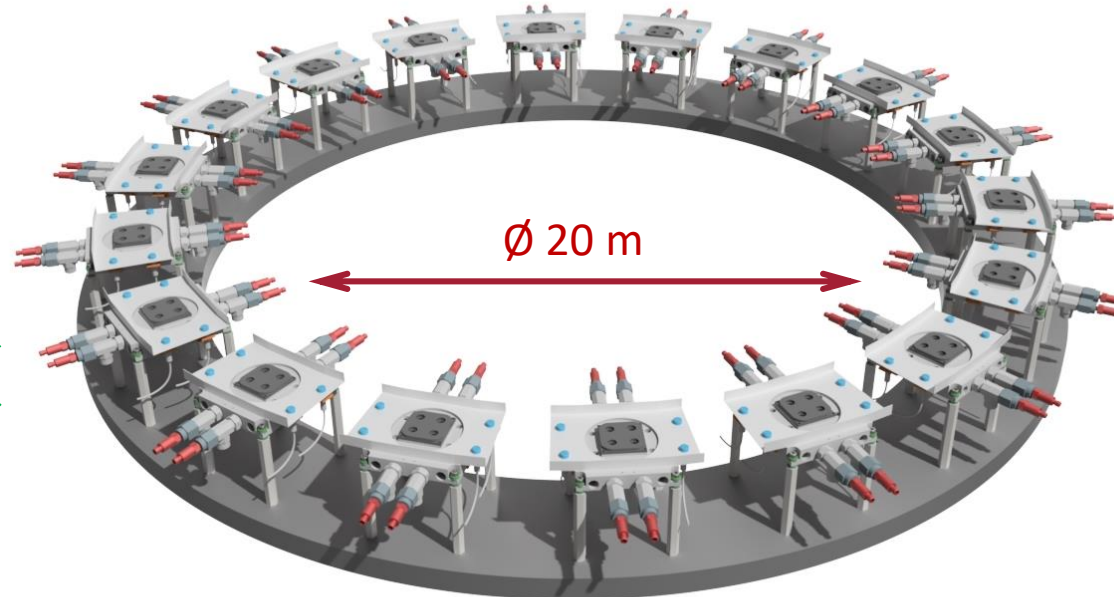


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# SUMMARY OF LITERATURE REVIEW

## LARGE-SCALE BEARINGS

- Pressure approach ✓
- High precision demand ✓
- Film thickness diagnostics ✗



## SAFETY

- Compliant supports ✓
- Erosion effects ✗
- Large-scale alignment ✗

# AIM OF THE THESIS

- Analyse the influence of geometric imperfections, hydraulic disturbances, and operating conditions on the minimum lubricating film thickness.
- Establish lubricating film thickness as safety-relevant parameter.

## Output:

*safety assessment based on lubricating film thickness and its distribution*

# SCIENTIFIC QUESTIONS AND HYPOTHESES

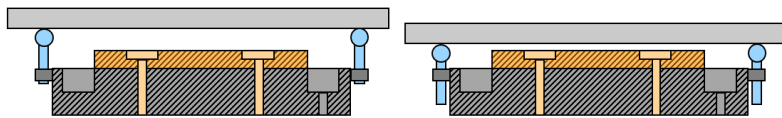
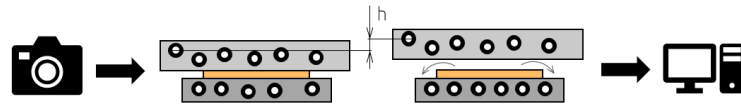
## QUESTION 1

How optical methods improve safety of lubricating film?

**H1**

Optical measurements enable safety-relevant evaluation of film thickness under real operating conditions.

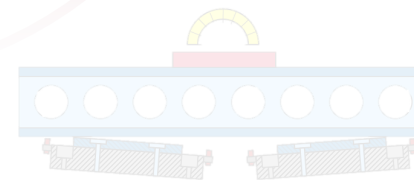
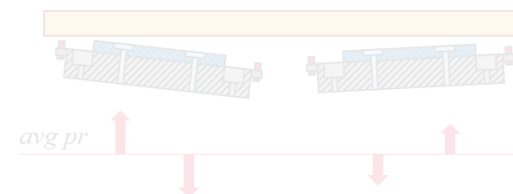
Thickness  
measurement  
precision



**H2**

Optical alignment improves the positioning of pads, leading to a more uniform lubricating film.

Alignment  
precision



# SCIENTIFIC QUESTIONS AND HYPOTHESES

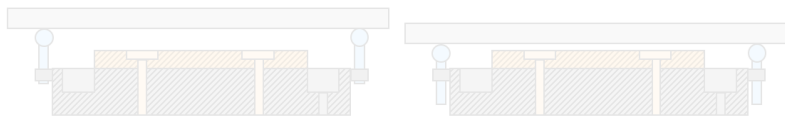
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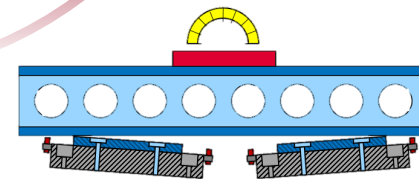
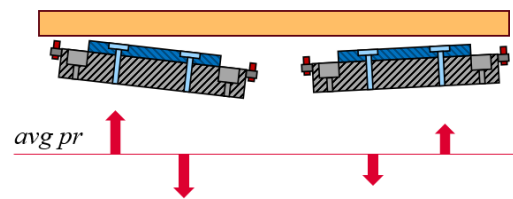
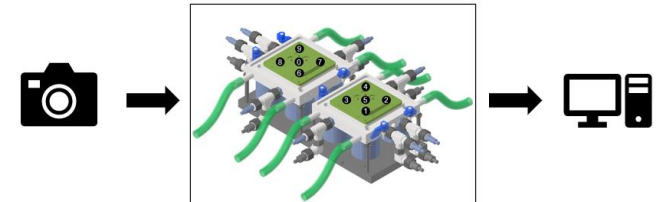
Thickness measurement precision



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Alignment precision



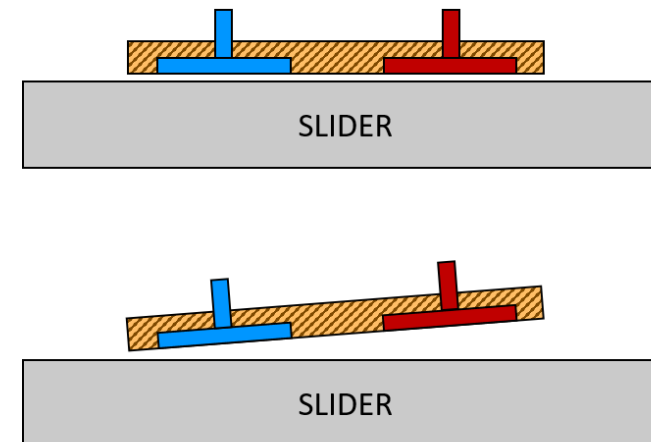
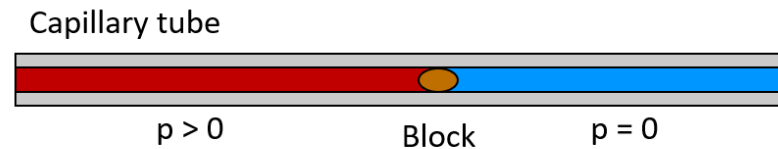
# SCIENTIFIC QUESTIONS AND HYPOTHESES

## QUESTION 2

How restrictor failure affect safety of lubricating film?

