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# Large size Tilting Pad Journal Bearings Test Rig

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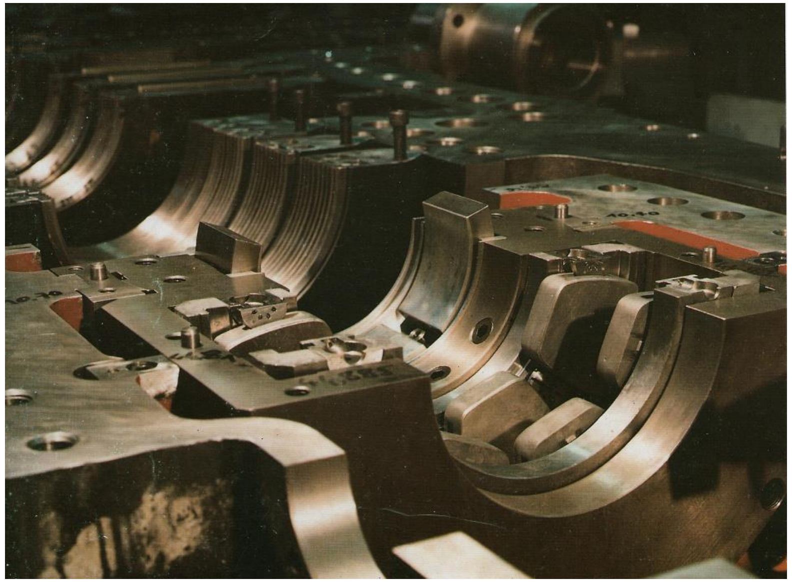
# Introduction (1/2)

- Rotating machinery speed and power density continue to increase, along with the complexity of the system. The dynamic behavior of such complex machines depends heavily on the bearings.

56 MW GE steam turbine with 400 mm diameter tilting pad journal bearings (Courtesy of GE)

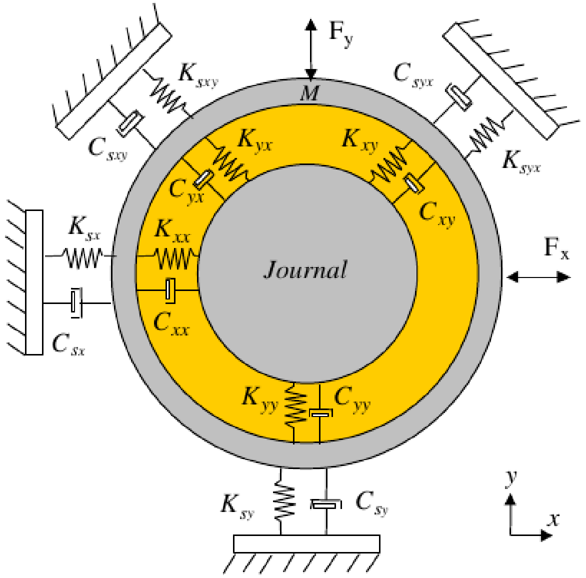


Steam turbine bearings (Glacier DHB5A Catalogue, 1987)

# Introduction (2/2)

- Tilting pad journal bearings are commonly used in these applications thanks to their dynamic stability and ability to accommodate for misalignments.

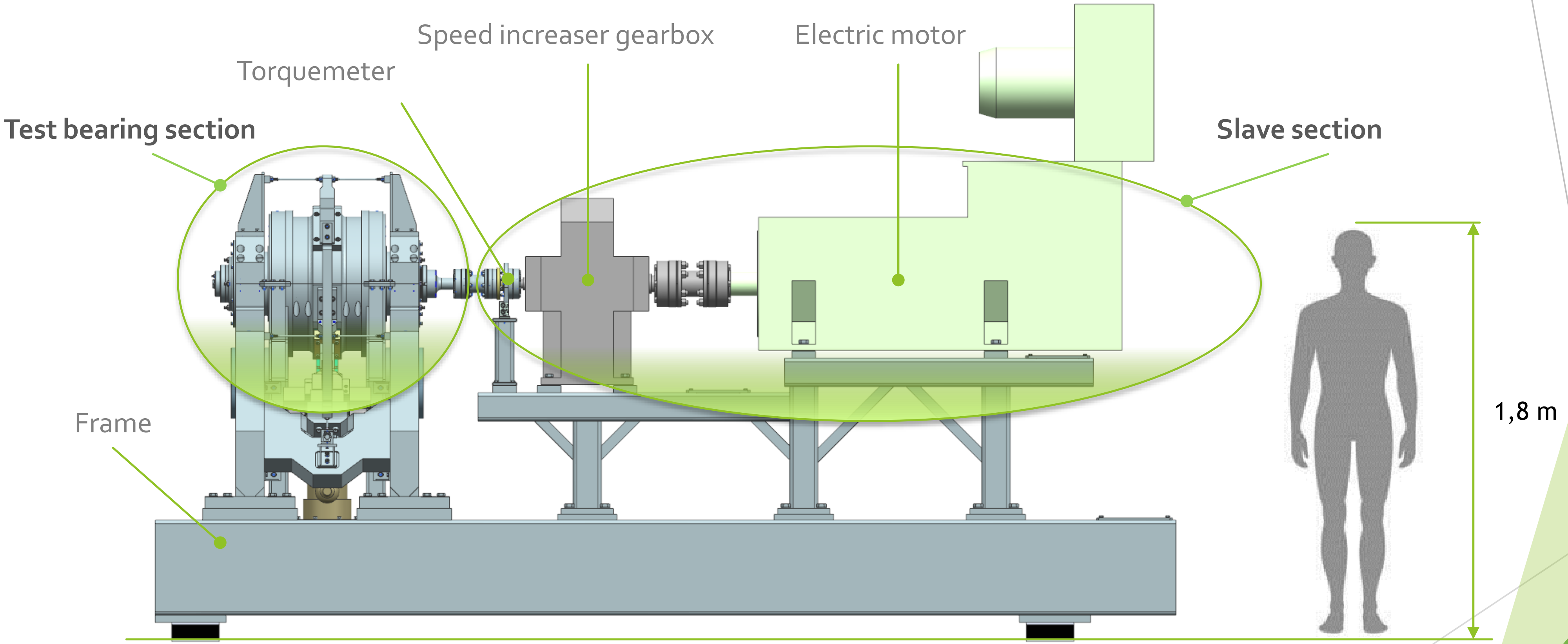
  The knowledge of the bearing stiffness and damping coefficients is fundamental for the study of the rotor stability particularly at the design stage.




