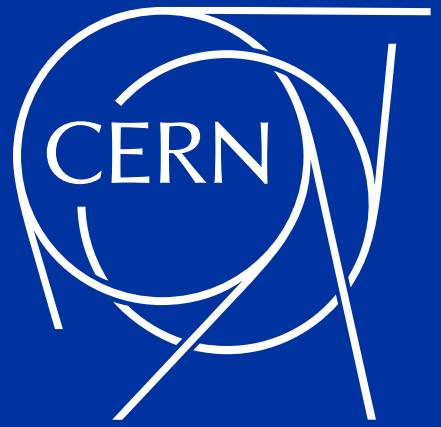


Rotational mechanism option status

Laura Hannemann

14 February 2023

Research Question

→Is the fast wire scanner bakeable?

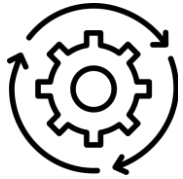
→Under which conditions is it bakeable?

Operational Test

→ **Test wire scanner parameters in its intended environment**

→ **Quantify change in parameters with bake-out**

Operational Tests



- **No additional sensors required**
- **Read out of control parameters**

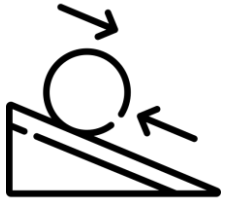
Verification Test

- Compliance with requirements
  - Magnetic brake test
  - Constant speed operation
  - Calibration
  - Electrical Insulation Test

Validation Test

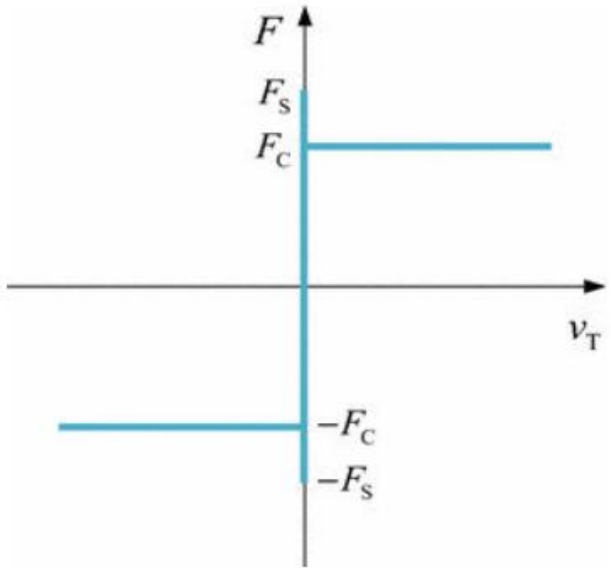
- Perform indented purpose in desired environment
  - Scans

Friction Torque Studies



Expectation: Dry Coulomb friction

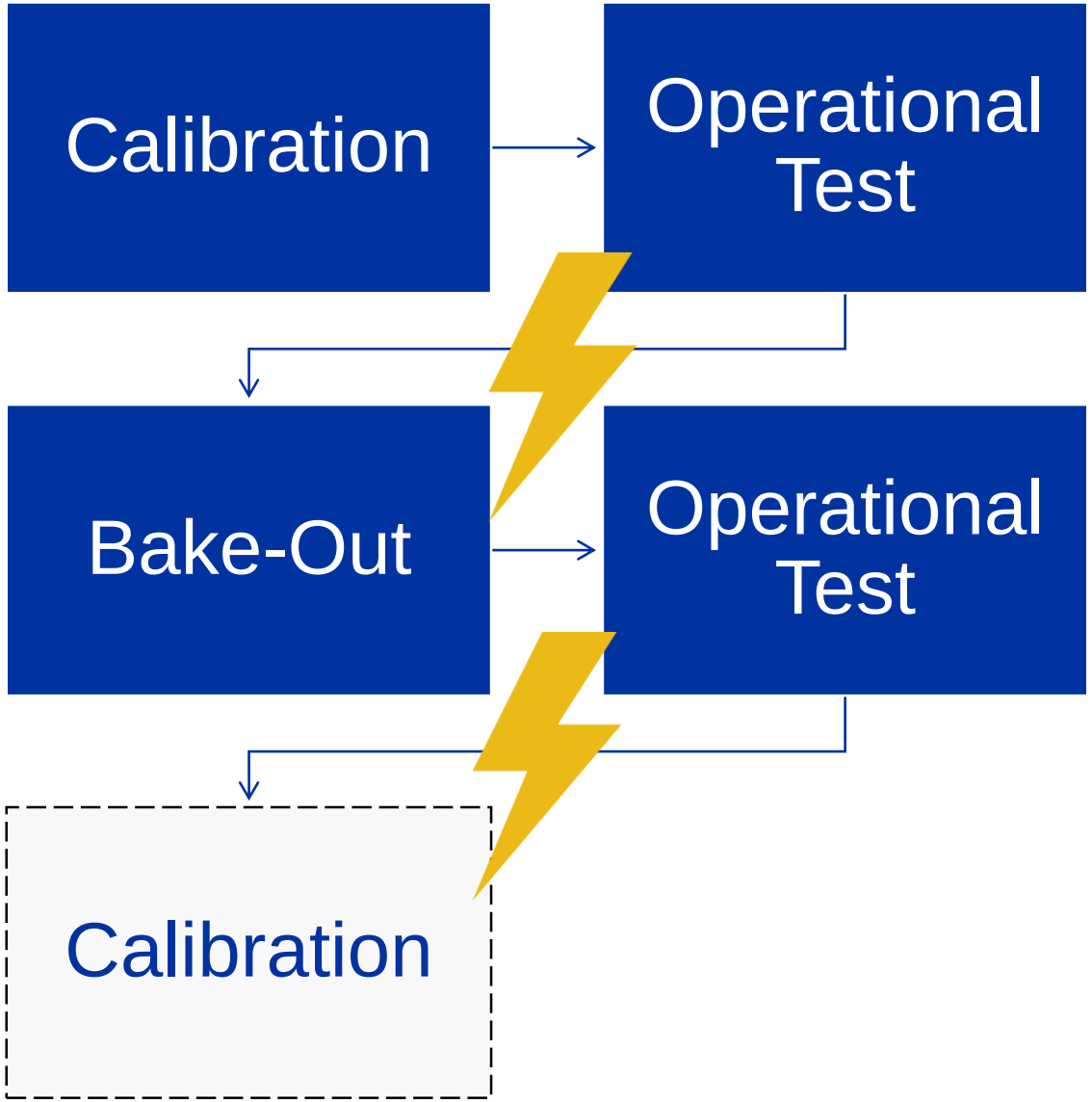
- **Static friction at zero speed**
- **Dynamic friction at non zero speed**



