EUROPEAN SYNCHROTRON RADIATION FACILITY

INSTALLATION EUROPEENNE DE RAYONNEMENT SYNCHROTRON

ISDD
Mechanical Engineering Group
Precision Dynamics & Mechatronics Team – Precision Engineering Laboratory (PEL)

Test report – µ station ID31

Date: 26.03.2019

From: H-P van der Kleij

Subject: µ station ID31

Object: This report is made out of four main parts:

1) NY translation.
2) NAI (tilt around Y).
3) Hexapod from the Symetrie company.
4)Air bearing spindle from the LAB company.

Situation: ID31 experimental hutch @23 ˚C +/_ 0.1˚C

Contents:

Instrumentation:

1) Laser interferometer system from Agilent for linear, angular and straightness measurements. *

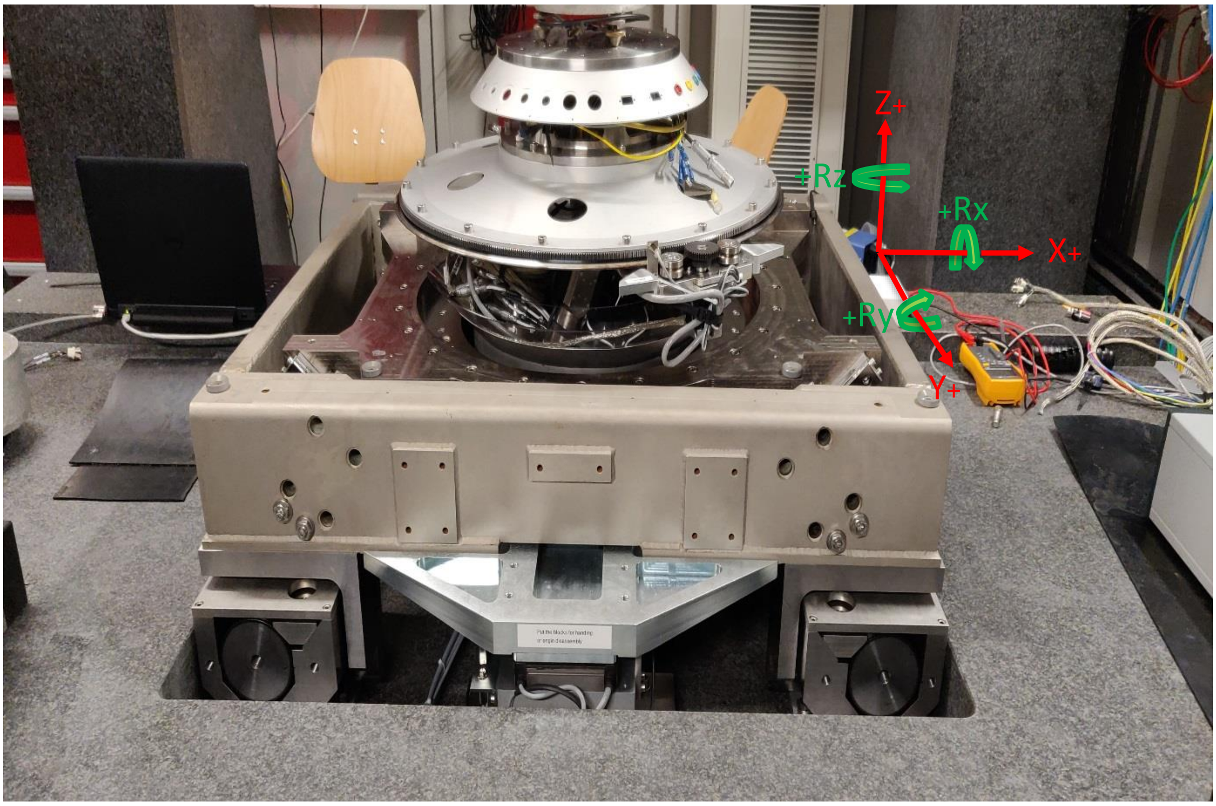
2) Spindle Error Analyser (SAE) from Lion with dual reference spheres from the PIC company.

3) 8 channel temperature data logger from the RBR company.

*All the measurements with the Agilent interferometer are done at @ 820 mm (sample height) from the centre of the NY guiding's and with a load of 15 kg.