Linearized test bearing system force coefficients

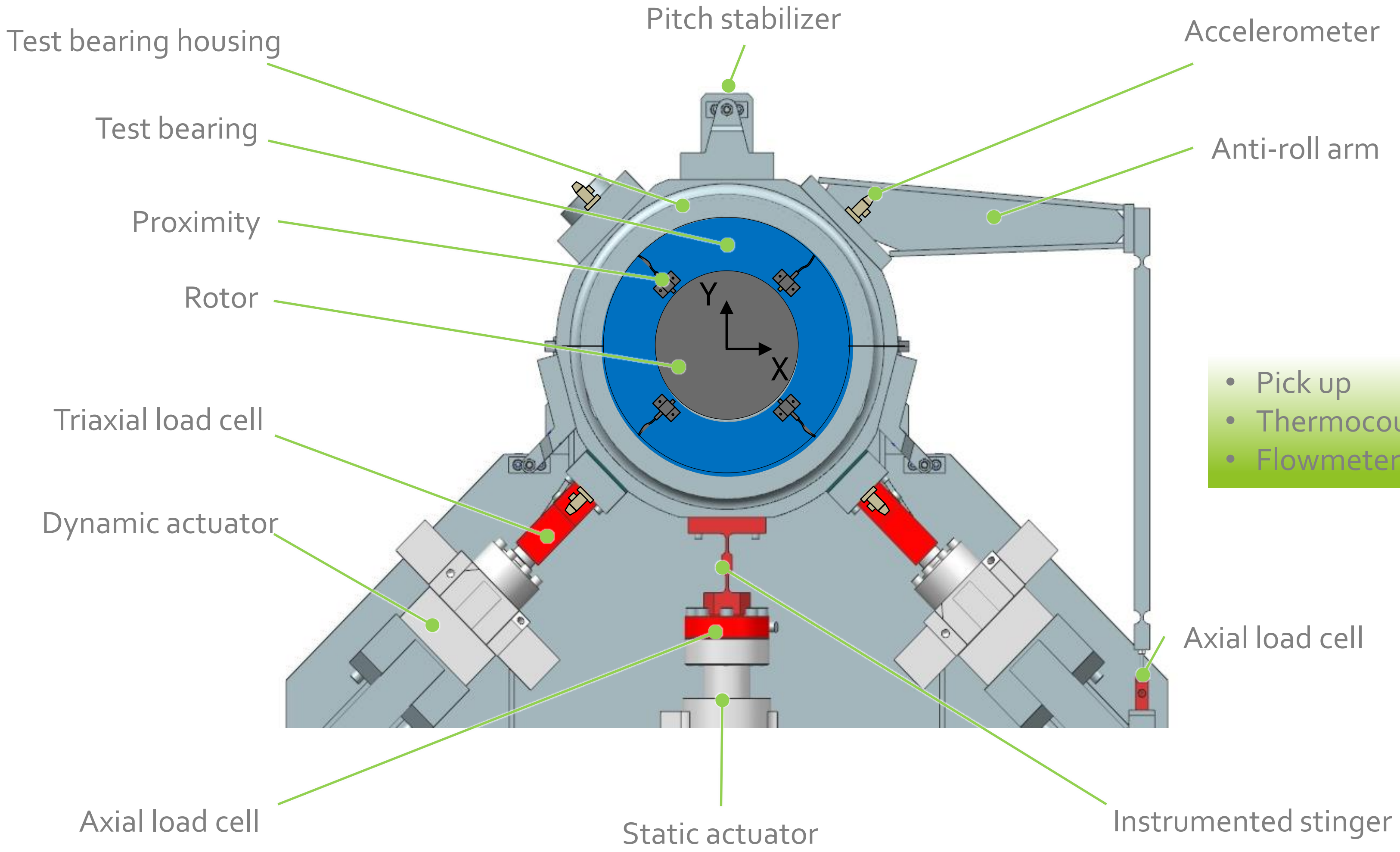
# Bearing test rig

The test rig, available at Pisa University, is based on the "floating" bearing design[1], where the loads are applied to the test article instead of the rotor. The rotor is supported by two roller bearings.




[1] Glienicke, J, 1966, "Experimental Investigation of Stiffness and Damping Coefficients of Turbine Bearings and Their Application to Instability Predictions," IMechE, Proceedings of the Journal Bearings for Reciprocating and Rotating Machinery, 1966-1967, **181**(3B), 116-129

# Bearing test rig section view

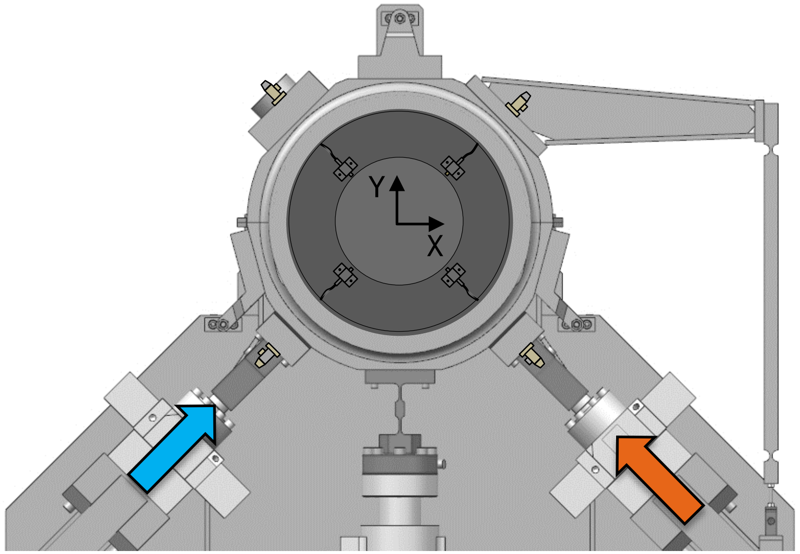



- Pick up
- Thermocouples
- Flowmeter

# Bearing test rig load application system

A vertical actuator is used to apply a steady load up to 270 kN, while two actuators arranged at 45° deliver synchronously dynamic forces (in-phase or anti-phase) up to 40 kN.