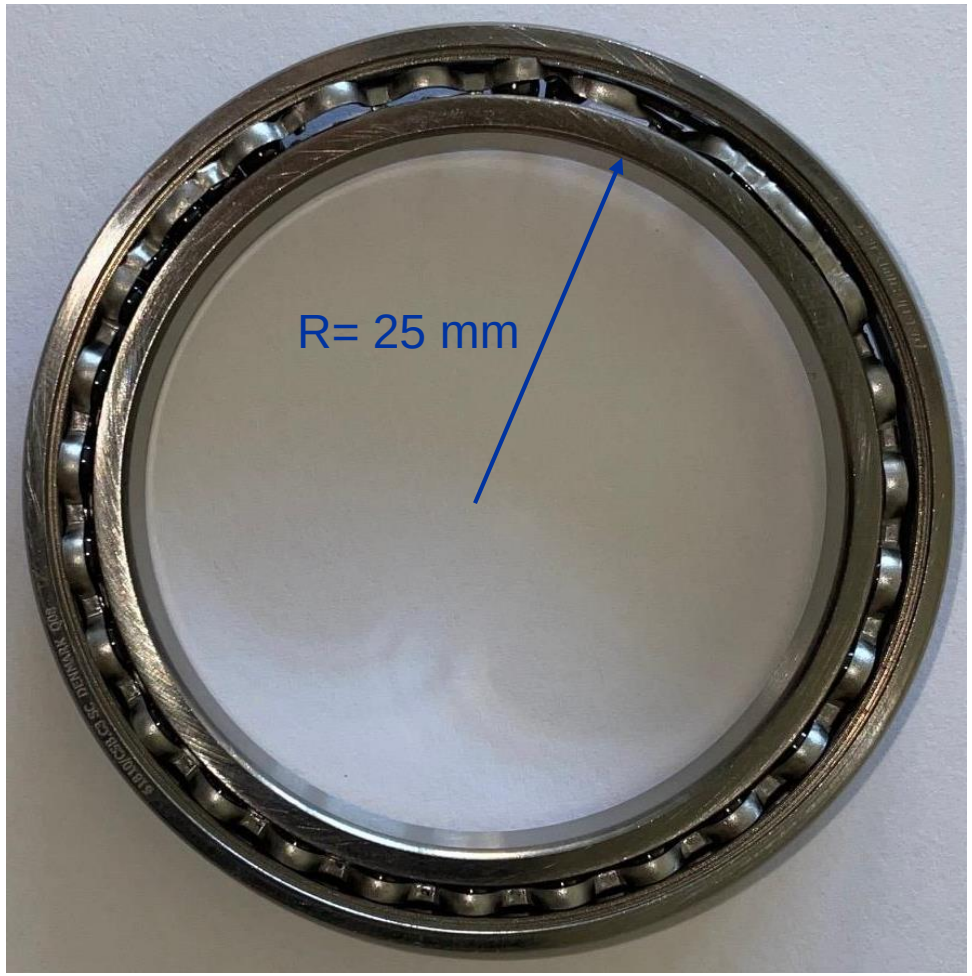
- **No lubrication**
- **Increased friction after bake-out**

Before bake-out	After bake-out
$T_{fr_{st}} = 150.27\ Nmm$	$T_{fr_{st_{bakeout}}} = 535.05 Nmm$
$T_{fr_{dyn}} = 132.24\ Nmm$	$T_{fr_{dyn_{bakeout}}} = 540.97\ Nmm$

Tests

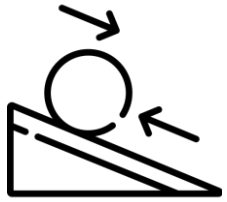

Calibration
Operational Test
Bake-Out
Operational Test
Calibration

Bearing Failures



At constant speed operation → cage rupture

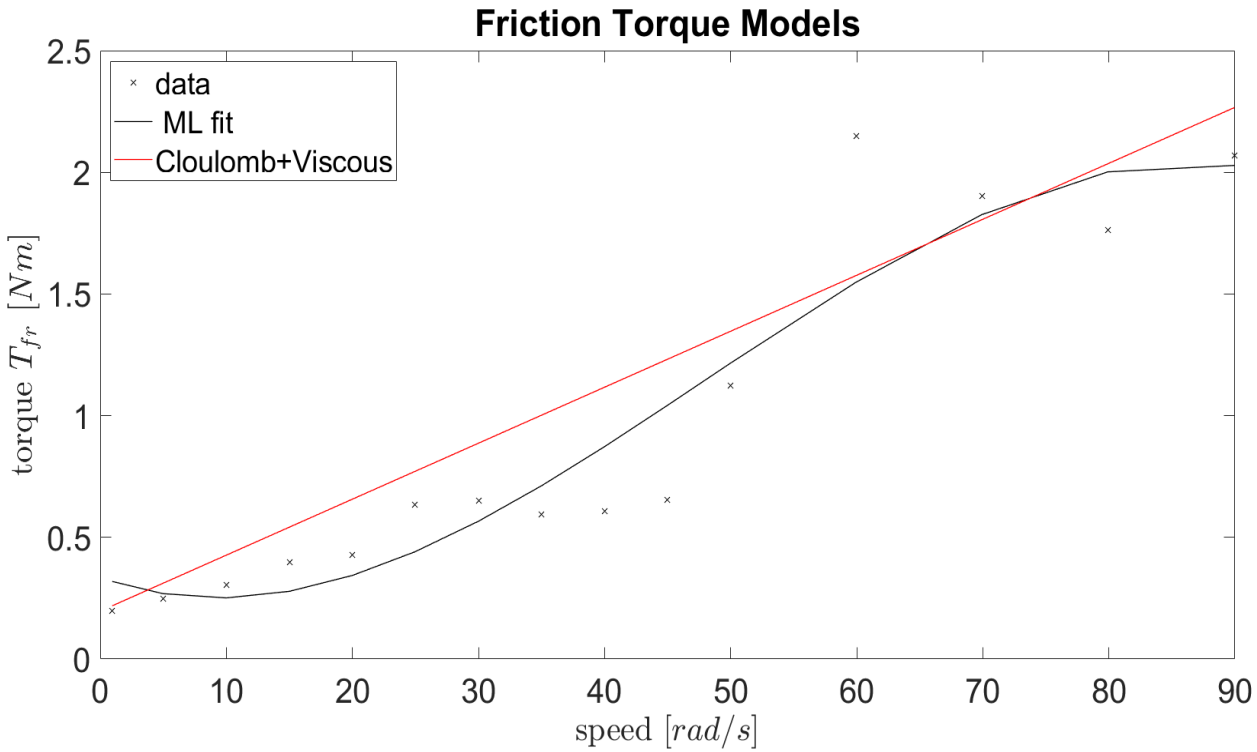
Friction Torque Studies



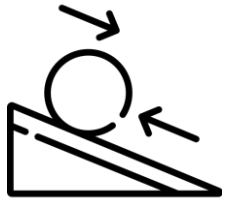
Test Results before Bake-out:

- **Linear regression model**
- **Linear dynamic friction model:**

$$T_{fr} = F_C + \mu_v \cdot \omega = 0.197\ Nm + 0.023 \frac{Nm}{\frac{rad}{s}} \cdot \omega$$



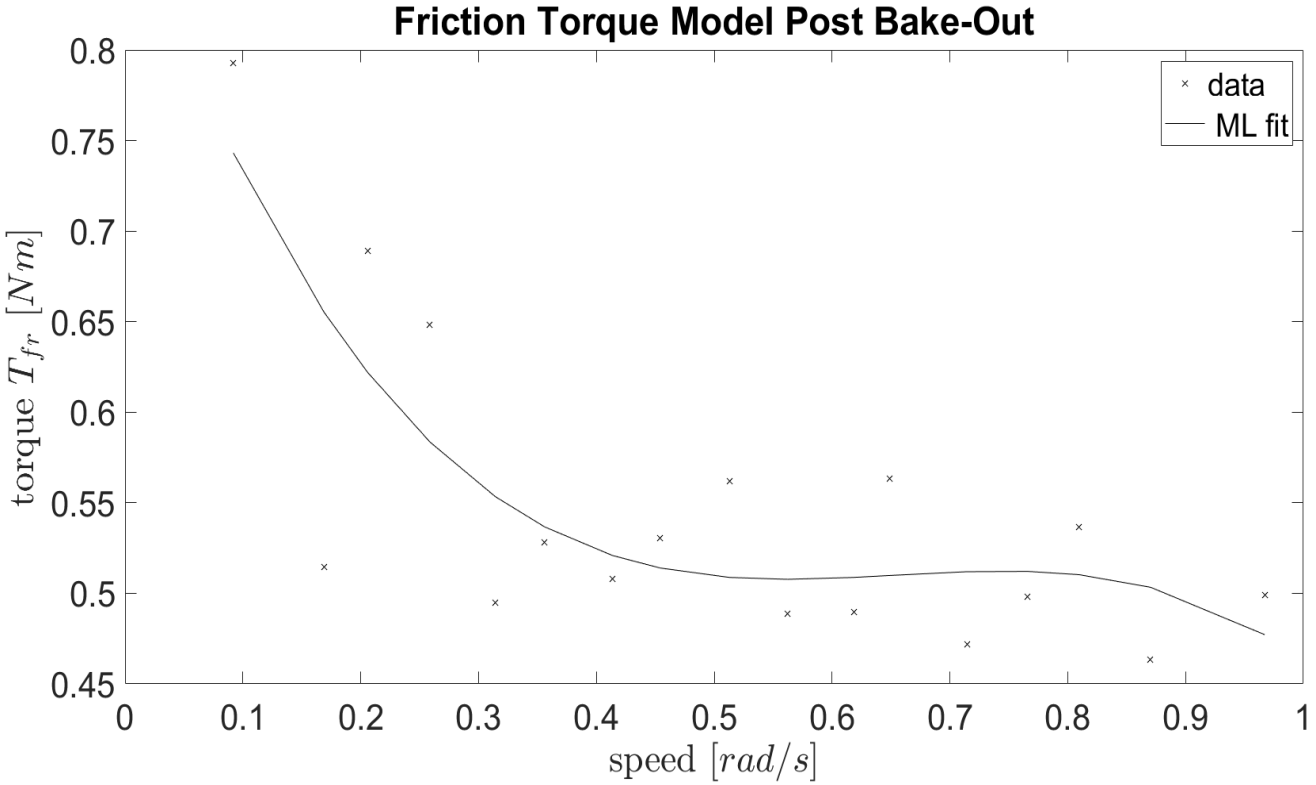
Friction Torque Studies



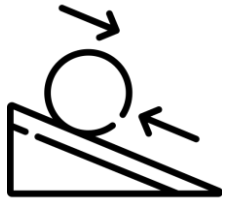
Test Results after Bake-out:

- **Static and dynamic friction:**

$$T_{fr} = \begin{cases} 0.79\ Nm & for\ \omega < 0.3\,\frac{rad}{s} \\ 0.49\ Nm & for\ \omega > 0.3\,\frac{rad}{s} \end{cases}$$



