Magnetically Levitated 6 DoF Controlled Sample Manipulator for Tomography

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Partners in Mechatronic Innovation

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R&D company, supporting innovation at our customers
with the focus on high-end mechatronic systems and products.

Founded in 2007

Located in the Eindhoven region, The Netherlands

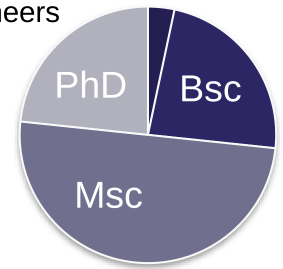
- Cleanrooms, Temp controlled enclosures, low-nose floor, …

Market segments, professional production equipment

- Semiconductor (Wafer scanners, die-bonders)
- Analytical and imaging (Electron microscopes)
- ….
- Scientific instrumentation (Synchrotron beamlines equipment)

Booth: C02

54 Engineers

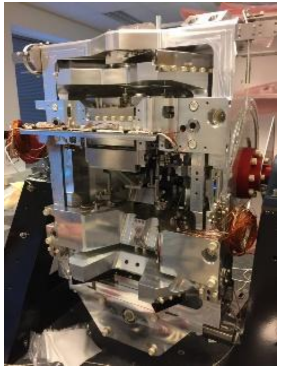


From quasi-static to high dynamic positioning

Trent in beamline equipment:

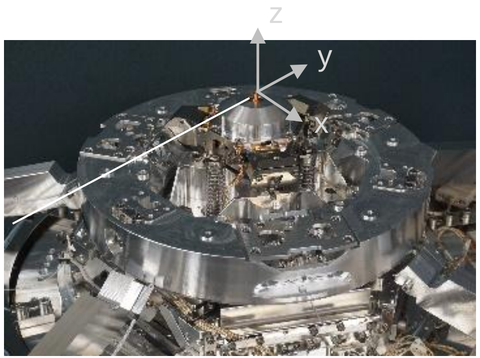
1. Higher accuracy: from sub-micron to nm
2. Faster: from quasi-static position to high dynamic scanning applications
3. Cleaner: not only UHV but also low-outgassing of CxHy to keep optics clean

High-dynamic DCM with nrad performance during fly scan (LNLS)



The High-Dynamic Double-Crystal Monochromator (Ph.D. Renan Geraldes, 2023)

Sample manipulator (x,y,z,Rz) with fast raster xz-scanning (LNLS)

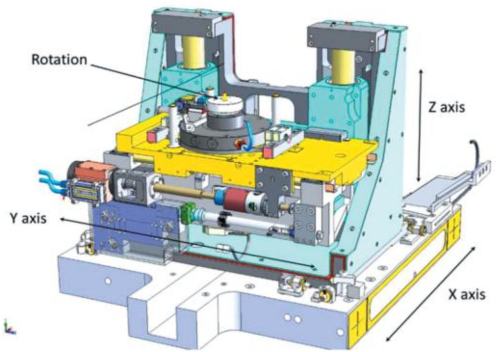


TUOBM02

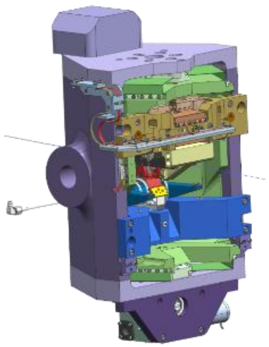
Way of approach: Mechatronic system design

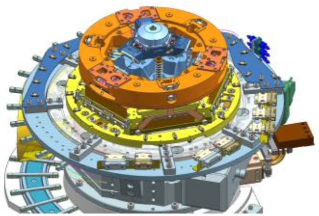
Stacking of multiple “standard 1DoF” motion stage → Fast and nm → Dedicated (Mechatronic) system design

Limitations:
- Limited stability and repeatability
- Lack of metrology, very indirect metrology loop with many uncontrolled DoF
- Limited dynamics performance
- Not UHV compatible, high CxHy outgassing

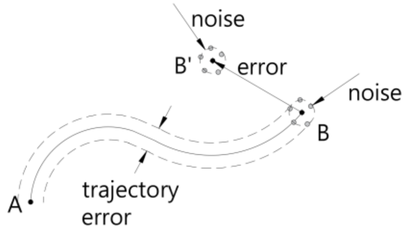


Source: Gema Martinez-Criado et al. J. Synchrotron Rad. (2016)