### H3

Blockage of a capillary restrictor in a multi-recess hydrostatic bearing causes a measurable decrease in local film thickness, and creating a safety-critical condition.

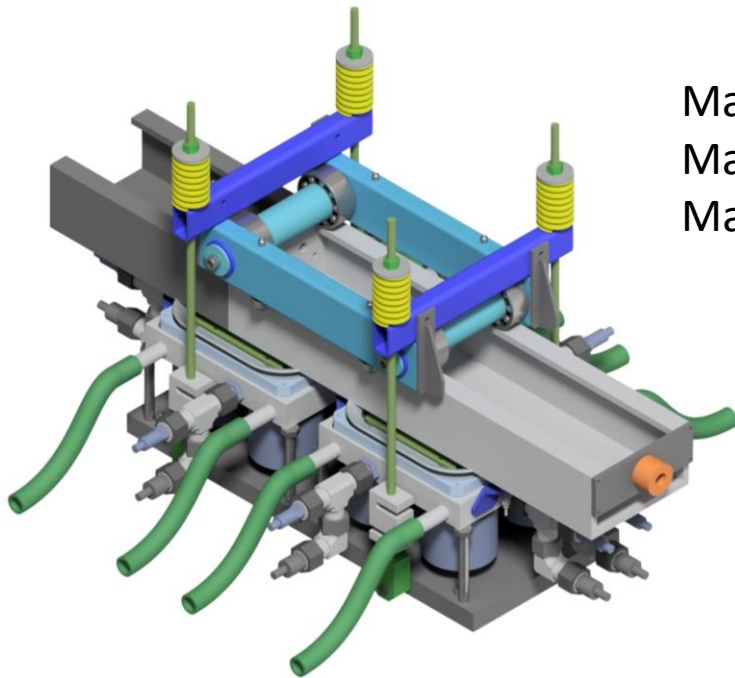


# MATERIAL AND METHODS

## EXPERIMENTAL OBJECTS

### Experimental hydrostatic bearing – 2PAD

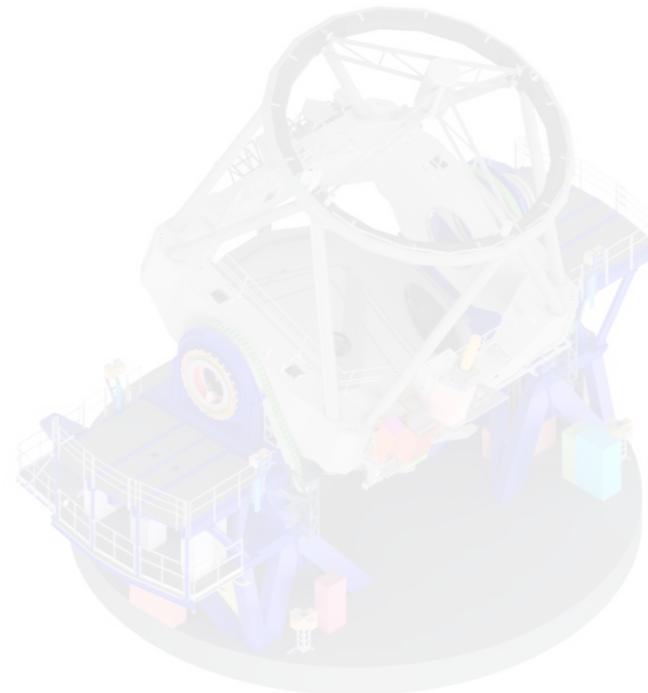
- Linear hydrostatic bearing
- 2 pads with 4 circular recesses



Max. load: **40 kN**  
Max. pressure: **100 bar**  
Max. flow: **20 l/min**

### Very Large Telescope - VLT

- Azimuth hydrostatic bearing of 20 meters diameter
- 16 pads with 4 square recesses



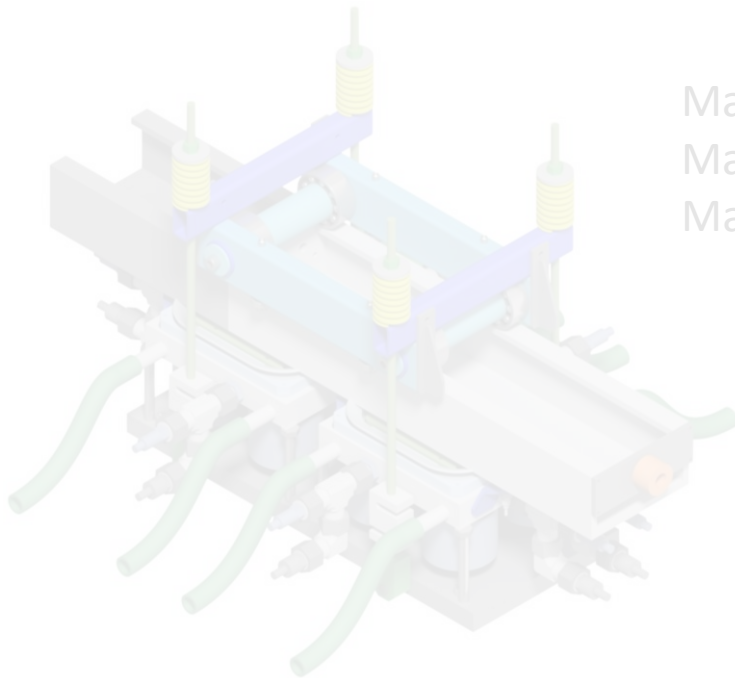
Load: **4 900 kN**  
Max. pressure: **85 bar**  
Max. flow: **16 l/min**