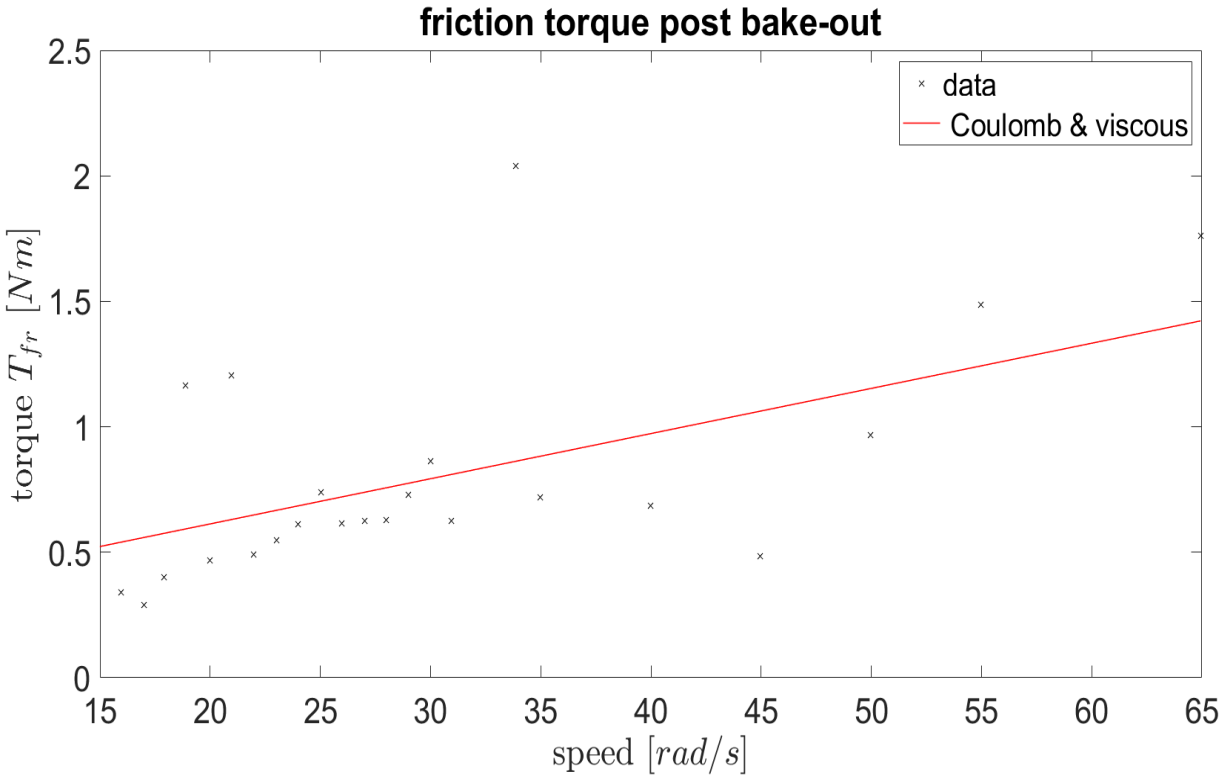
Friction Torque Studies



Test Results after Bake-out:

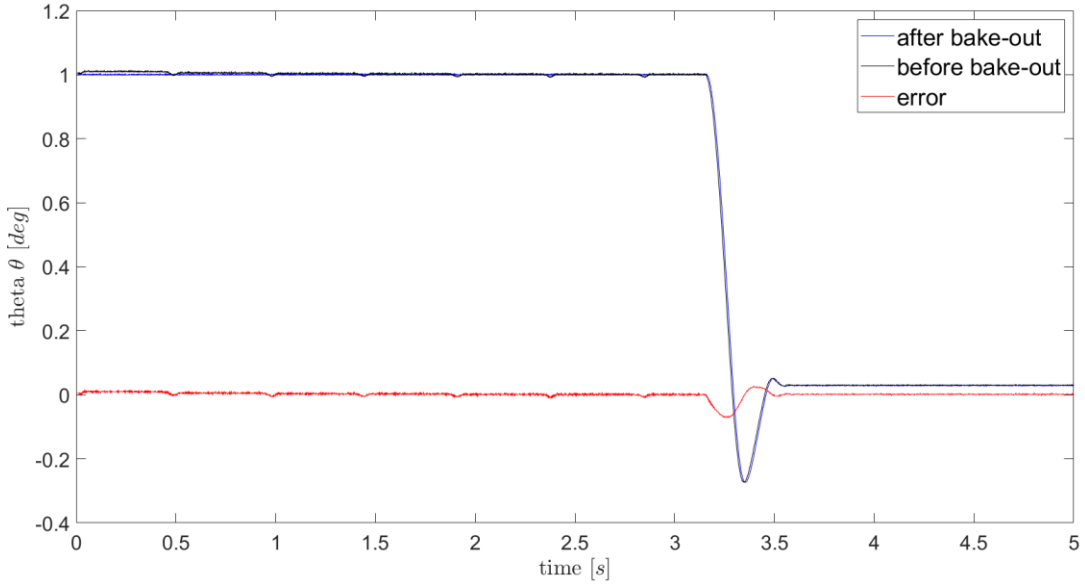
- **Speed dependent dynamic friction linear model**