Sign convention, specification and overview:

The ID 31 µstation (see picture below)



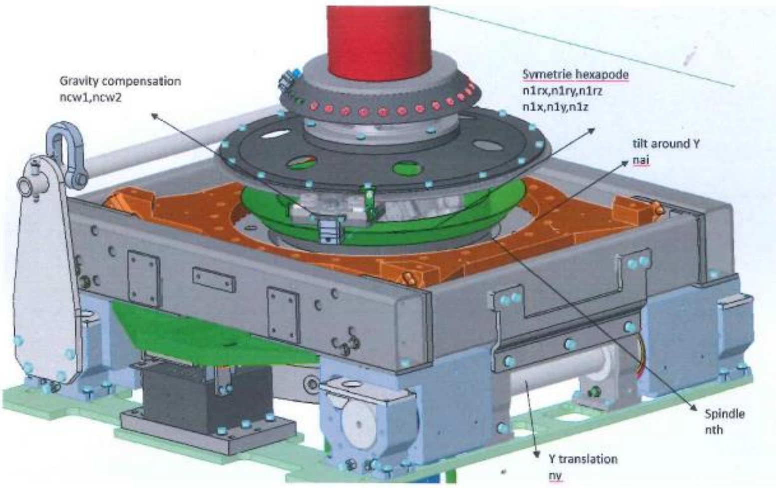
Specifications of the ID31 µ station

Motion	stroke	repeatability	MIM	Axial error	Radial error	tilt error
Ny (TY)	+/- 5 mm	0,02 µm	0,005 µm			
NAI (Theta Y)	+/- 3 deg	5 µm/m	2 µm/m			
NTH (spindle RZ)	infinit	2 µm/m	0,5µm/m	0,01 µm	0,5 µm	1,7 µm/m
nhx, nhy and nhz (hexapod)	+/- 10 mm	0,01 µm	0,003 µm			
nhrx, nhry and nhrz (hexapod)	+/- 3 deg	NA	1,7 µm/m			

ID31 NANO-STATION

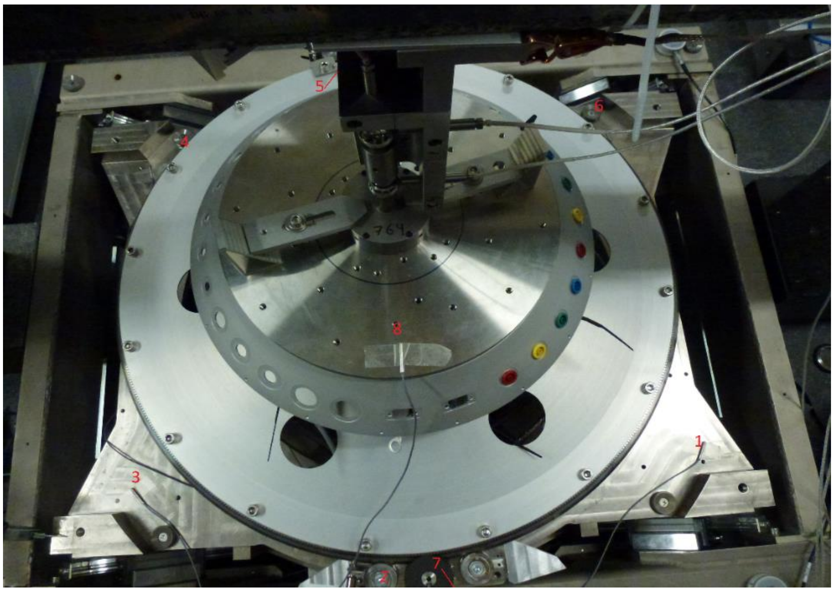
INTRODUCTION

Specification of the motions of the microstation



Overview of the station

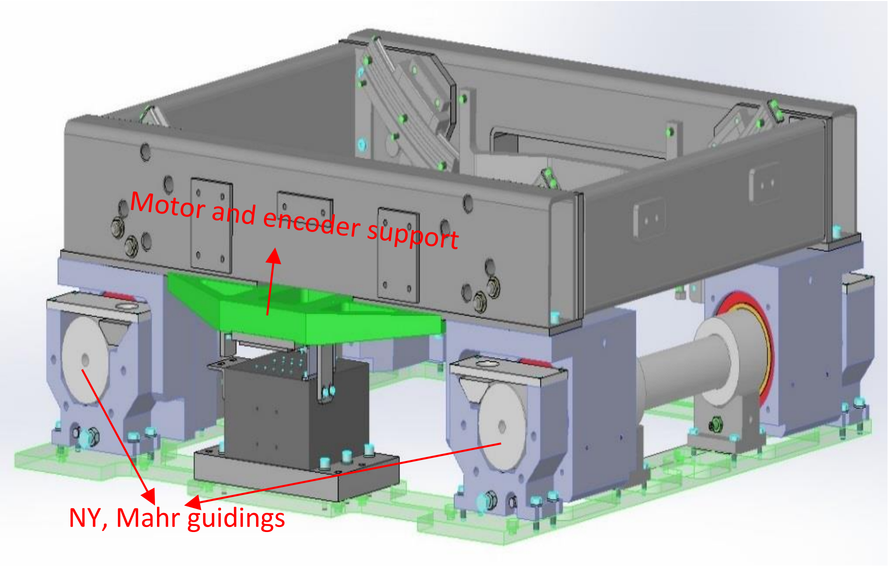
Temperature sensors positioning



As mentioned above we will treat four items of the ID31 µ station.