A pseudorandom load, generated by a sum of up to 5 sinusoidal signals, allows to investigate the frequency range [20% - 120%]  around the synchronous frequency in a single test.



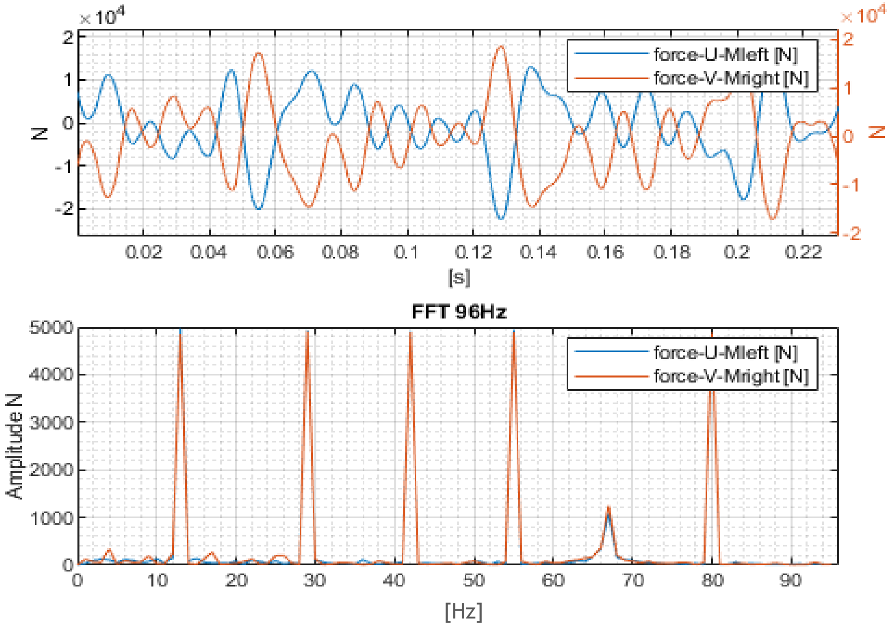




Figure – Dynamic actuators forces read by load cells and displayed respectively in time and frequency domain for a test at 4000 rpm

# Bearing test rig main features

- **Static and dynamic loading** of the test bearing by using hydraulic actuators.
- **High frequency sampling** of forces, displacements and accelerations.
- **High power** tests.

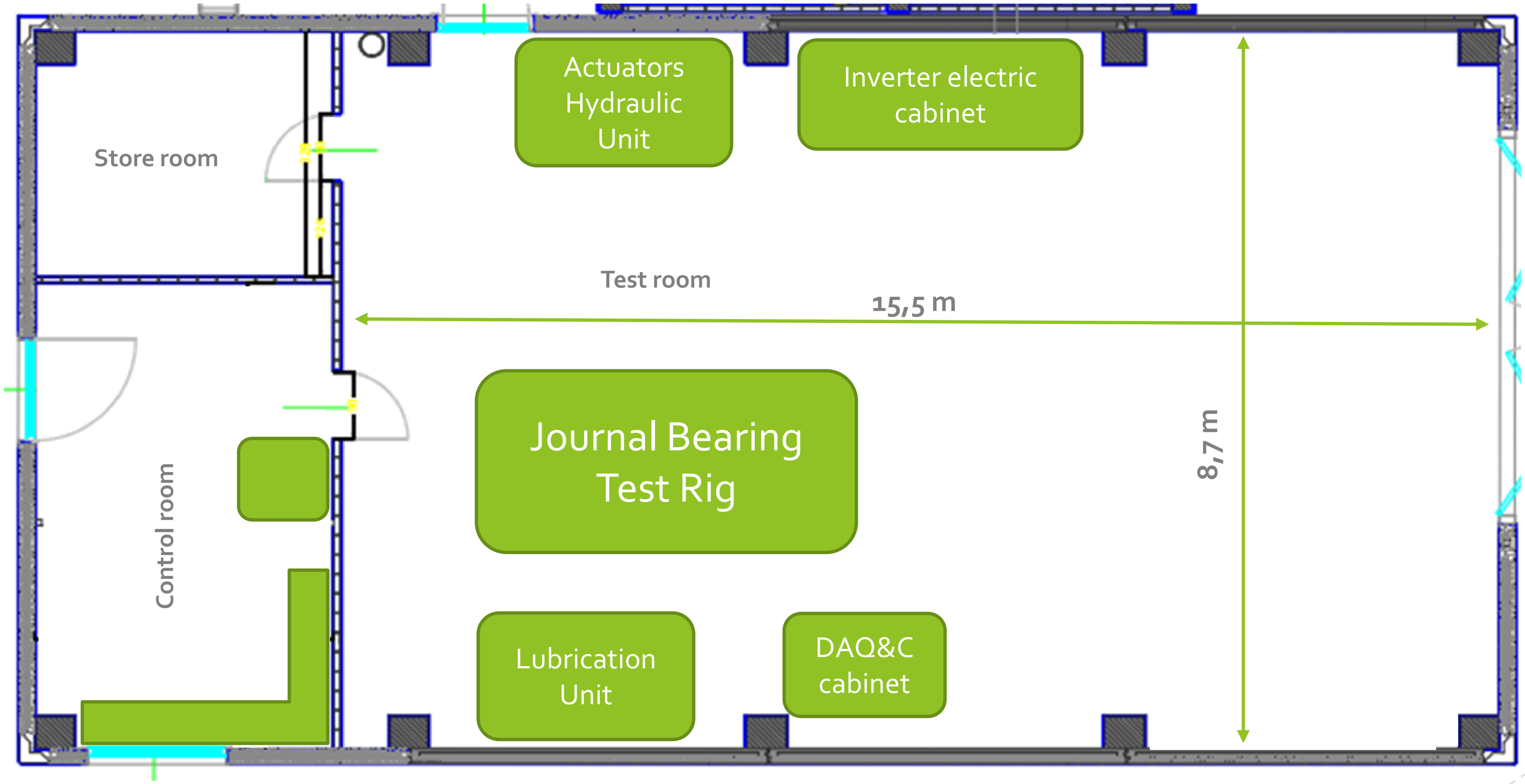
| Operational parameters (input) | | Measured data (output) |
|---|---|---|
| Oil flow | → | Bearing power loss |
| Inlet oil temperature | | Pad temperature |
| Static load | | Outlet oil temperature |
| Rotor speed | | Test bearing eccentricity |
| Dynamic load | | Dynamic stiffness and damping coefficients |