$$T_{fr} = 0.253Nm + 0.018\frac{Nm}{\frac{rad}{s}} \cdot \omega$$

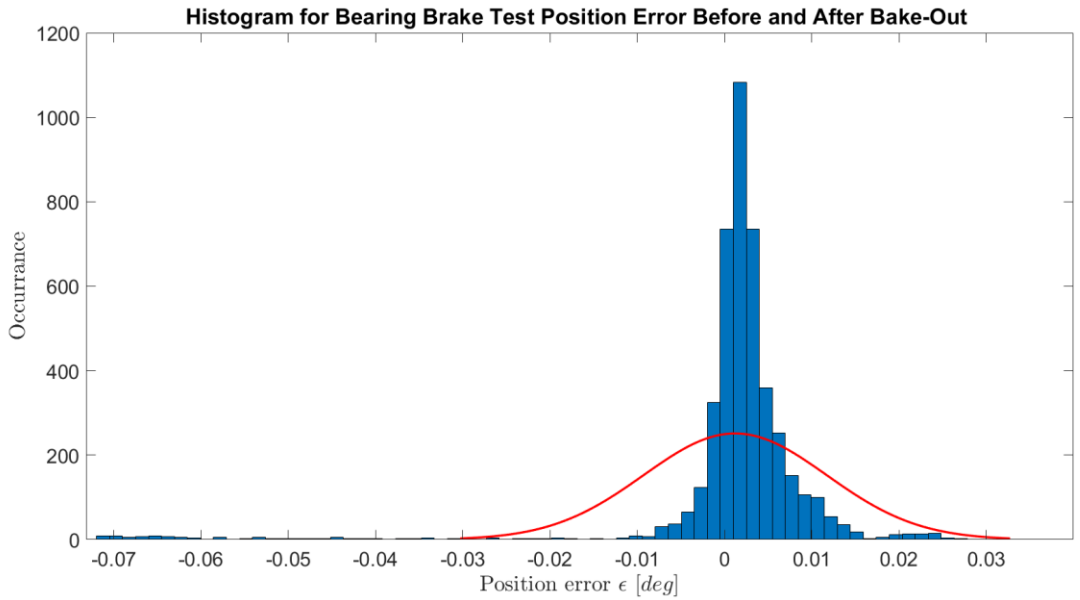


Results Nominal Bearings

Magnetic Brake Restoring Test Position

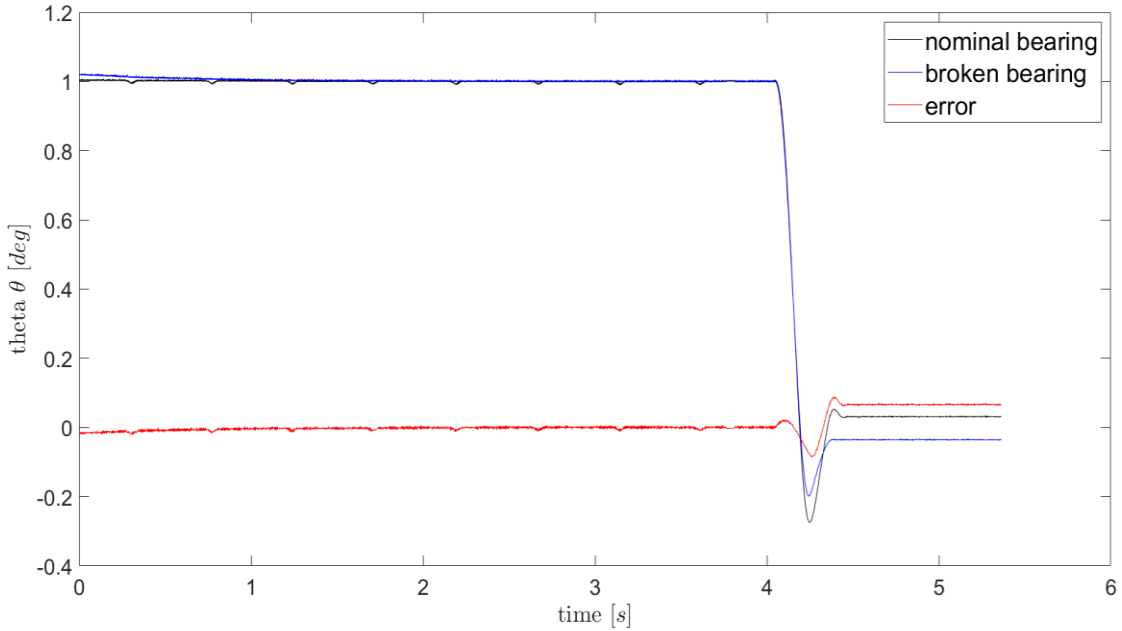


Error Histogram

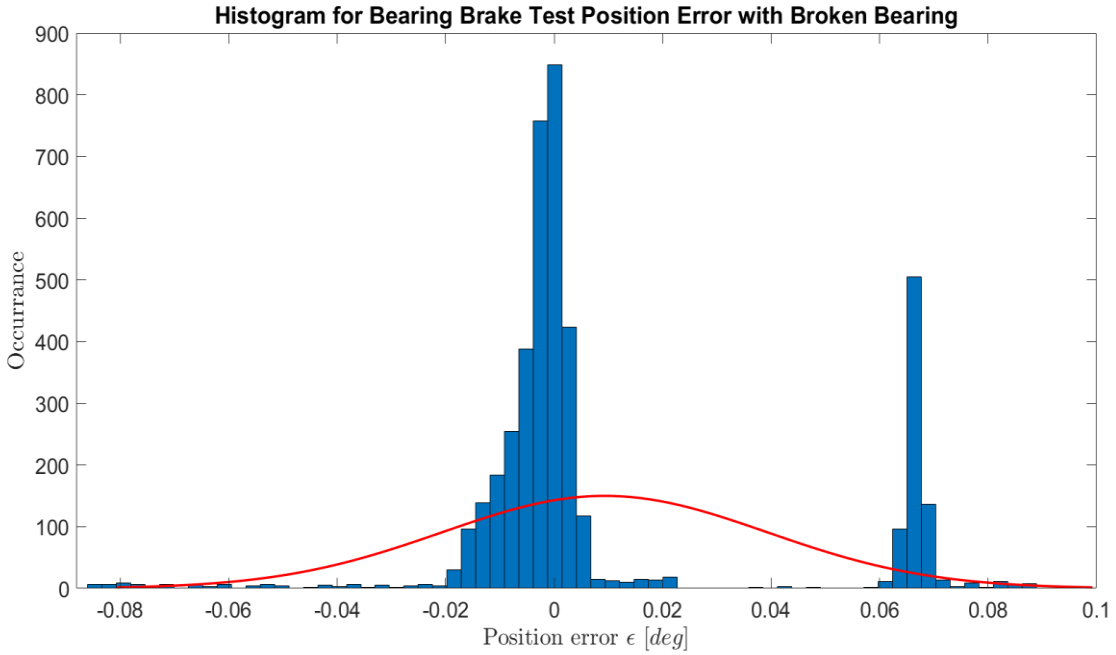


Results Broken Bearings

Magnetic Brake Restoring Test Position



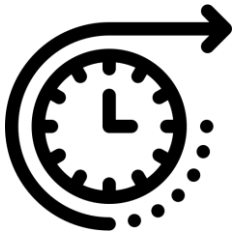
Error Histogram



Conclusion

- **Wire scanner is operational after bake-out**
- **Successfully conducted tests:**
  - Insulation resistance
  - Calibration
  - Magnetic brake restoring mechanism
  - Scan operation
  - Friction torque measurements
- **Wire scanner can operate with constant speed**
- **Ball bearing cages are source of failure**
- **Friction torque in current system is speed dependent**

Ball Bearing Updates



- No clearance issues according to manufacturer
- Inspection for wear in the racers
- Possibility to add solid lubricant

Solid Lubricants

Requirements:

- **UHV compability $(10^{-10} mbar)$**
- **High temperature resistance**
- **Radiation resistance**
- **Durability**
- **Chemical cleaning approved**

Solid Lubricants

- **Soft metal coatings: lead, gold, silver**
- **Lamellar solids: molybdenum disulfide (MoS2) and tungsten disulfide (WS2)**
- **Polymers: PTFE and PEEK**

Soft metals

- **Lower outgassing rate than MoS2**

Ion-plated lead	• Used in space applications • Limited life in ambient conditions due to oxidation
Ion-plated silver	• Good electrical conductor. • Lowest mechanically stimulated outgassing rates reported • Better wear life in high load conditions than led or gold • Frequently used in rotating anode X-ray tubes.
Ion-plated gold	• Best conductor • Non-reactive metal

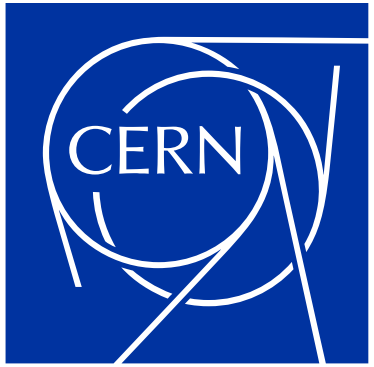
https://edms.cern.ch/ui/file/976275/1/Bearings_in_vacuum.pdf

Molybdenum-Disulfide

- ✓ **Vacuum acceptance test for ELENA**
- ✓ **Bake-out at 250°C**
- ✓ **Low friction coefficient: $\mu < 0.01$**
- ✓ **Good radiation stability**
- ✓ **Low electrical conductance**
- • **Poor performance under atmospheric conditions**
- • **Oxidation due to storage**
- • **Corrosion**

Tungsten-Disulfide

- ✓ **Better oxidation resistance**
- ✓ **Worse sliding endurance in vacuum than MoS2**
- ✓ **Friction coefficient: $\mu = 0.03\ to\ 0.09$**
- ✓ **Thermal stability: $-188°C\ to\ 1316°C$**
- ✓ **Chemical cleaning with acid ☹**