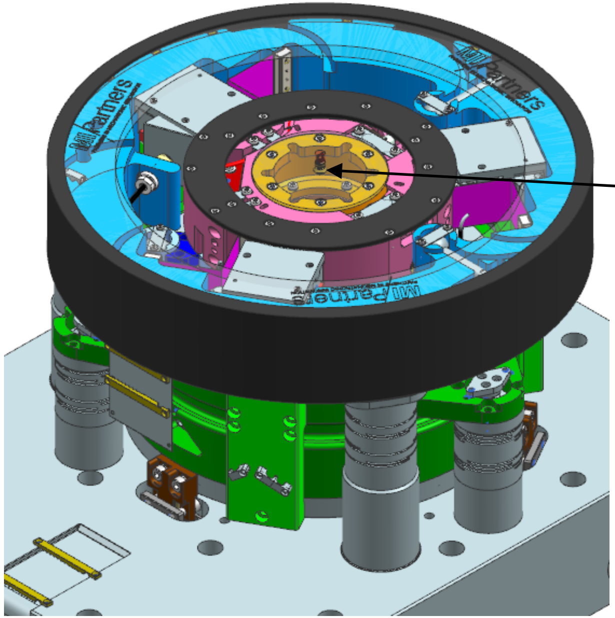


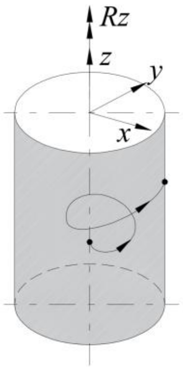
Benefit:
- Direct control and metrology of all essential DoF
  → high stability and repeatability
- Optimize design: stiff and low mass
  → High mechanical eigenfrequencies and servo band with high disturbance rejection and tracking performance
- Short/optimal metrology loop
  → high (thermal) stability
- UHV design, control of outgassing components, cleaning, ….
- ….



Magnetically Levitated 6 DOF Manipulator

Single step 6 DoF motion stage with precise 6 DoF metrology for e.g. tomography





Arbitrary scanning motions simultaneously [x,y,z,Rz]:
(spiral, raster, ….)

Stokes:
x,y,z: 3 mm
Rz: continuously
Rx,Ry: ≈ 0 (2 mrad)

Velocities:
x,y,z: 50 mm/s (limited by metrology resolution)
Rz: 5 Hz (depending on offset)

Accelerations:
x,y,z: 2 m/s^2

Metrology and motion performance:
x,y,z: 5 nm (RMS)
Rx,Ry: 20 nrad (RMS)
Rz: 50 nrad (RMS)

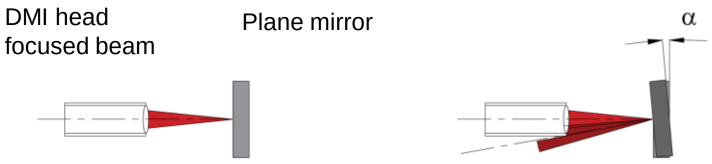
Content

- Position Metrology
- System Overview
- Actuator Design
- Control Architecture
- Positioning Performance

Metrology challenge

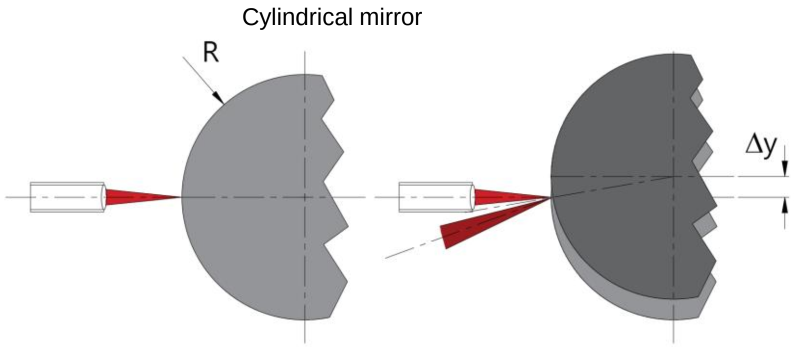
Position metrology in high-end stages typically by Distance Metrology Interferometer (DMI):

- High resolution/accuracy with long travel ranges
- Angular alignment limitations in “plane mirror” configuration



Angular range is very limited: typical 0.1…0.3 °

Tomography manipulator continues Rz: rotation symmetric DMI target



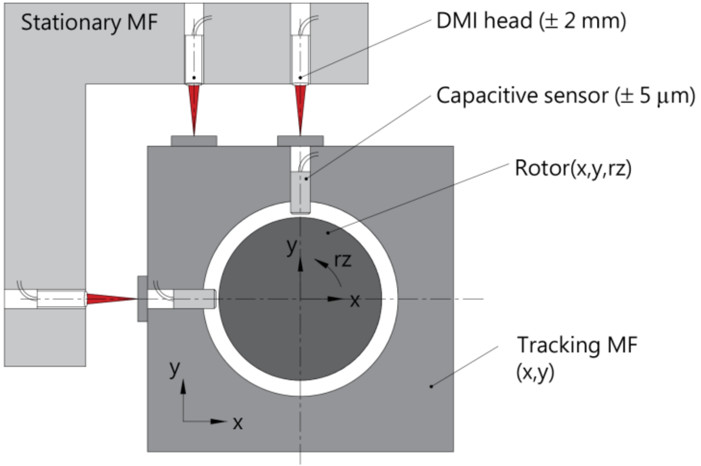
Offset of cylindrical mirror is very limited: 0.1…0.3 mm

$$\Delta y = R\tan(\alpha); R \approx 50\ mm$$

Metrology with Tracking Metrology Frame

To allow large translations of the rotor: intermediate tracking metrology frame is used