# Bearing test rig performances

| Parameter | Unit | Value |
|---|---|---|
| Electric motor maximum power | kW | 630 |
| Test bearing diameter* [mm] | mm | **250 - 300** |
| Test bearing length to diameter ratio | # | 0,4 - 1 |
| Test bearing rotational speed | rpm | 300 - 12.000 |
| Test bearing peripheral speed | m/s | 4 - 150 |
| Test bearing maximum applicable torque | Nm | 500 |
| Static load | kN | 5 – 270 |
| Dynamic load | kN | 1 - 40 |
| Dynamic load frequency | Hz | **1 - 200** |
| Sampling frequency | kHz | 25 - 100 |
| Test bearing oil flow rate | l/min | 125 - 1.100 |
| Test bearing oil inlet temperature | °C | 40 - 120 |

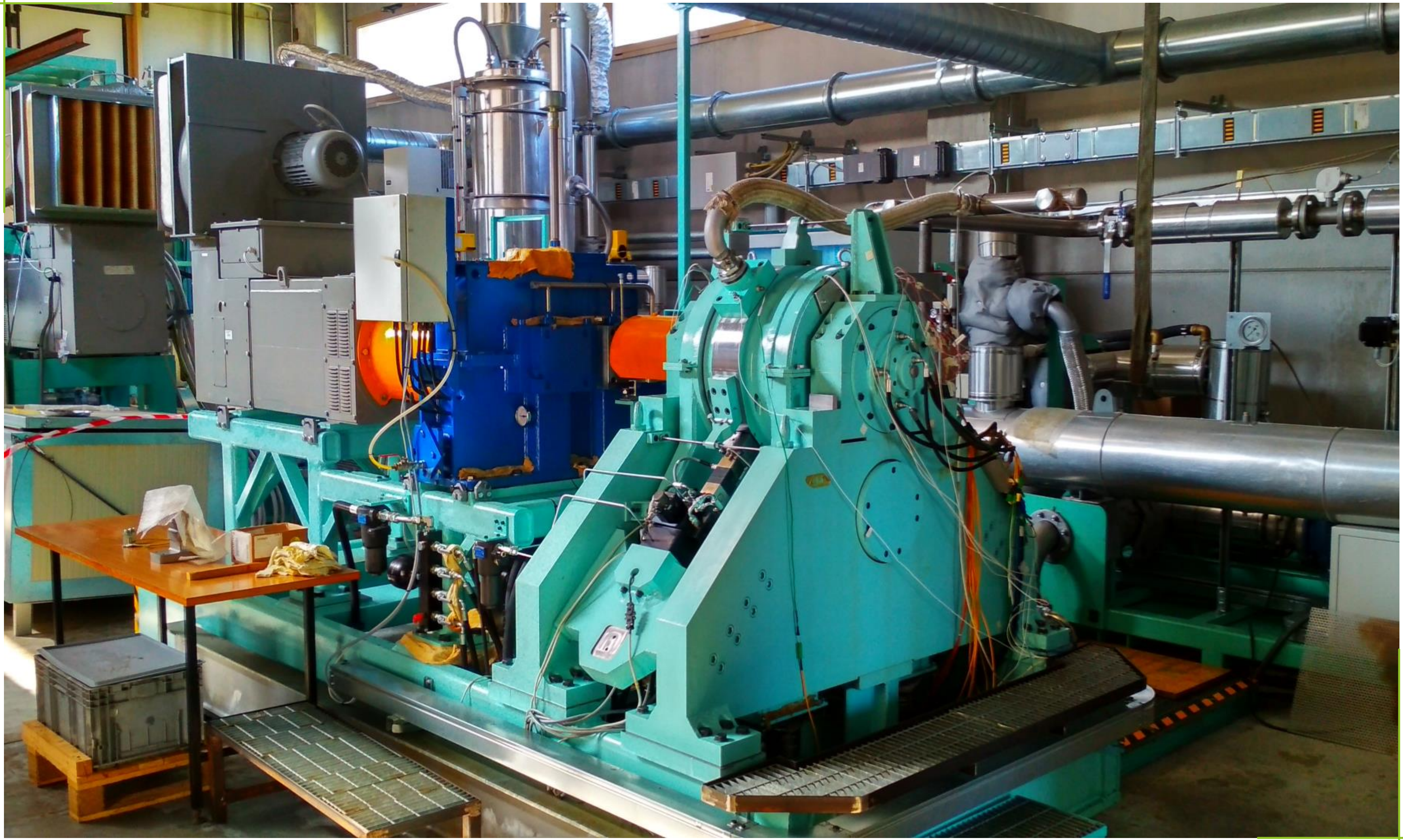
*A rotor with a diameter of 280 mm is currently installed on the test rig.