# MATERIAL AND METHODS

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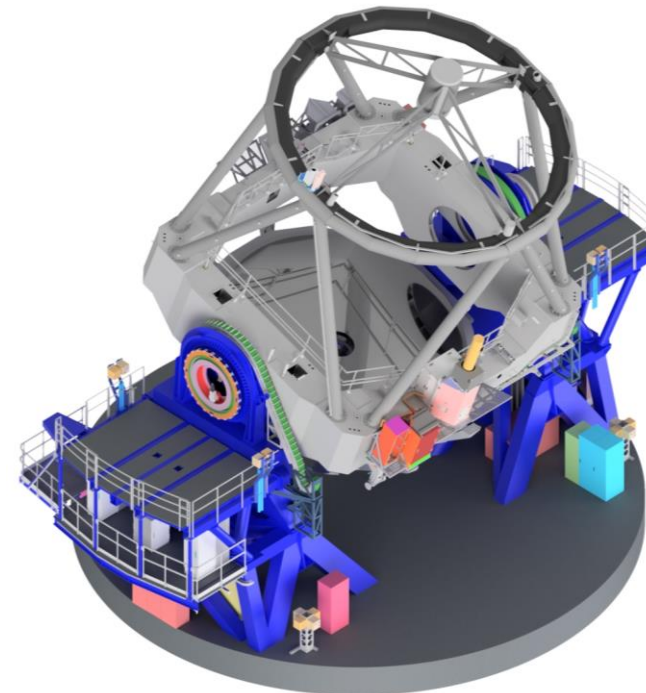
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# MATERIAL AND METHODS

## FILM THICKNESS MEASUREMENT

### DIAL INDICATORS

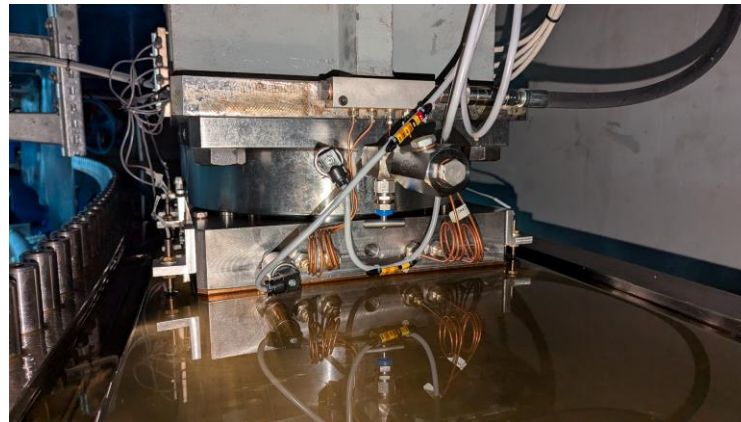
- Current method on VLT
- Only for static condition
- Operator dependent



Measurement on outer ring (VLT)

### INDUCTIVE SENSORS

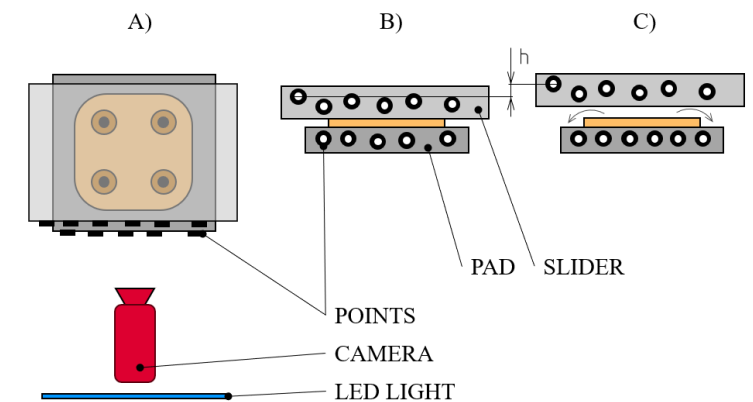
- Online diagnostics
- Precise position of sensor
- Proposed upgrade for VLT



Measurement on outer ring (VLT)

### OPTICAL POINT TRACKING

- Static camera
- Detection of points deviations
- Tested on 2PAD



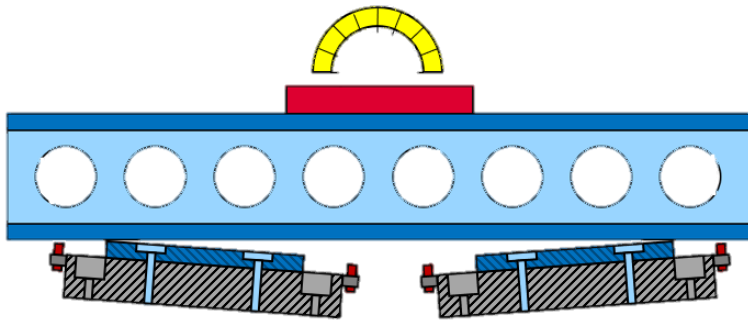
OPT setup

# MATERIAL AND METHODS

## ALIGNMENT METHODS – 2PAD

### CONVENTIONAL GAUGES

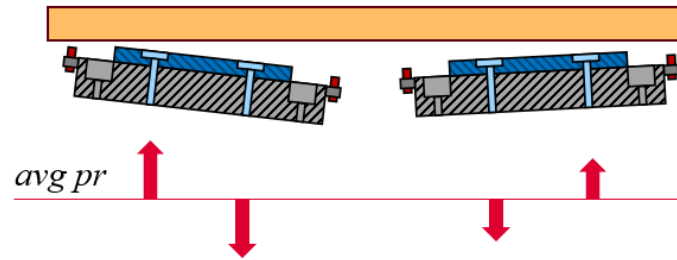
- Operator dependent
- Large deviations



Measurement with straight edge and spirit level

### PRESSURE METHOD

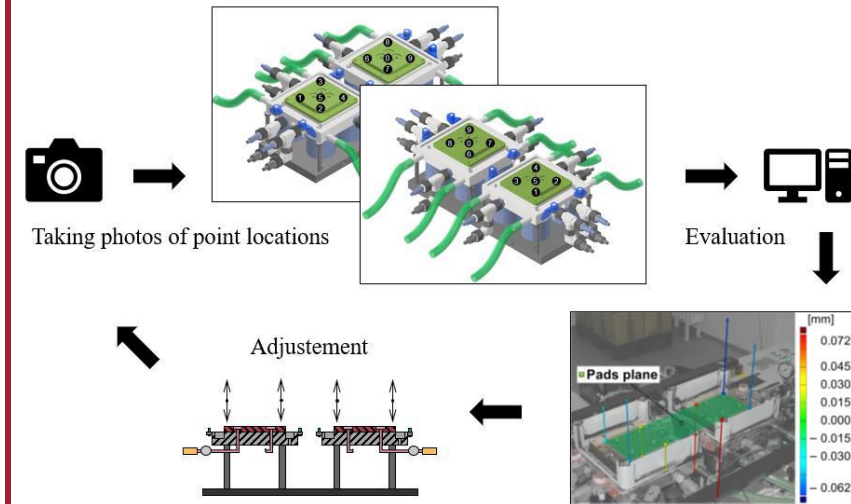
- In-situ potential
- Equal pressure in recesses