- Part 1) The NY translation with linear motor.
- Part 2) The NAI movement (rotation around the Y axis.
- Part 3) The NHU axis of the hexapod from Symetrie.
- Part 4) The NTH air spindle from LAB.

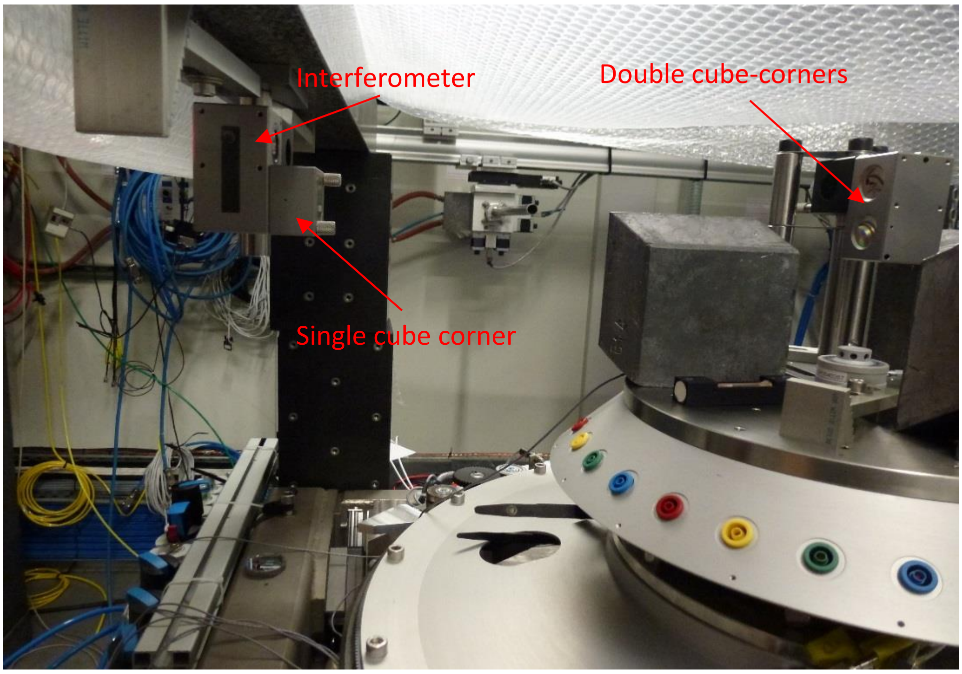
Part 1) NY translation



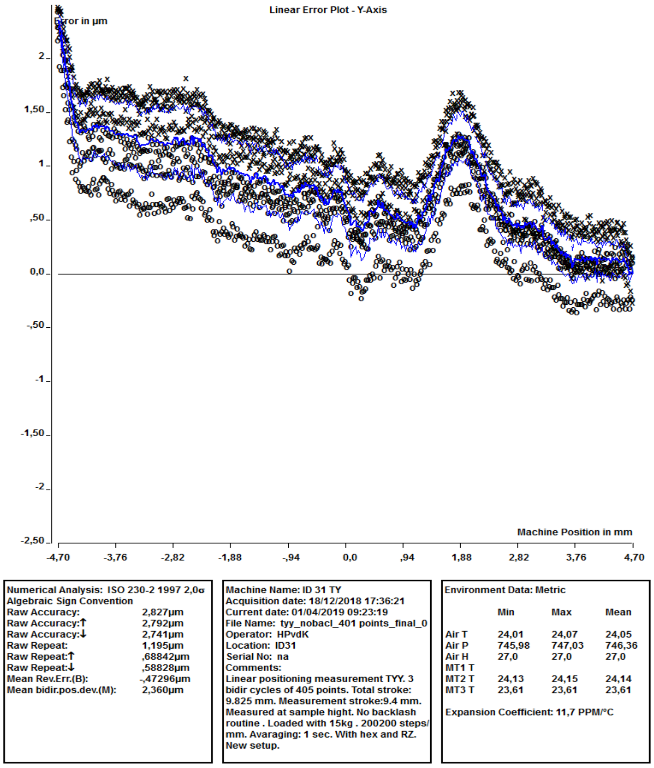
Linear positioning:

The results of the measurement done at the PEL on 4/2017 are written in Red.