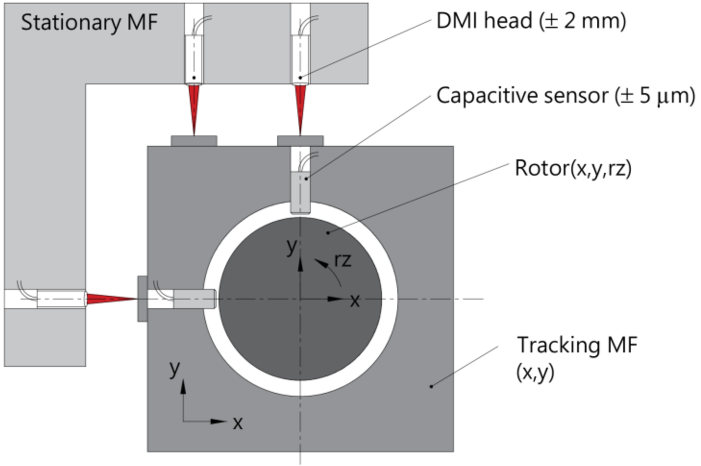
1. Large motion between Stationary MF and Tracking MF measured by DMI (± 2 mm)
2. Small tracking error between Tracking MF and rotor (~ 5…10 nm)

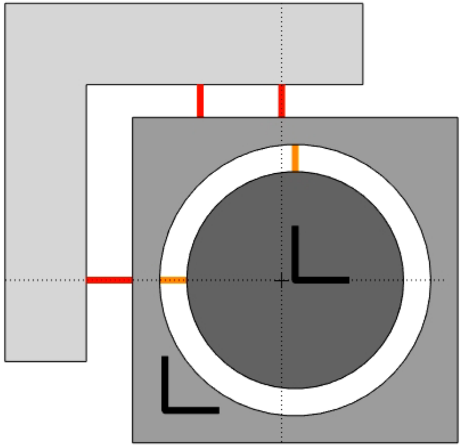


Metrology with Tracking Metrology Frame

To allow large translations of the rotor: intermediate tracking metrology frame is used

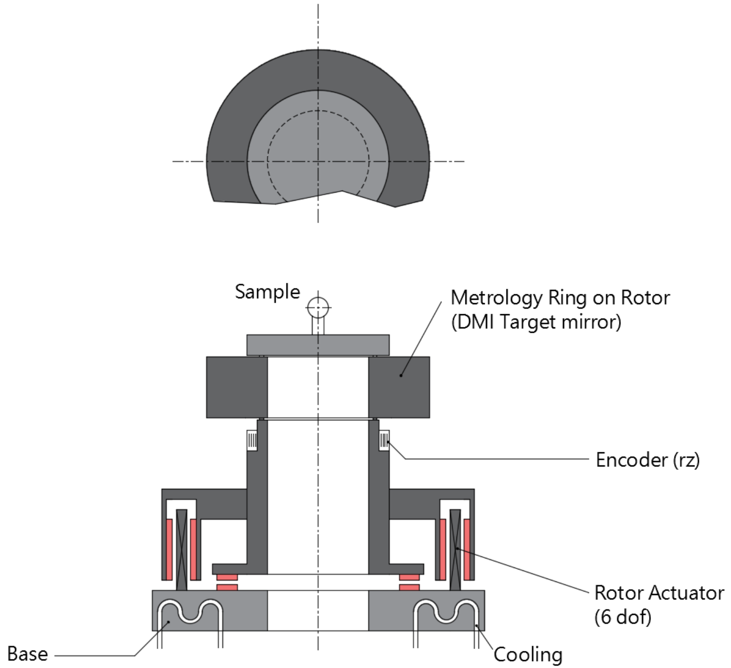
1. Large motion between Stationary MF and Tracking MF measured by DMI (± 2 mm)
2. Small tracking error between Tracking MF and rotor (± 1 µm)





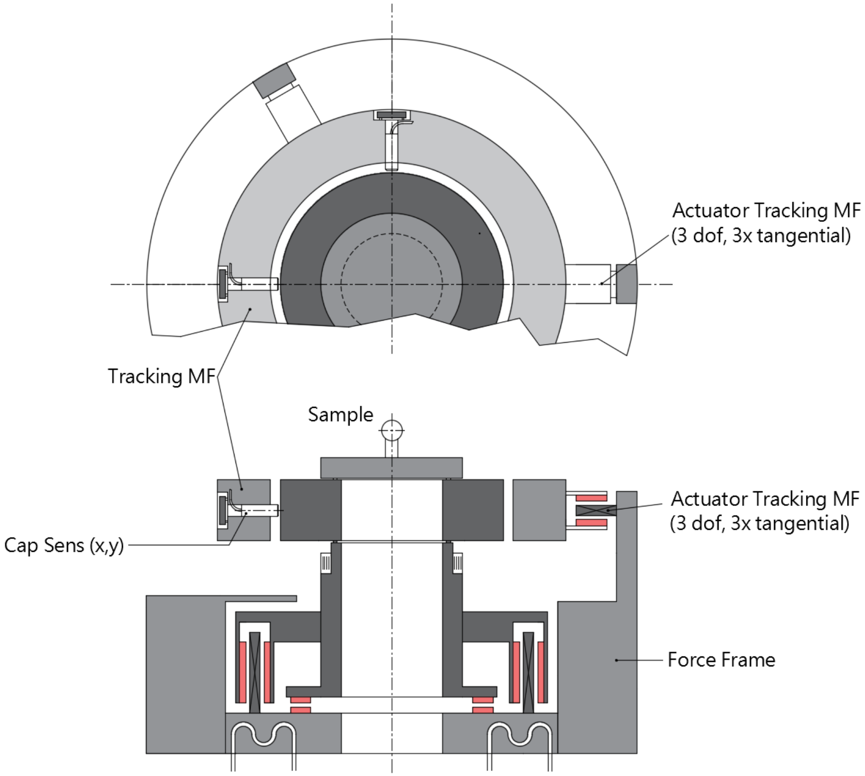
System Overview

Actuation: Rotor with Actuator and Metrology Ring (DMI target)