Adjustment of recess pressure

### OPTICAL COORDINATE MEASUREMENT

- Position of points in 3D space
- Reference plane fitting



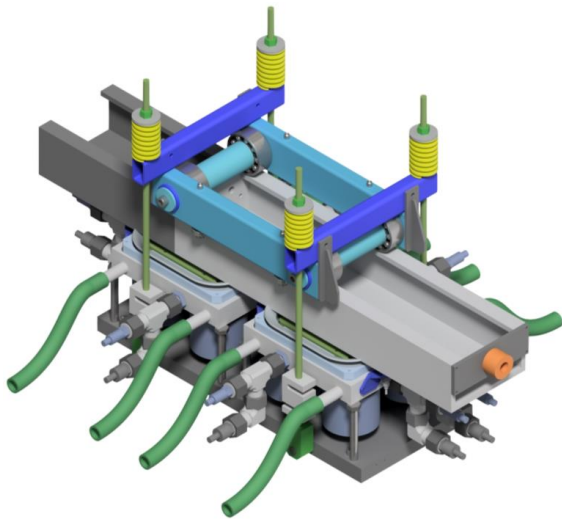
Work flow of OCM method

# RESULTS

## FILM THICKNESS MEASUREMENT

### OPTICAL POINT TRACKING

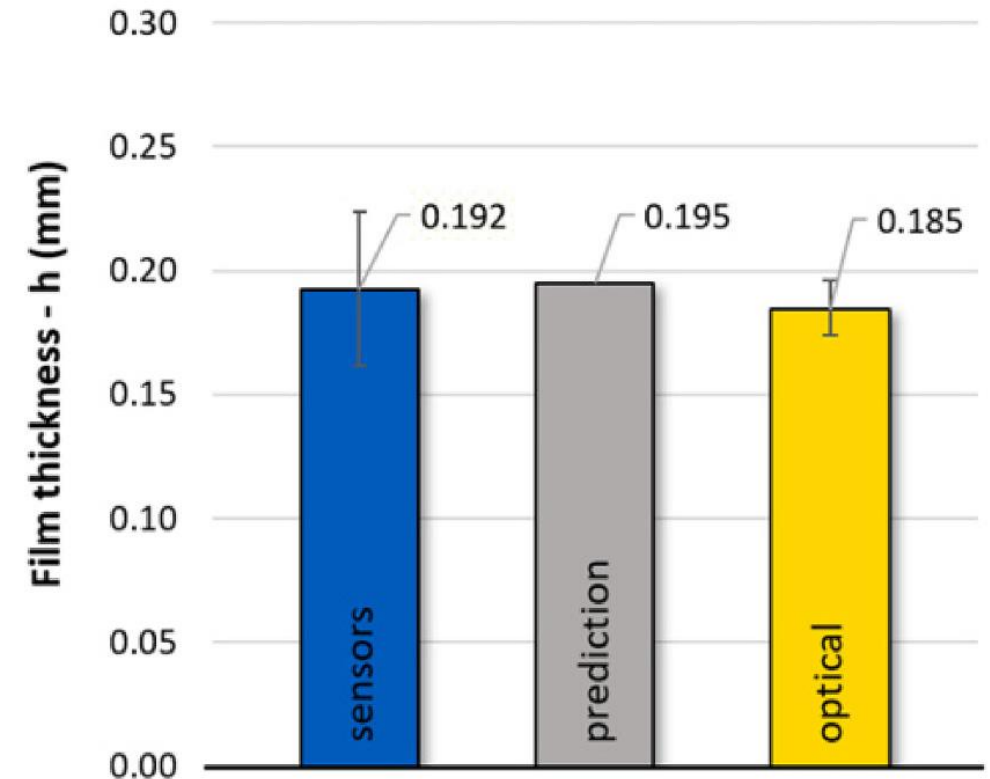
- New method of film thickness measurement
- Lower measured film deviation than sensors



Load: **16 kN**  
Pressure: **5 bar**  
Flow: **4 l/min**



Michalec, M.; Hurník, J.; Foltýn, J.; Svoboda, P. Contactless measurement of hydrostatic bearing lubricating film using optical point tracking method. Proc. Inst. Mech. Eng. Part J.-J. Eng. Tribol. (2023).