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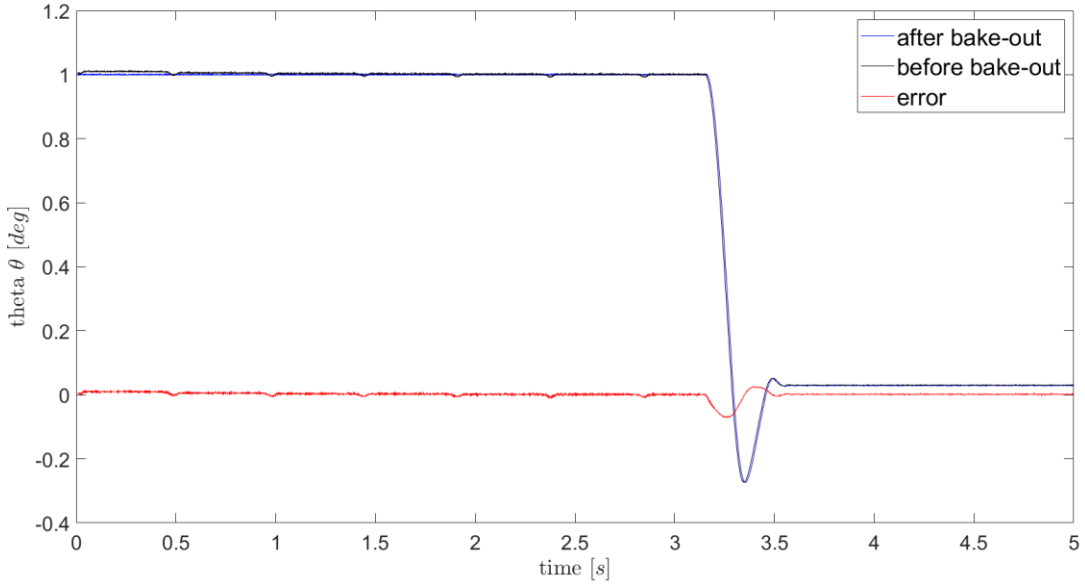
LHC Beam

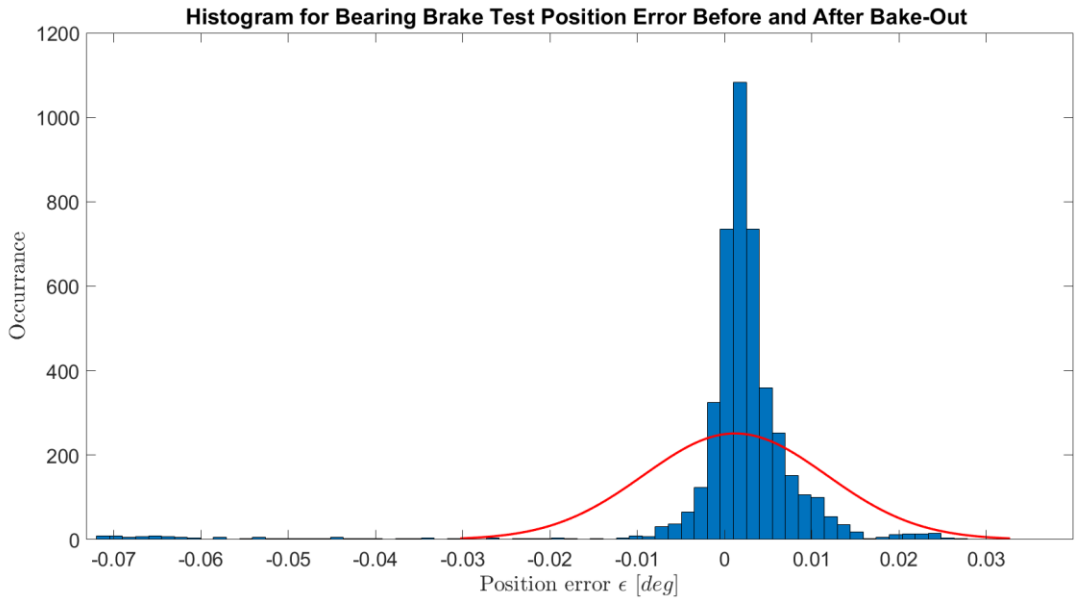
Characteristic	Values
Top Energy	$E = 13\,TeV$
Injection Energy	$E = 0.45\,TeV$
Injection Profile	$\sigma_x = 0.53\,mm$
	$\sigma_y = 0.8\,mm$
Required Position Accuracy	$\epsilon_y = 20\,\mu m$