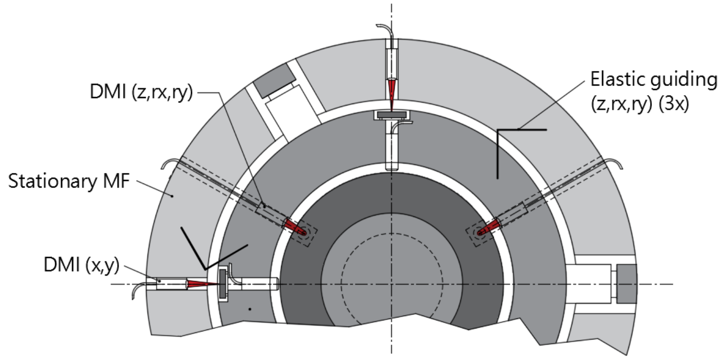
System Overview

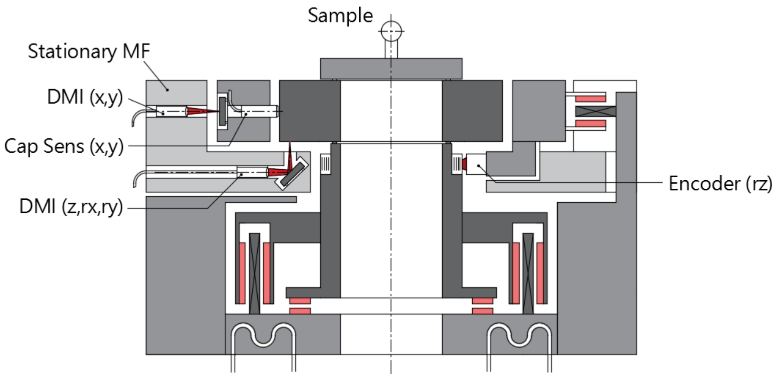
Tracking Metrology Frame



System Overview

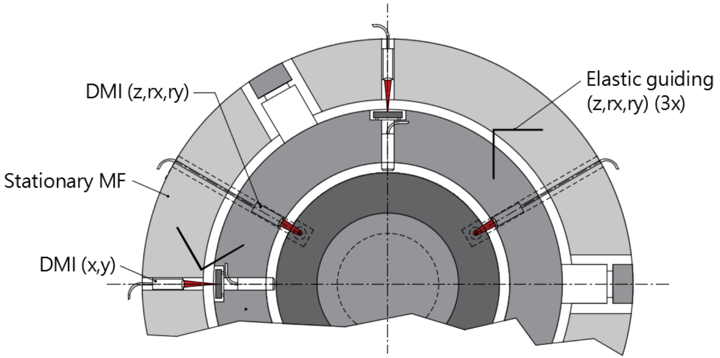
Stationary Metrology Frame

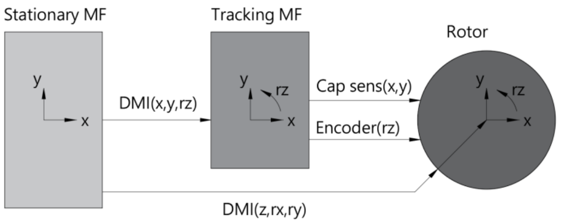


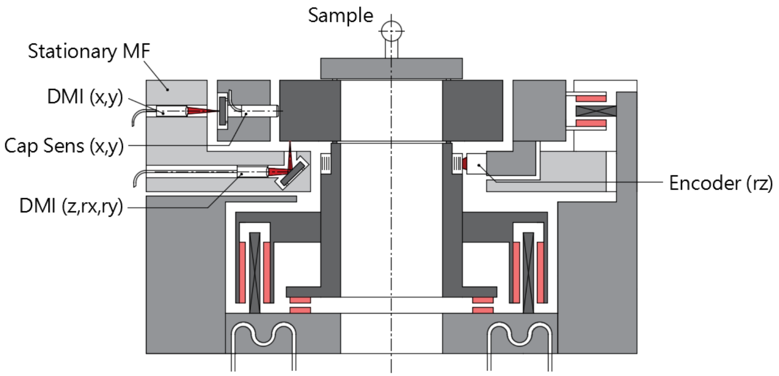


System Overview