Measurement setup of the linear positioning calibration TYY (See picture below).



<u>Linear positioning</u> of the NY translation. Stroke +/- 4.7 mm.



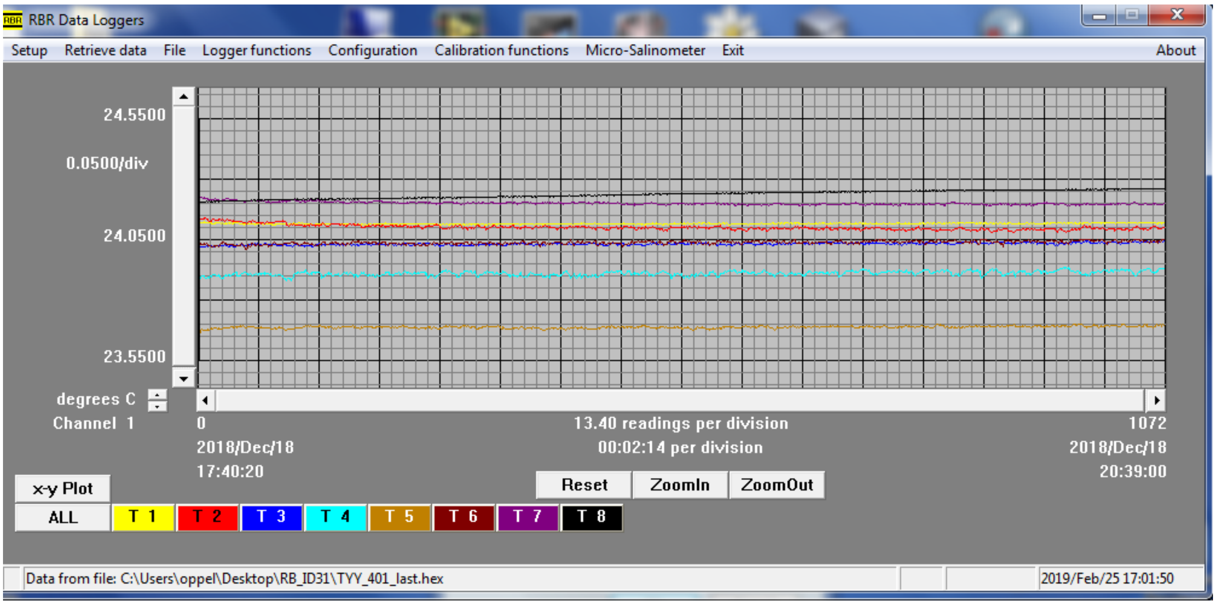
Accuracy : 2.83 µm

Repeat : 1.2 µm

Repeat↑ : 0.69 µm

Repeat↓ : 0.59 µm

Temperature recording during the above mentioned test.



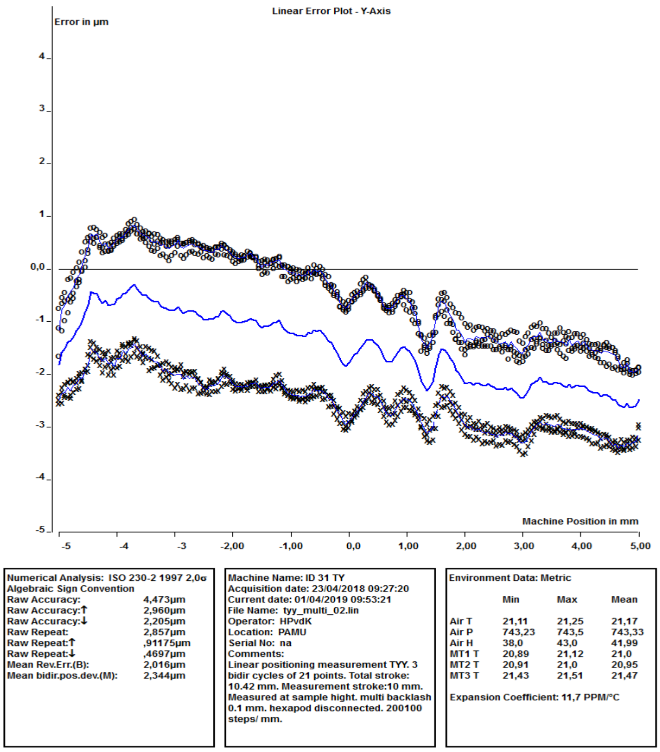
Linear positioning of the NY translation. Stroke +/- 5 mm.
Done at the **PAMU @ 4/2018**, with hexapod and NTH motors switched **off**.