# Test facility layout



# Test facility overview

# Bearing test rig overview



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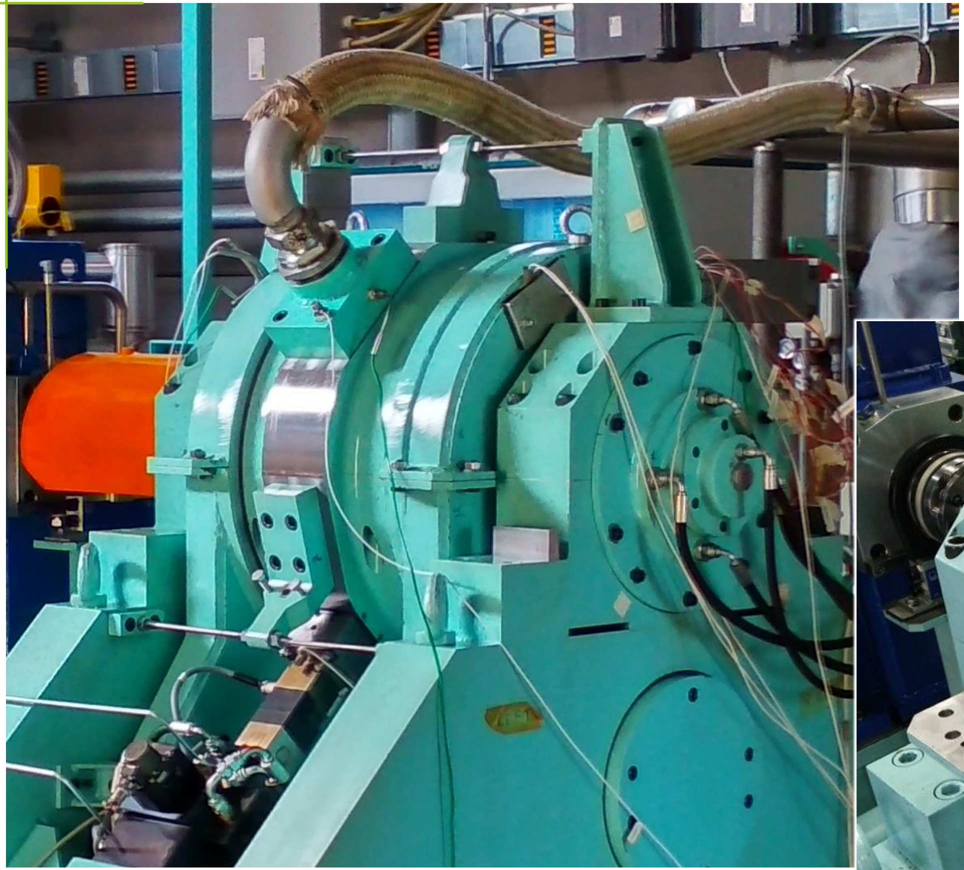
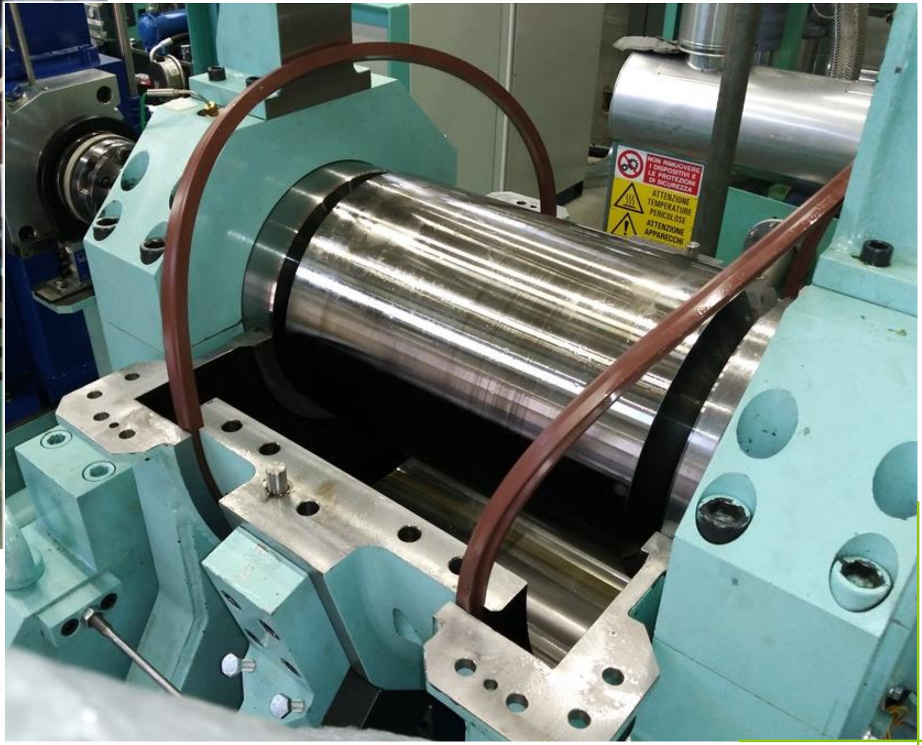
# Bearing test rig detailed views

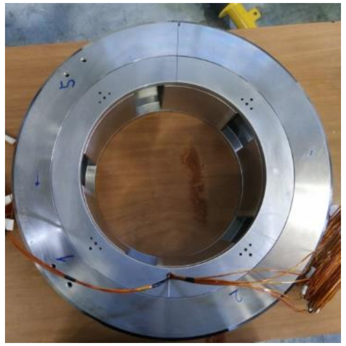


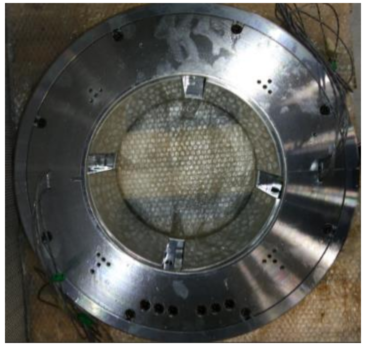


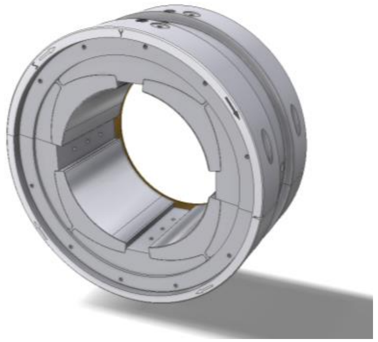
# Test article – journal bearings

Various bearings have been tested so far. Some of them are briefly described and listed below.

| | Direct lube RB‡ | Flooded RB‡ | Flooded B&S‡ | Flexural Pivot$^{\delta}$ |
|---|---|---|---|---|
| **Pad Number** | 5 | 5 | 4 | 4 |
| **L/D** | 0.7 | 0.55 | 0.7 | 0.7 |
| **Pivot Type** | Cylindrical | Cylindrical | Ball&Socket | Flexural |
| **Diameter** | 280 | 280 | 280 | 280 |







‡ Ciulli E. etc., 2020, "Dynamic identification of 280 mm diameter tilting pad journal bearings: test results and measurement uncertainties assessment of different designs" ASME TurboExpo, Proceedings of the ASME 2020.