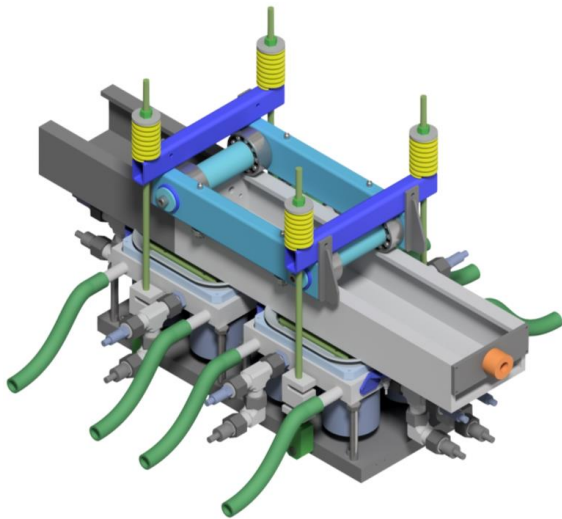


# RESULTS

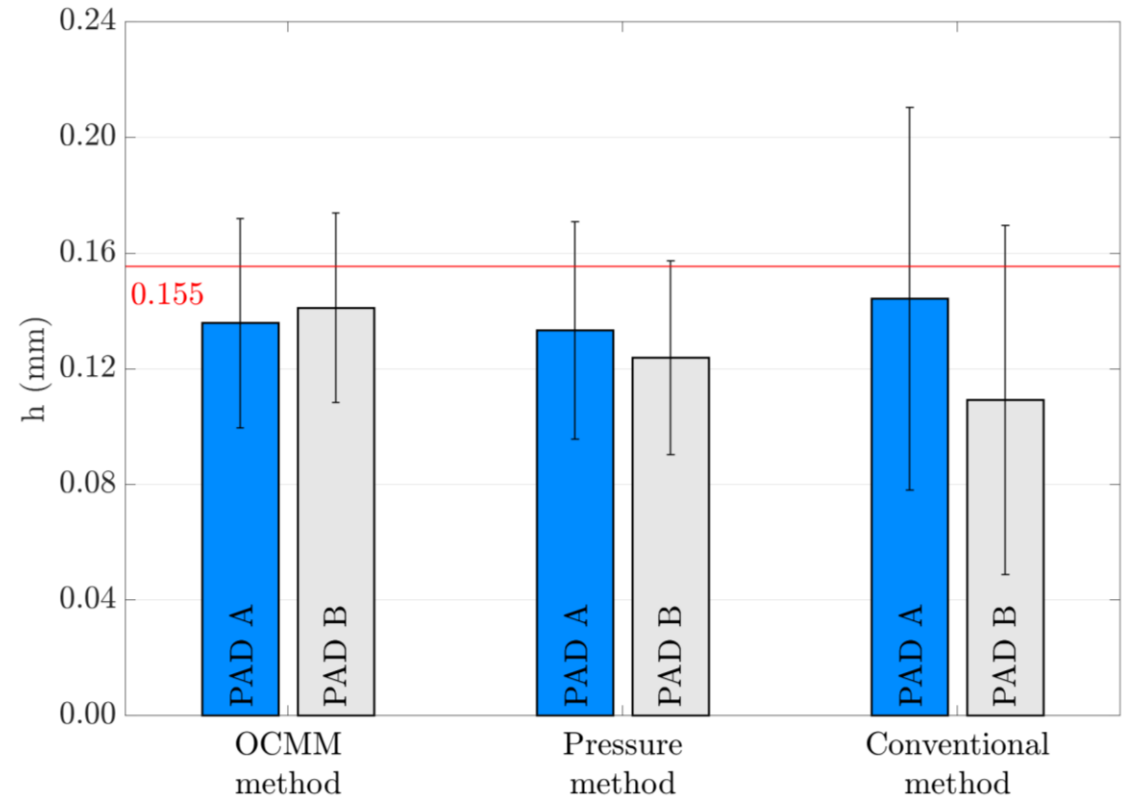
## ALIGNMENT

### THICKNESS MEASUREMENT

- Comparison with prediction
- Combined influence of measurement errors



Load: **19,6 kN**  
Pressure: **7 bar**  
Flow: **6 l/min**

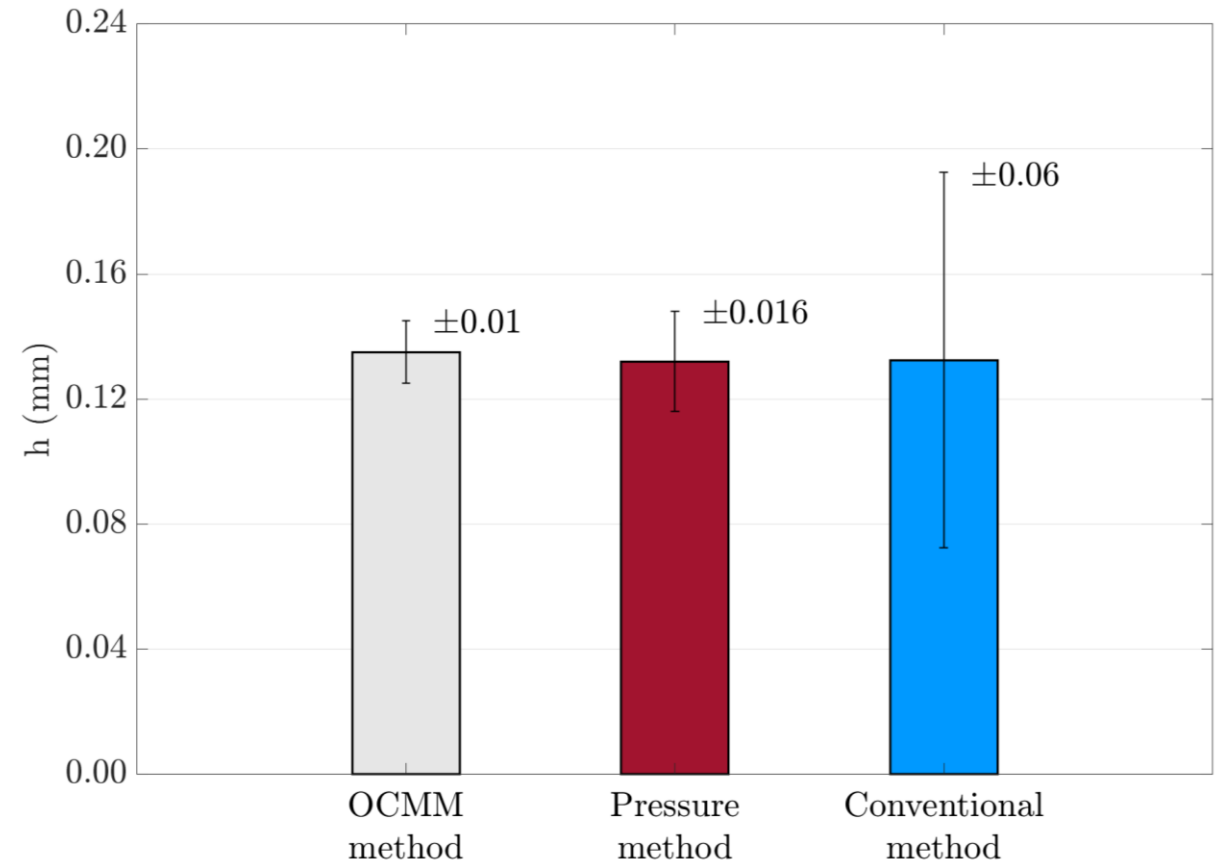


# RESULTS

## ALIGNMENT

### OPTICAL COORDINATE MEASUREMENT

- Most uniform film
  - Thickness variation of  $\pm 0.01$  mm
- Repeatable



Alignment methods comparison