Results Nominal Bearings

Magnetic Brake Restoring Test Position

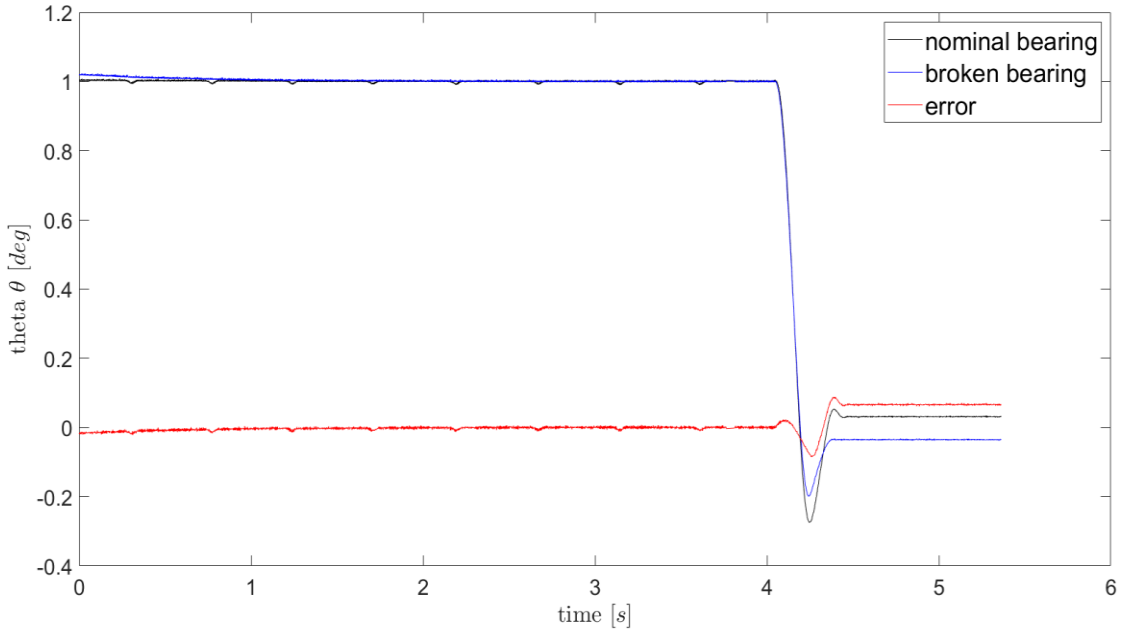


Error Histogram

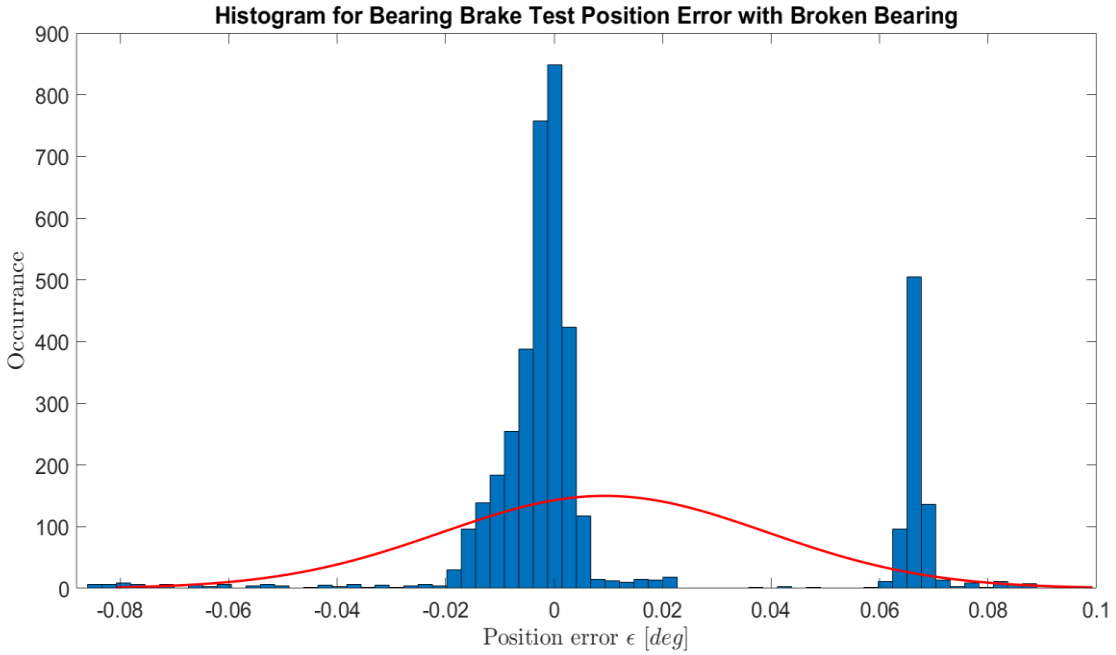


Results Broken Bearings

Magnetic Brake Restoring Test Position

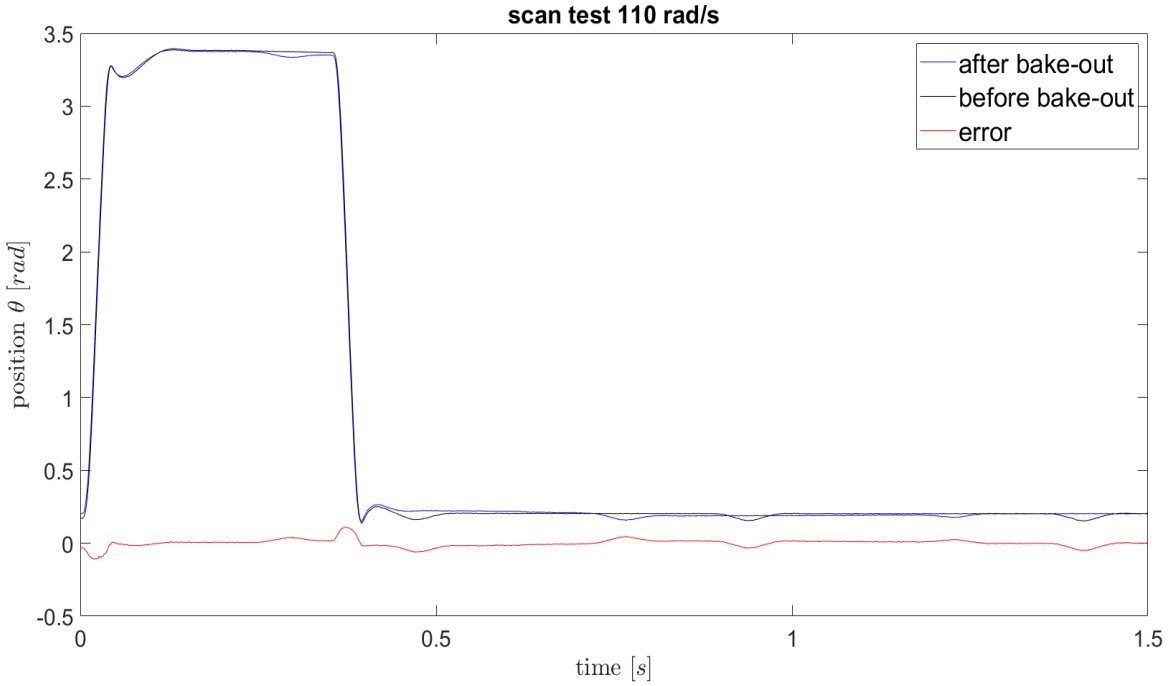


Error Histogram

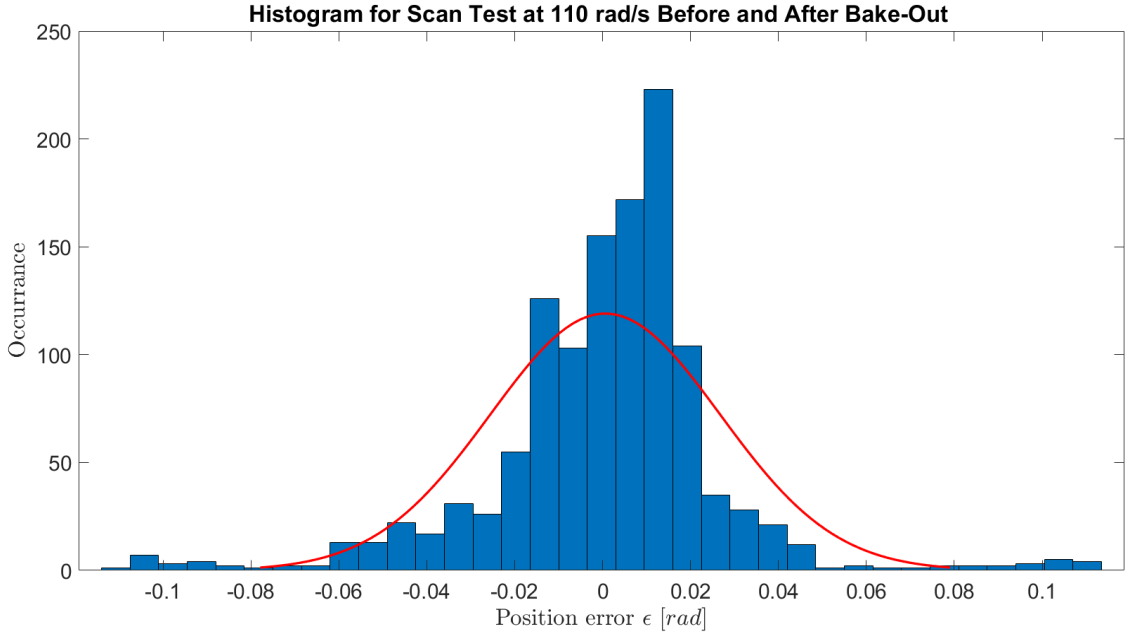


Scans