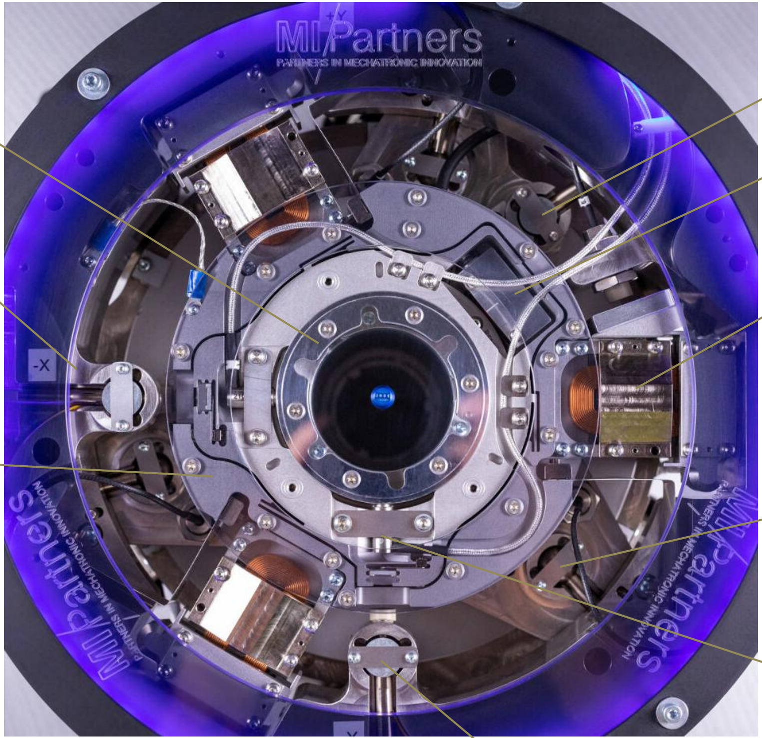
Stationary Metrology Frame





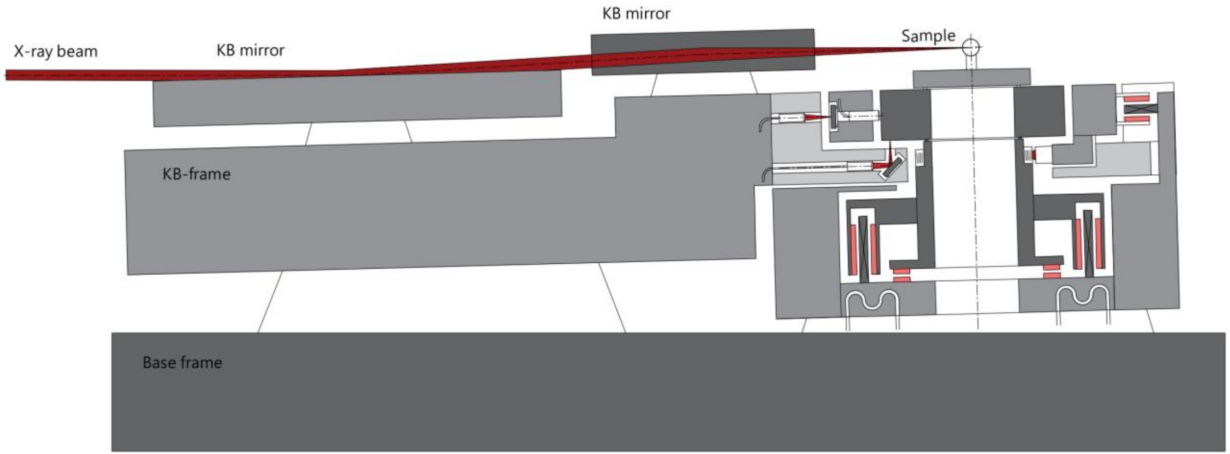


System Overview: Metrology



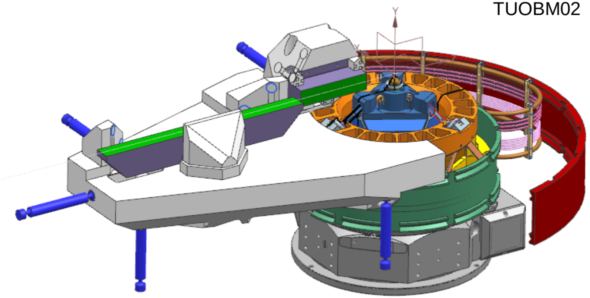
Metrology towards X-ray beam

Metrology frame integrated with dedicated KB frame: sample relative to X-ray beam