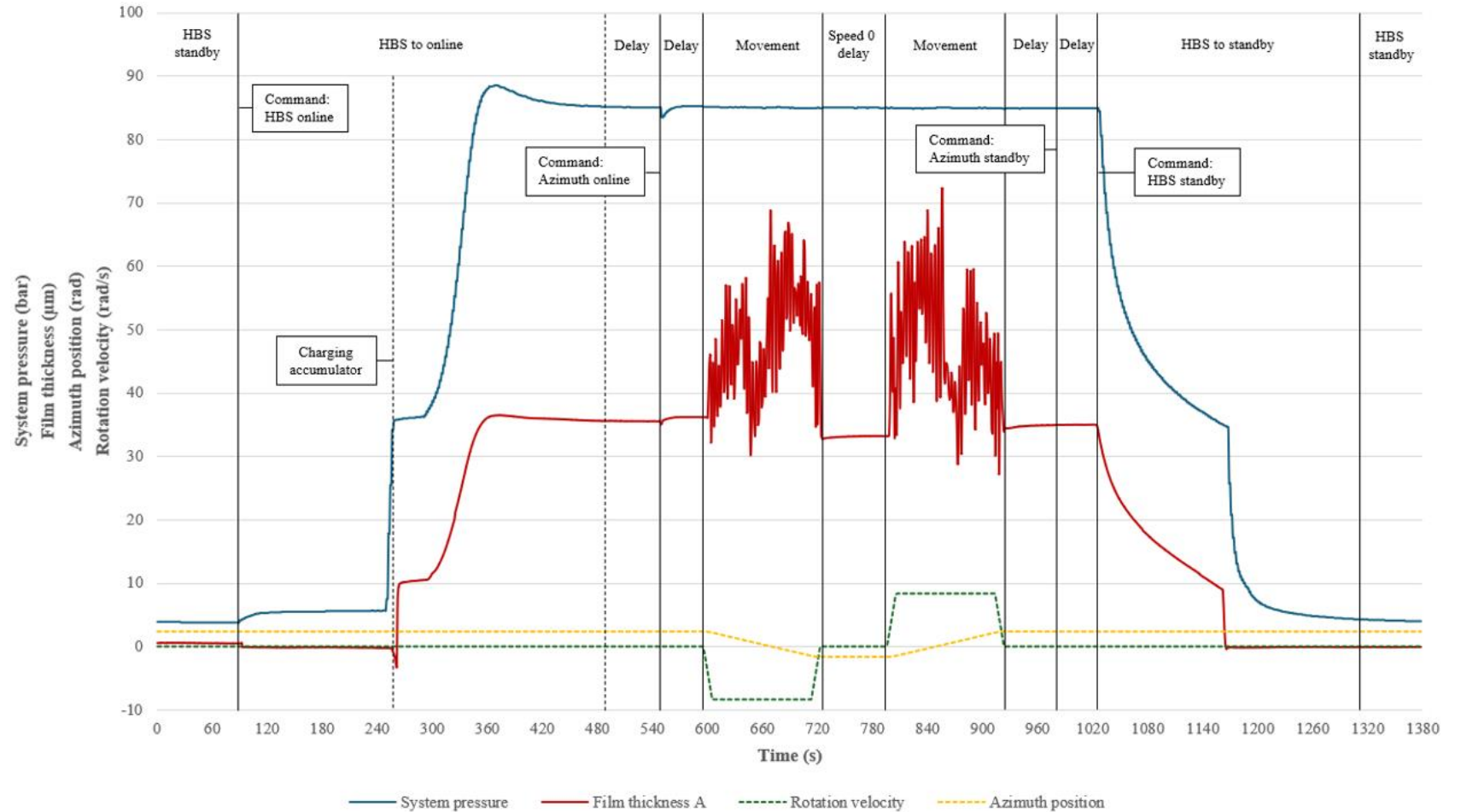
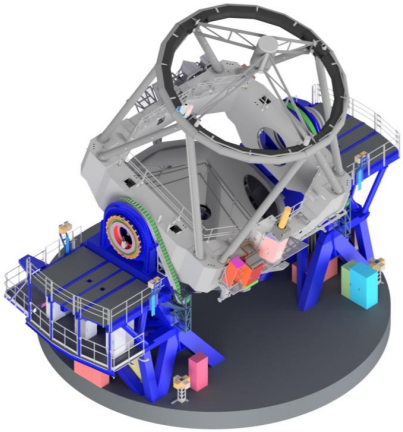
Foltýn, J.; et.al: Pad Alignment Methods and Their Impact on Large Hydrostatic Bearing Precision. *Machines*. (2024).

# RESULTS

## SAFETY PROCEDURE

### THICKNESS MEASUREMENT

- New method proposed
- Operational fluctuation  $40 \mu\text{m}$
- Connected with alignment
- Movement of  $230 \text{ deg}$

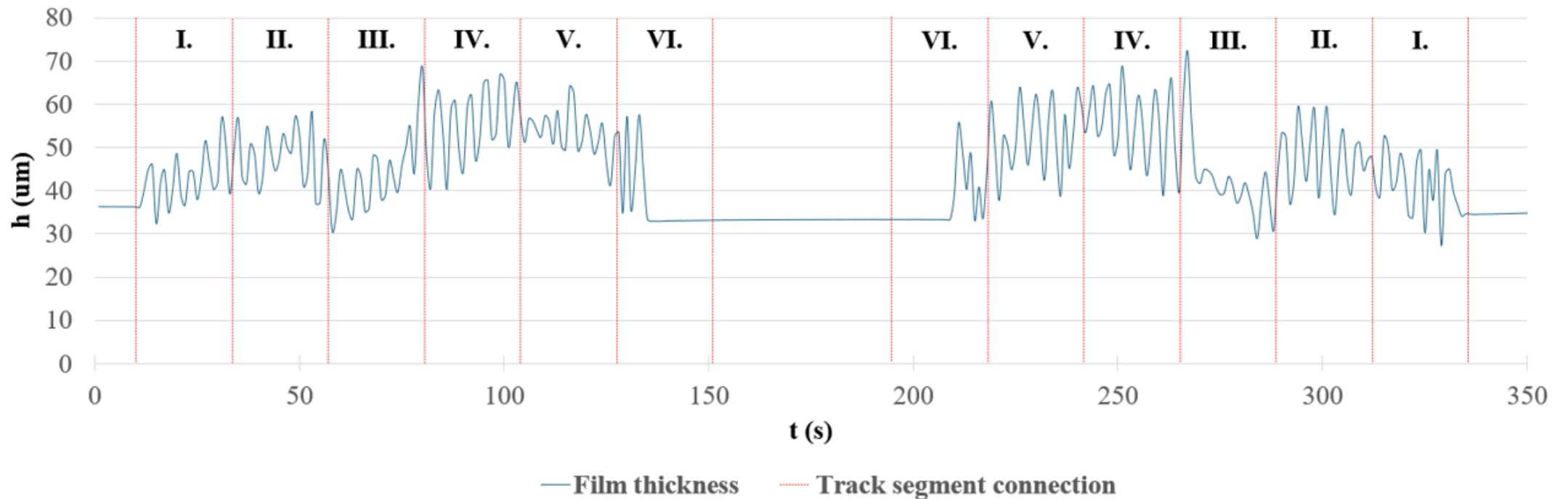
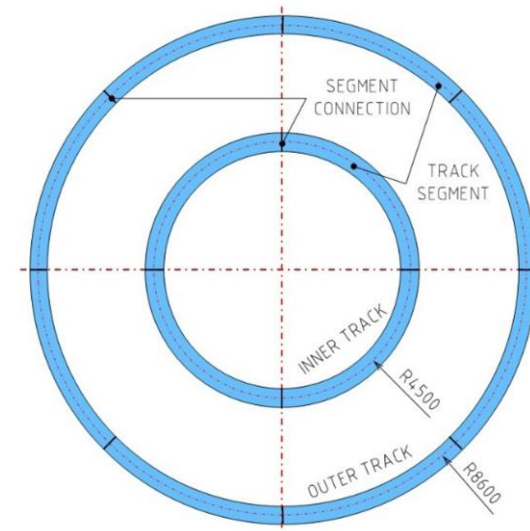