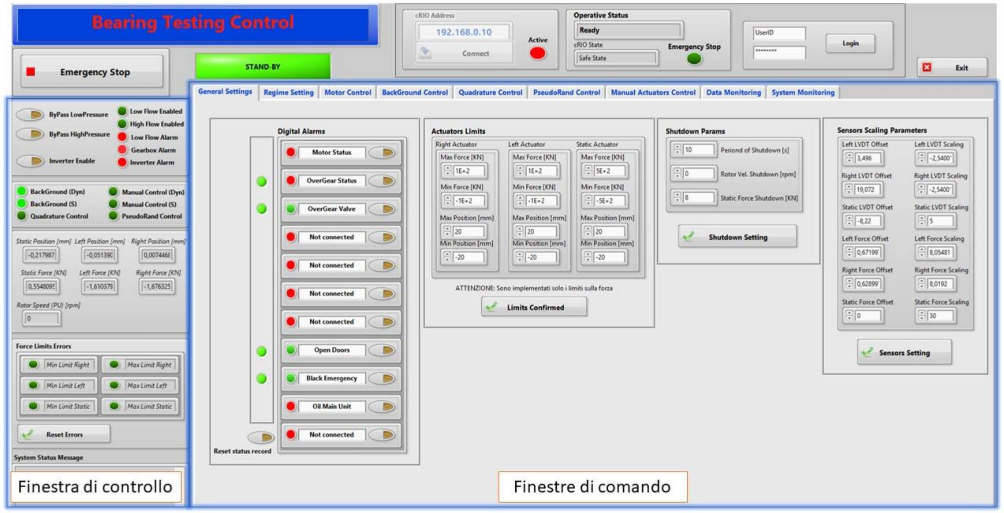
δ Vannini G etc. 2020. "Experiments on a Large Flexure Pivot Journal Bearing: Summary of Test Results and Comparison With Predictions." ASME. J. Eng. Gas Turbines Power. March 2020, 142(3).

# Bearing test rig data acquisition and control system

A data acquisition and control system (DAQ&C) based on National Instruments PXI and Compact RIO platforms was developed in order to acquire high and low frequency signals.

High frequency data (approximately 30 channels) are logged at 100 kHz , while low frequency data (approximately 60 channels) are logged at 1 Hz.

Purposely developed Matlab® routines perform the data processing for the identification of the dynamic coefficients.



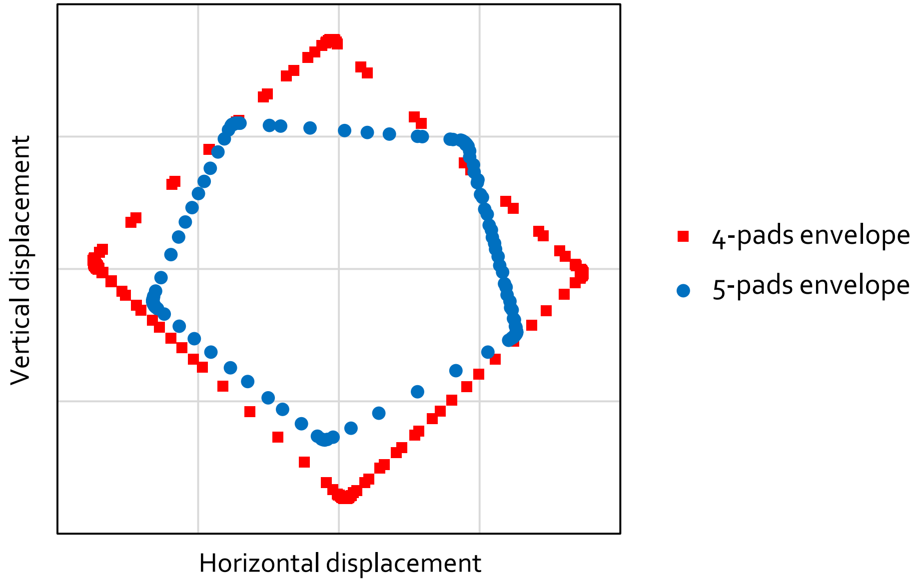

Control system GUI

# Bearing test rig control room

# Example of test results: Bump test

The Bump test allows the measurement of bearing clearance and the determination of the bearing center.

A rotating force vector is generated by sinusoidal signals with 90° phase difference (provided by dynamic actuators). The force are increased until the polygon does not change.