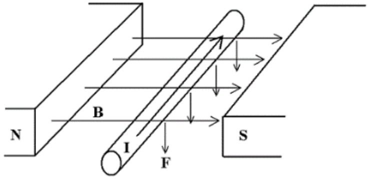
Example: Nanoprobe LNLS

TUOBM02

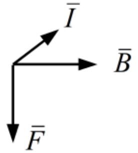


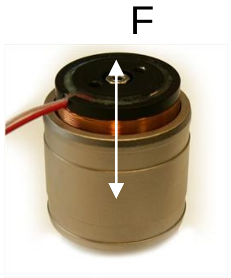
Actuation Principle: Lorentz forces

Lorentz force F



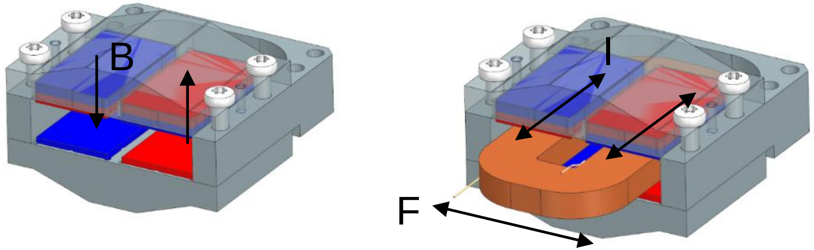
$$\bar{F} = l.\bar{I}x\bar{B}$$



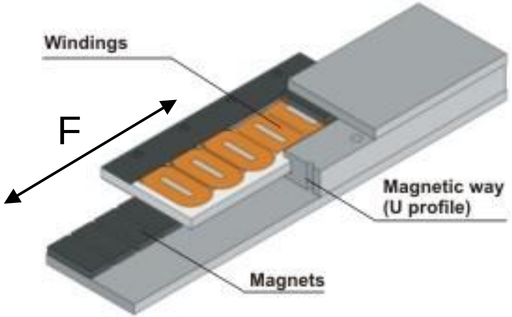


Voice coil actuator

1-phase actauator (small stroke)



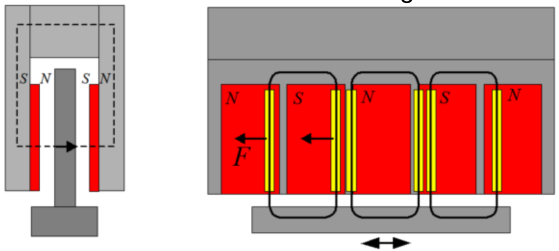
Iron-less linear actuator: 3-phase motor



Actuation Principle: Tangential and axial forcer

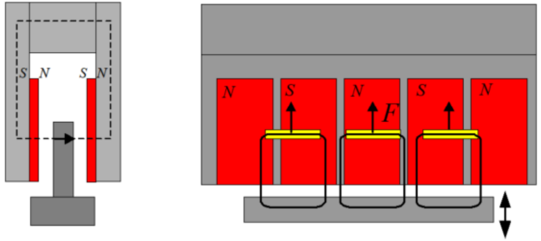
Tangential forcer: 3-phase

Circular magnet track

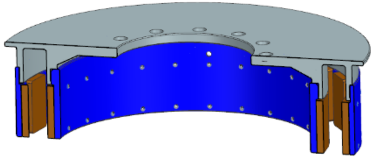


Axial forcer: 3-phase

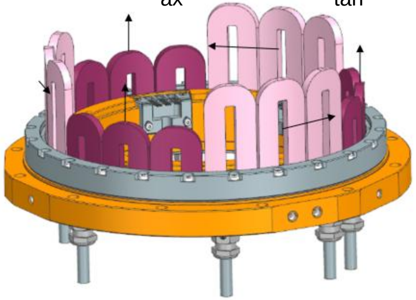
Circular magnet track



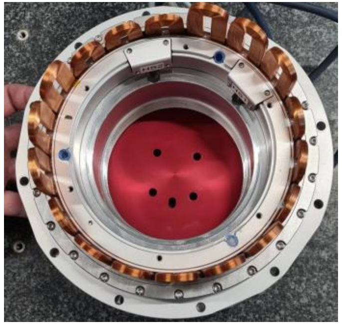
Actuator assembly:
- 3x tangential force
- 3x axial force



3x F_{ax} 3x F_{tan}



Patent Pending



System Overview

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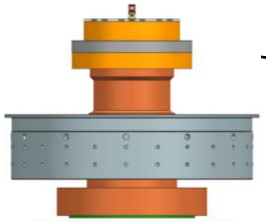
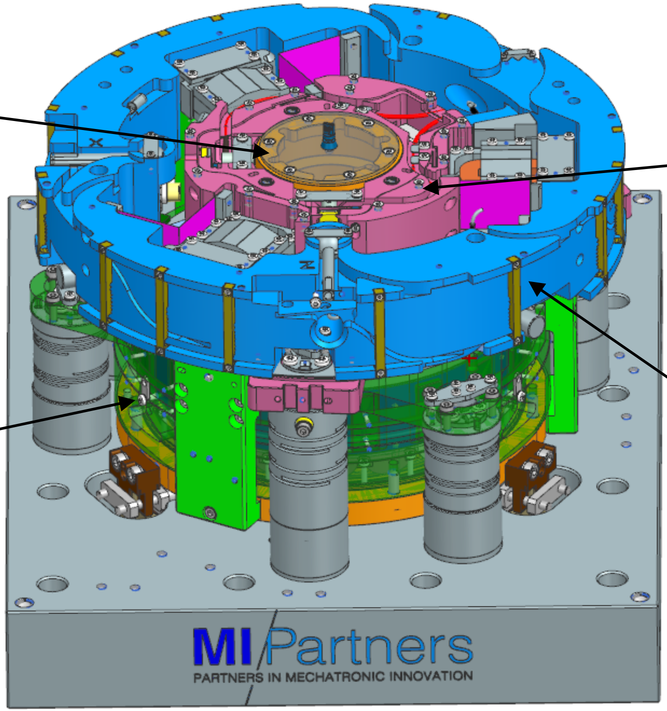
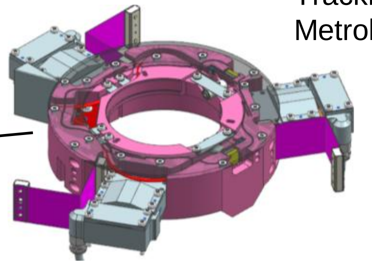
Rotor with metrology target
and actuator magnets