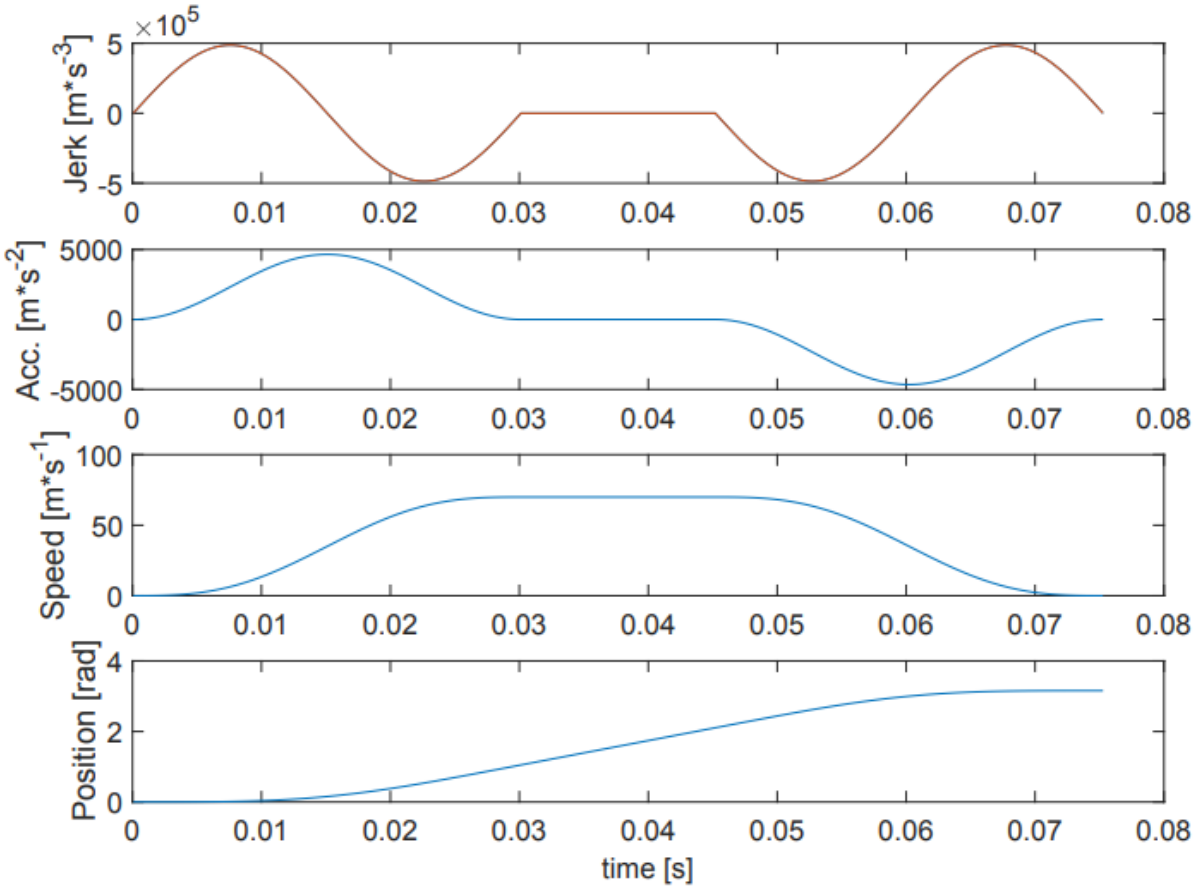
Scan Test at $110\,\frac{rad}{s}$



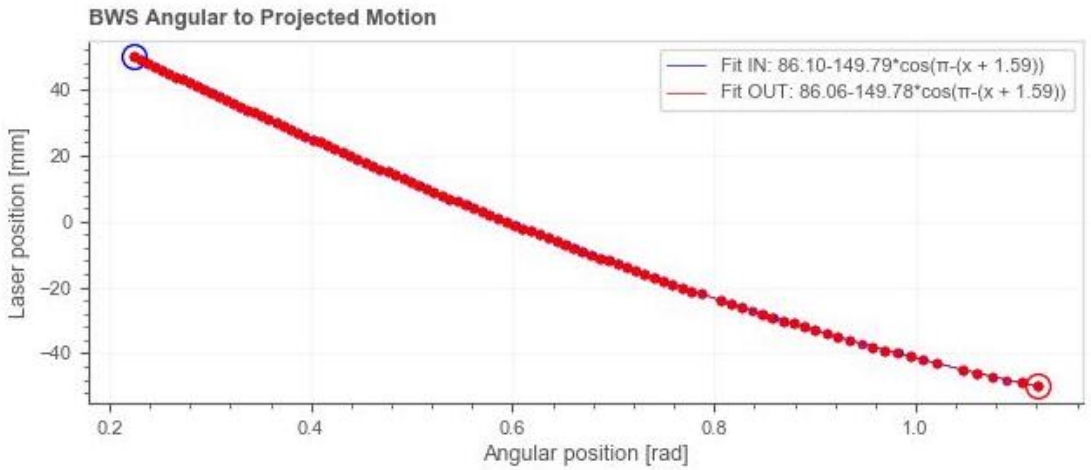
Error Histogram



Motion Profile



Calibration Results



- **Scan at** $55\,\frac{rad}{s}$
- **Expected wire position error:**
  - **IN-OUT offset:** $31.9\ \mu m$
- **Measured wire position error:**
  - **IN-OUT offset:** $26\ \mu m$