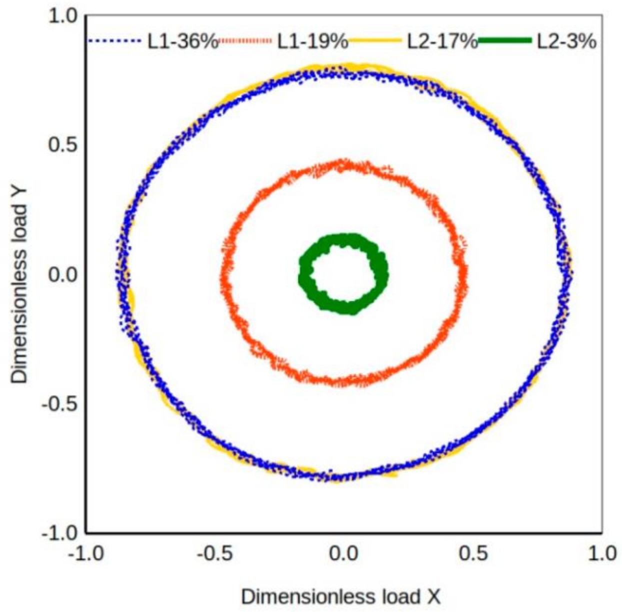



**Envelopes of bump tests for a 4-pads and 5-pads TPJB ‡**

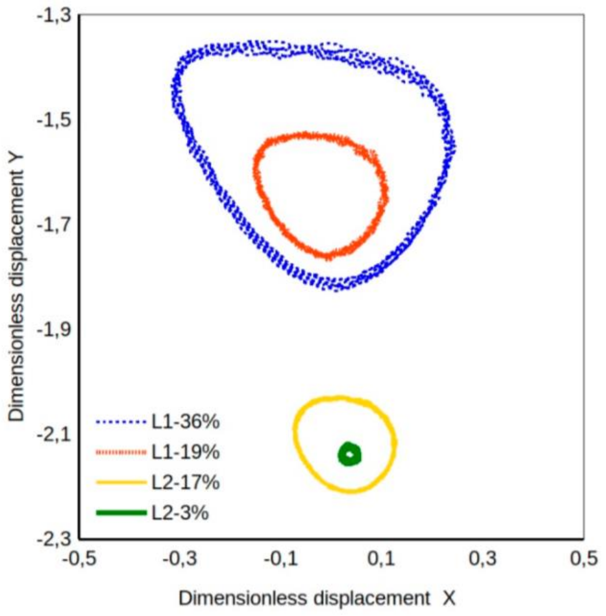
‡ Ciulli E. etc., 2020, "Experimental Tests on 280 mm Diameter Tilting Pad Journal Bearings", 7° Workshop AIT "Tribologia e Industria", 2020.

# Example of test results: Non-linear responses

By applying a slowly rotating force to the floating stator in steady operating conditions and measuring the relative displacement of the stator from the rotating shaft, it is possible to investigate the linear boundaries of bearing displacements response.




Various dimensionless rotating forces, applied for two level of static load acting on bearing (L1 & L2) ‡

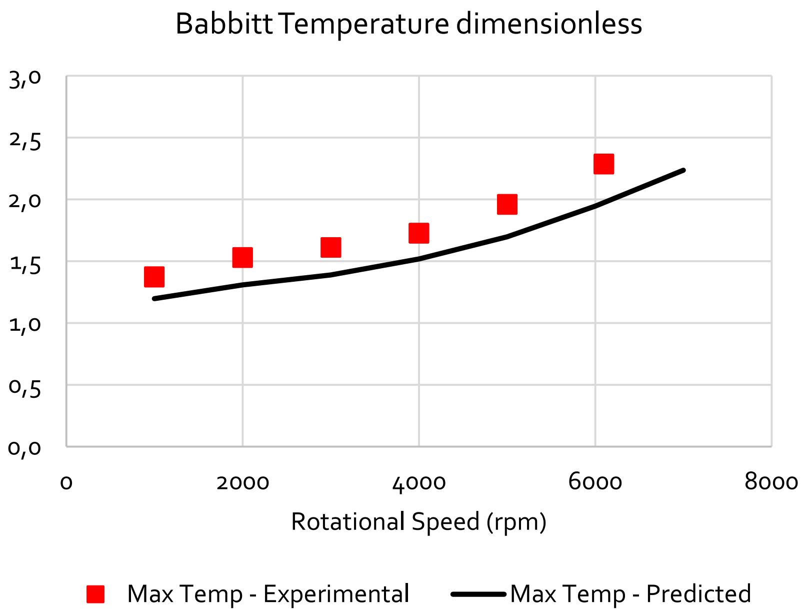



Eccentricity response of bearing for each test ‡

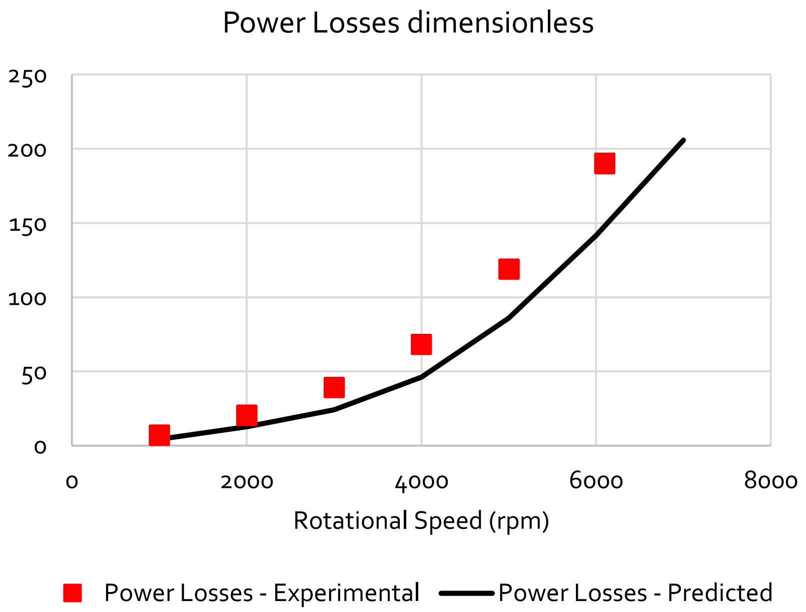
‡ Ciulli E. etc., 2019, "Nonlinear Response of Tilting Pad Journal Bearings to Harmonic Excitation", Machines 2019.

# Example of test results: Static performances

By running the test rig for approximately 1,5 hour stationary conditions are reached and maintained for at least 30 minutes. Once the target speed is reached the static performance is evaluated.




**Babbitt temperature dimensionless for Flooded B&S‡**




**Power losses dimensionless for Flooded B&S‡**

‡ Ciulli E. etc., 2020, "Dynamic identification of 280 mm diameter tilting pad journal bearings: test results and measurement uncertainties assessment of different designs" ASME TurboExpo, Proceedings of the ASME 2020.