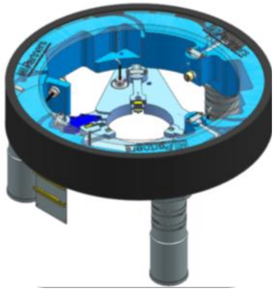




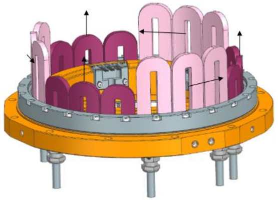
Tracking
Metrology Frame



Stationary
Metrology Frame



Actuator coils on force frame
active cooling (e.g. water)



Control Architecture

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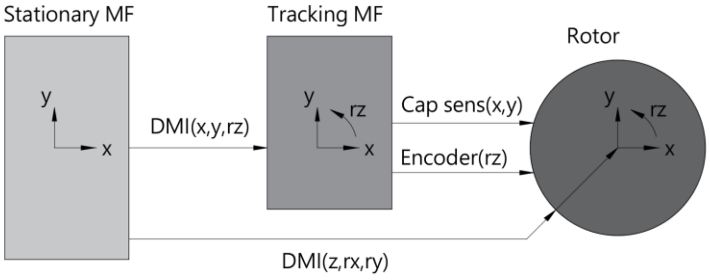
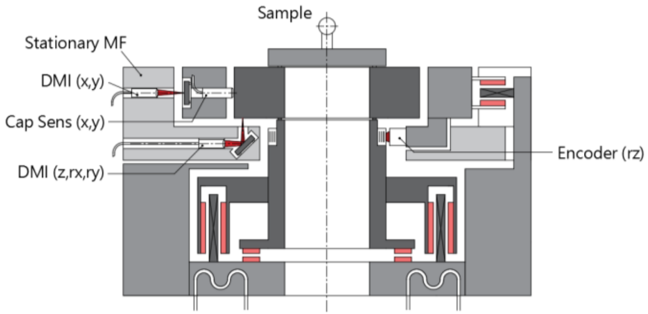
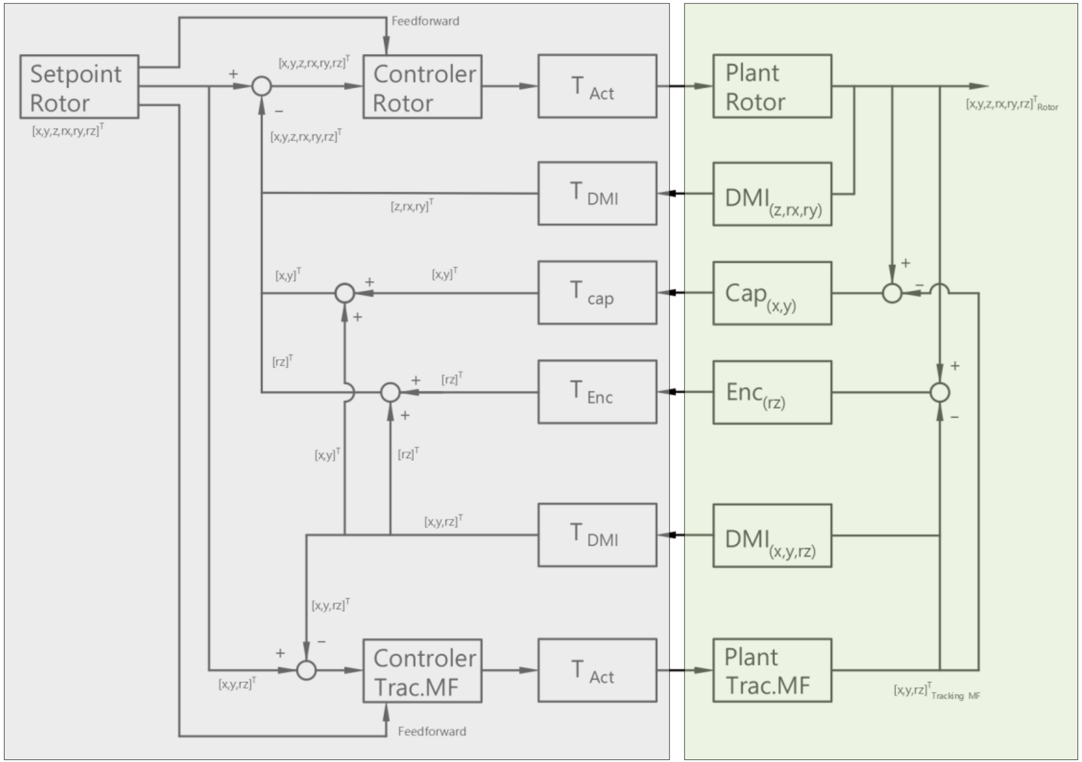
Metrology structure