# RESULTS

## SAFETY PROCEDURE

### TRACK INFLUENCE

- Symmetrical behavior
- Segment connections changes the trend
- Solution - alignment

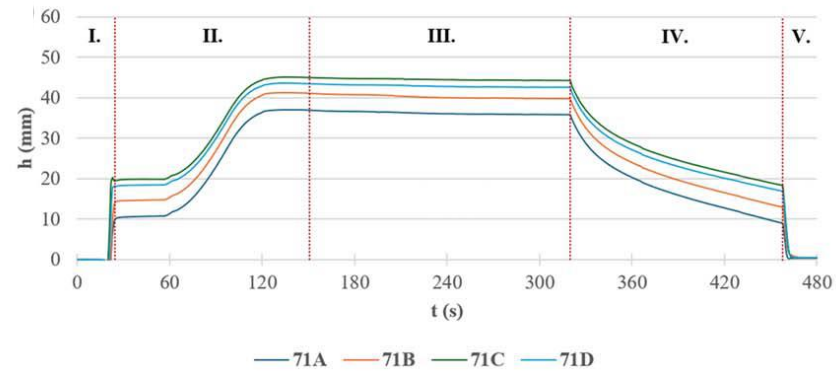
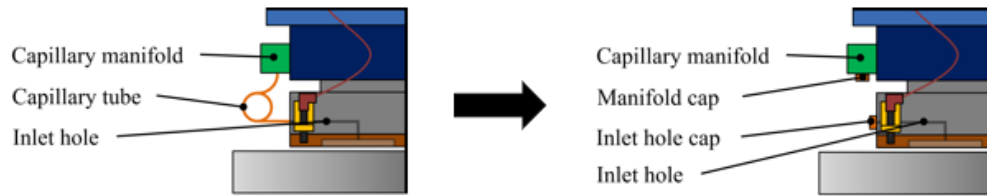
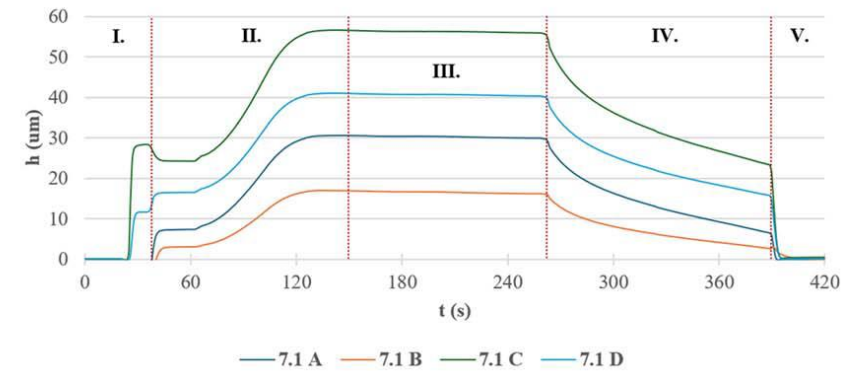
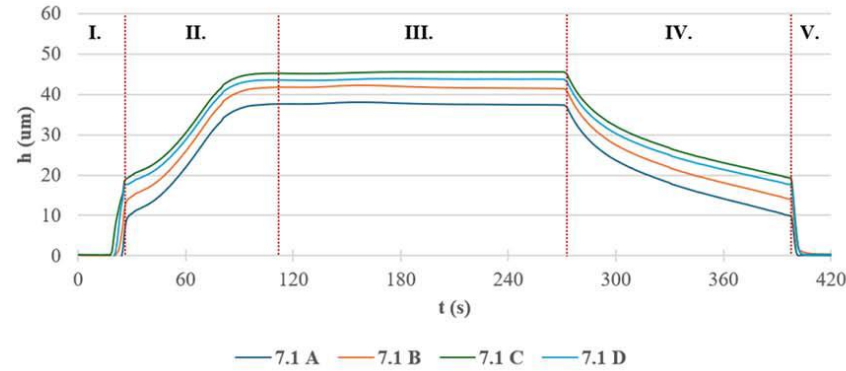


# RESULTS

## SAFETY PROCEDURE

### CAPILLARY BLOCKAGE

- Artificial blockage - cap
- Azimuth static
- Film thickness drop  $>20 \mu\text{m}$



ASME

JOURNAL OF TRIBOLOGY



Foltýn, J.; et.al.: "Failure prevention procedure of the Very Large Telescope hydrostatic bearing pads based on lubricating film thickness measurement." ASME. J. Tribol. (2025).

# CONCLUSION

SCIENTIFIC QUESTION 1

HYPOTHESIS 1

VERIFIED

Optical methods can reliably support assessment of minimum film thickness

*Measurement deviation: 3.6%*

*Measurement resolution: up to 0.001 mm*

SCIENTIFIC QUESTION 1

HYPOTHESIS 2

VERIFIED

Optical alignment methods thus represent an effective preventive measure against local film thinning

*Alignment precision:  $\pm 0.01$  mm*

*Improvement vs mechanical method: 6× reduction in deviation*

SCIENTIFIC QUESTION 2

HYPOTHESIS 3

VERIFIED

Ideal assumptions of restrictors do not adequately account for realistic fault scenarios.  
Continuous film thickness monitoring can provide early identification of critical states.