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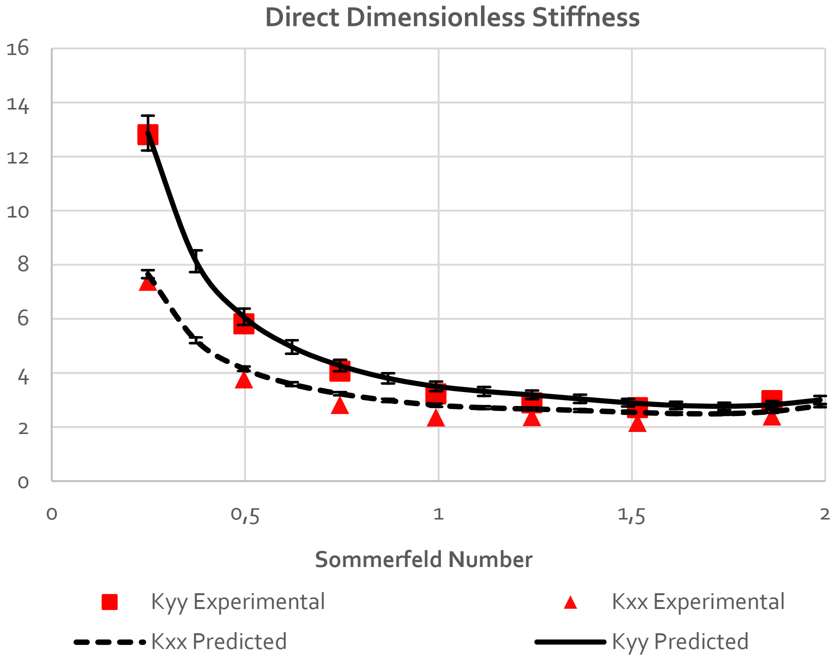
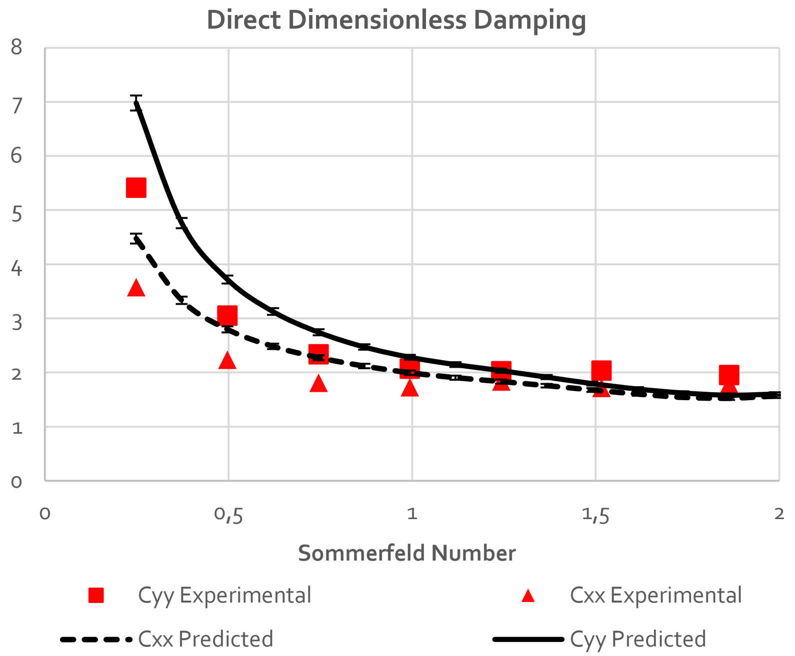
# Example of test results: Dynamic coefficients identification

For the identification of the bearing dynamic coefficients two tests with linearly independent excitations are required. They are usually obtained by using the dynamic actuators accordingly to the in-phase (vertical force) and anti-phase (horizontal force) operational modes.




Direct dimensionless stiffness for direct lube TPJB ‡




Direct dimensionless damping for direct lube TPJB ‡

‡ Ciulli E. etc., 2020, "Dynamic identification of 280 mm diameter tilting pad journal bearings: test results and measurement uncertainties assessment of different designs" ASME TurboExpo, Proceedings of the ASME 2020.

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# Papers


1. E. Ciulli, P. Forte, M. Libraschi and M. and Nuti, "Set-up of a novel test plant for high power turbomachinery tilting pad journal bearings", Tribology International, vol. 127, pp. 276-287, 2018.
2. P. Forte, E. Ciulli, F. Maestrale, M. Nuti and M. Libraschi, "Commissioning of a Novel Test Apparatus for the Identification of the Dynamic Coefficients of Large Tilting Pad Journal Bearings", Procedia Structural Integrity, vol. 8, pp. 462-473, 2018.
3. E. Ciulli, P. Forte, M. Libraschi, L. Naldi and M. Nuti, "Characterization of High-Power Turbomachinery Tilting Pad Journal Bearings: First Results Obtained on a Novel Test Bench.", Lubricants, vol. 6, no. 4, pp. 1-15, 2018.
4. E. Ciulli, P.; Forte, "Nonlinear Effects in the Dynamic Characterization of Tilting Pad Journal Bearings", in the proceedings of the International Conference of IFToMM ITALY, Cassino, Italy, 29–30 November 2018.
5. M. Barsanti, E. Ciulli and P. Forte, "Random error propagation and uncertainty analysis in the dynamic characterization of Tilting Pad Journal", in Journal of Physics: Conference Proceedings, 2019.
6. E. Ciulli, P. Forte, M. Nuti, "Experimental tests on large size tilting pad journal bearings for turbomachinery", Proceeding of BALTTRIB, 2019.
7. M. Barsanti, E. Ciulli, P. Forte, M. Libraschi and M. Strambi, "Error analysis in the determination of the dynamic coefficients of tilting pad journal bearings", in Procedia Structural Integrity AIAS2019 - 48th Conference on Stress Analysis and Mechanical Engineering Design, Assisi (PG), Italy, 4-7 September 2019.
8. G. Vannini, F. Cangioli, E. Ciulli, M. Nuti, P. Forte, J. Kim and R. Livermore-Hardy, "Experiments on a Large Flexure Pivot Journal Bearing: Summary of Test Results and Comparison With Predictions." ASME. J. Eng. Gas Turbines Power. March 2020; 142(3)