Control HW/SW

Physical system



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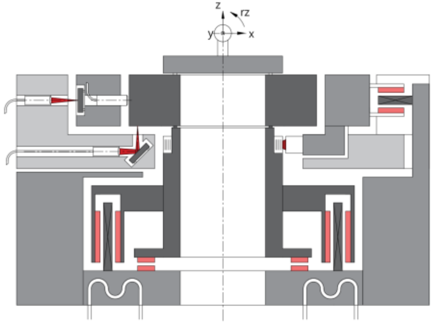
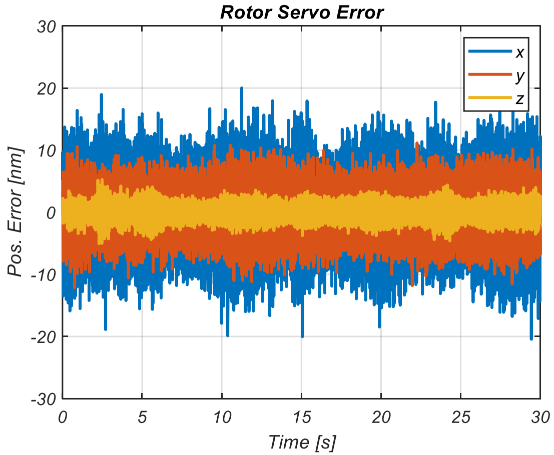
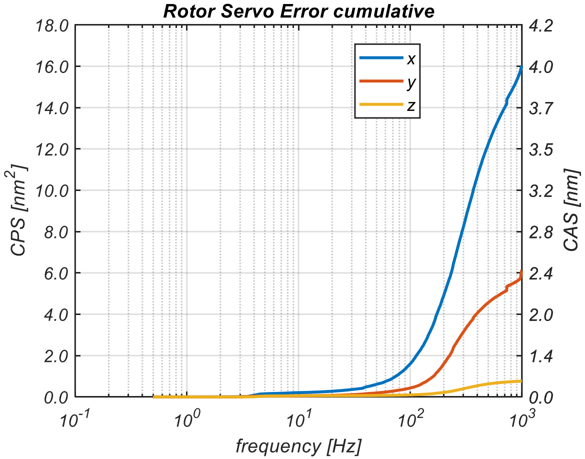
Servo positioning error
1st results

Stand still performance at Rz = fixed







Servo positioning error
X: 4 nm_{RMS}
Y: 2.4 nm_{RMS}
Z: 0.9 nm_{RMS}

Frequency range
0.3…1000 Hz

Positioning performance Rz = 1 Hz (1st results)

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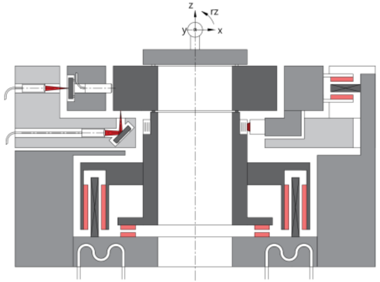
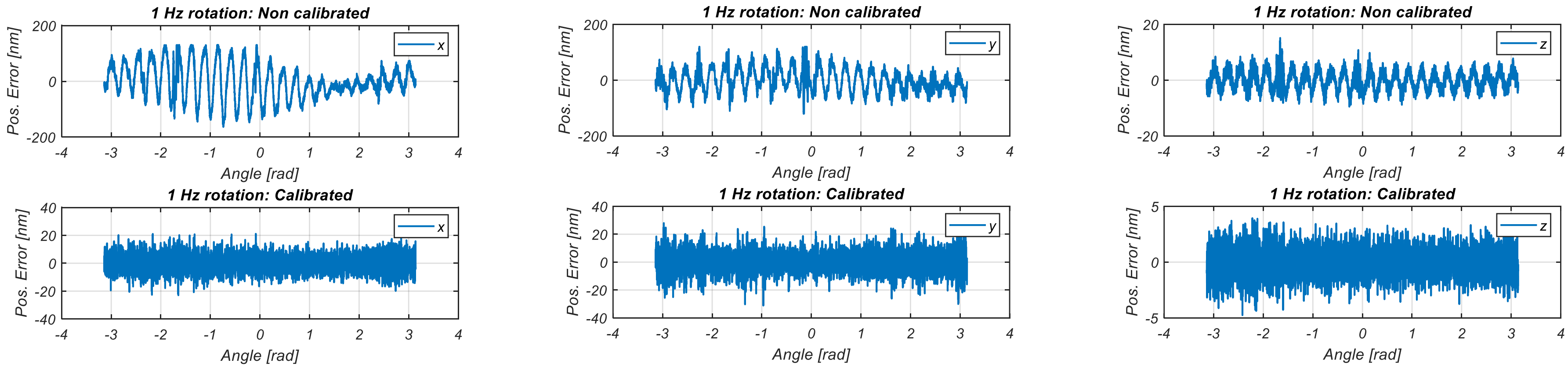
Servo positioning error

Rz rotation (centric) at 1 Hz

Without actuator calibration and after calibration

Results are comparable to stand-still





x,y : 3…4 nm_{RMS}

z : < 1 nm_{RMS}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