*Film thickness drop due blockage:  $>20$   $\mu\text{m}$*

*Operational dynamic fluctuation: up to 40  $\mu\text{m}$*

# CONCLUSION

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# CONCLUSION

FILM THICKNESS MEASUREMENT



PAD ALIGNMENT



Scaleable also for larger bearings



## SAFETY PROCEDURE

The measurement of film thickness is used as a safety criterion for the **VLT**, with future application to an **Extremely Large Telescope**

# LIST OF PUBLICATIONS

**Foltýn, J.**; Flores, E.; Tapia, M.; Álvarez, N.; Michalec, M.; and Svoboda, P. "Failure prevention procedure of the Very Large Telescope hydrostatic bearing pads based on lubricating film thickness measurement." *ASME. J. Tribol.* (2025). <https://doi.org/10.1115/1.4068788> [IF 3.0]



**Foltýn, J.**; Hurník, J.; Michalec, M.; Svoboda, P.; Křupka, I.; and Hartl, M. Pad Alignment Methods and Their Impact on Large Hydrostatic Bearing Precision. *Machines.* (2024). <https://doi.org/10.3390/machines12080549> [IF 2.5]

Michalec, M.; Hurník, J.; Foltýn, J.; Svoboda, P. Contactless measurement of hydrostatic bearing lubricating film using optical point tracking method. *Proc. Inst. Mech. Eng. Part J.-J. Eng. Tribol.* (2023). <https://doi.org/10.1177/13506501221108138> [IF 1.8]

**Foltýn, J.**, Maccioni, L., Michalec, M., Concli, F., Svoboda, P. Uncertainty analysis of hydrostatic bearing working conditions with experimental, CFD, and analytical approach. *Forsch Ingenieurwes* 89, 67 (2025). <https://doi.org/10.1007/s10010-025-00836-9> [IF 1.2]



**Foltýn, J.**, Maccioni, L., Michalec, M., Concli, F., Svoboda, P. (2024). The Influence of Measurement Uncertainties and Input Parameters on Hydrostatic Bearing Performance: Analytical, Experimental, and Numerical Comparison. In: *ISIEA 2024. Lecture Notes in Networks and Systems*, vol 1124. Springer, Cham. [https://doi.org/10.1007/978-3-031-70462-8\\_2](https://doi.org/10.1007/978-3-031-70462-8_2)



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Michalec, M., Foltýn, J., Svoboda, P., Křupka, I., Hartl, M. Performance and stability comparison of hydrostatic bearing pad geometry optimization approaches. *Forsch Ingenieurwes* 89, 65 (2025). <https://doi.org/10.1007/s10010-025-00837-8> [IF 1.2]

Michalec, M., Daněk, L., Foltýn, J., Svoboda, P., Gachot, C., Hartl, M. and Křupka, I. (2025), Comparative Wear and Friction Analysis of Sliding Surface Materials for Hydrostatic Bearing under Oil Supply Failure Conditions. *Adv. Eng. Mater.* 2401733. <https://doi.org/10.1002/adem.202401733>

Michalec, M., Foltýn, J., Svoboda, P., Křupka, I., Hartl, M. (2024). Experimental Comparison of Hydrostatic Bearing Pad Geometry Optimization Approaches Under Static Conditions. In: *ISIEA 2024. Lecture Notes in Networks and Systems*, vol 1124. Springer, Cham. [https://doi.org/10.1007/978-3-031-70462-8\\_1](https://doi.org/10.1007/978-3-031-70462-8_1)

Michalec, M.; Foltýn, J.; Dryml, T.; Snopek, L.; Javorský, D.; Čupr, M.; Svoboda, P. Assembly Error Tolerance Estimation for Large-Scale Hydrostatic Bearing Segmented Sliders under Static and Low-Speed Conditions. *Machines*, (2023), vol. 11, no. 11, <https://doi.org/10.3390/machines11111025>

Michalec, M., Polnický, V., Foltýn, J., Svoboda, P., Šperka, P., Hurník, J.: The prediction of large-scale hydrostatic bearing pad misalignment error and its compensation using compliant support. *Precis. Eng.* 75, 67–79 (2022). <https://doi.org/10.1016/j.precisioneng.2022.01.011>



# OTHER RESULTS

## APPLIED RESEARCH OUTCOMES

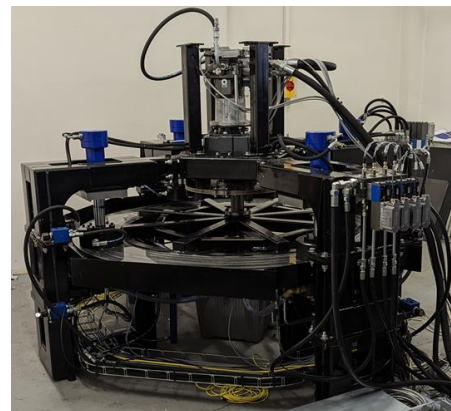
SWOBODA, P.; POLNICKÝ, V.; MICHALEC, M.; FOLTÝN, J.; MARTINEK, J.; ROBENEK, V.; DRHA, V.: **Device for testing operating conditions of hydrostatic support.**, 37631, 2024, *utility model*

FOLTÝN, J.; MICHALEC, M.; POLNICKÝ, V.; SWOBODA, P.; MARTINEK, J.; ROBENEK, V.; DRHA, V.: **Experimental device 4PAD; hydrostatic rotary table with mechatronic systems based on adaptive control loops.**, 2023, *functional sample*

FOLTÝN, J.; POLNICKÝ, V.; MICHALEC, M.; SWOBODA, P.; MARTINEK, J.; ROBENEK, V.: **Experimental device 3PAD; hydrostatic bearing with feedback control of the lubricant film thickness**, 2023, *functional sample*



3PAD



4PAD

## CONFERENCE

### ITC FUKUOKA 2023 (Poster)

**MOTIVATION**  
Hydrostatic bearing pad alignment directly affects its precision and performance, and therefore is essential for a proper and precise function. The aim was to investigate which alignment method provides the highest precision for large-scale hydrostatic bearings.

**INTRODUCTION**  
In case of large-scale bearings exceeding tens of metres, it is not possible for some of its parts to be created in a single piece or to secure desirable machining precision. Moreover, they are difficult to transport and assemble.

**MATERIAL & METHODS**  
The experimental hydrostatic bearing device consisted of two pads (Fig. 2), a load frame and a hydraulic unit. The pad geometry was designed with four circular recesses. The load can be applied up to 5 t. The hydraulic unit was able to supply a flow rate of up to 10 l/min at a pressure of 100 bar.

**EXPERIMENTAL CONDITIONS**  

- Load 2 t/pad
- Total flow: 6 l/min
- Hydraulic oil: ISO VG 46
- Proximity sensors  $\pm 0.1$  mm
- Pressure gauges  $\pm 0.56$  bar
- Repeated 4 times

**RESULTS & DISCUSSION**  
The lubricating film thickness achieved the highest average values and the best prediction agreement with OCMM method (Fig. 5). The bearing operated in an optimal mode, which led to better performance and precision of the bearing. At the same time, the smallest thickness variations occurred over the pad area (Fig. 6). The method is characterized by high alignment accuracy and can be used for a wide range of hydrostatic bearing sizes. In addition, no sensors on the bearing are required for alignment.

**THANK YOU FOR YOUR ATTENTION**

**Jan Foltýn, Ing.**

[Jan.Foltyn@vut.cz](mailto:Jan.Foltyn@vut.cz)



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