Accuracy : 4.47 µm

Repeat : 2.86 µm

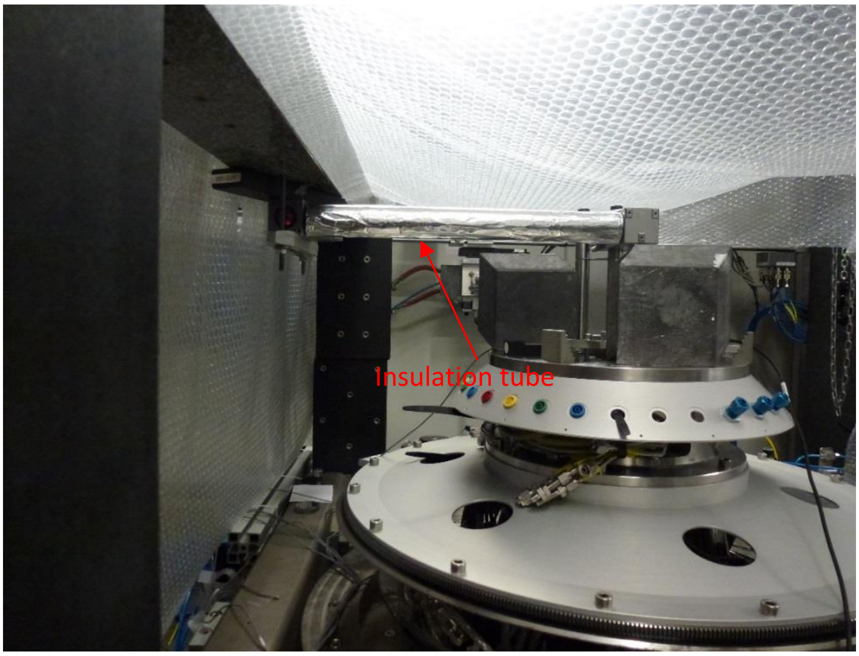
Repeat↑ : 0.91 µm

Repeat↓ : 0.47 µm

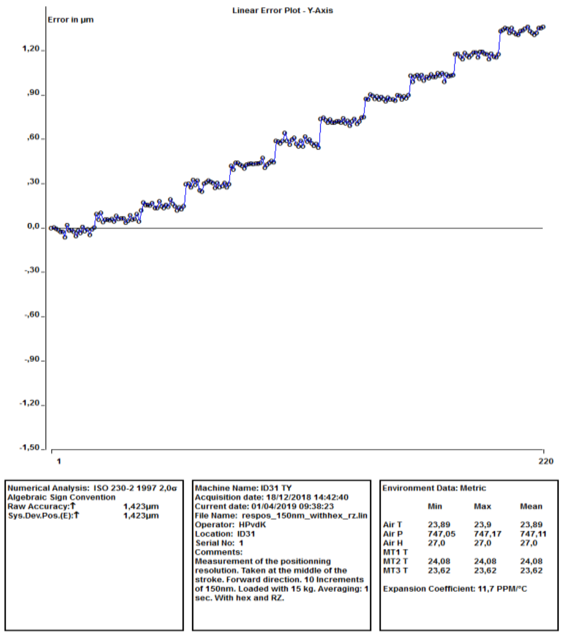


Stability and MIM:

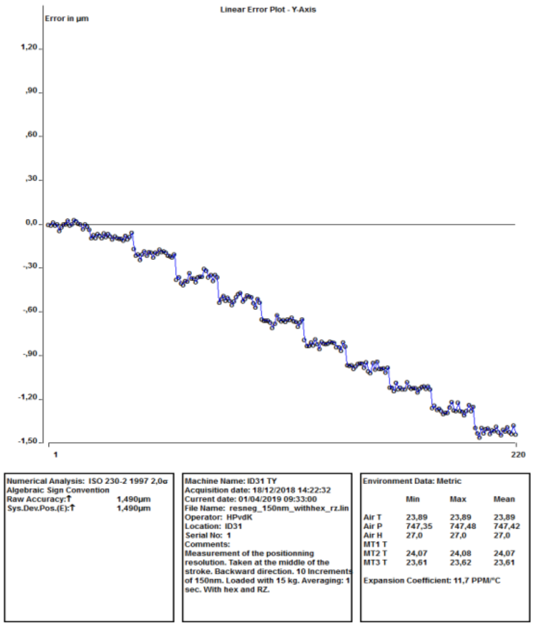
Measurement setup for MIM, linear and angular stability measurements (See picture below).



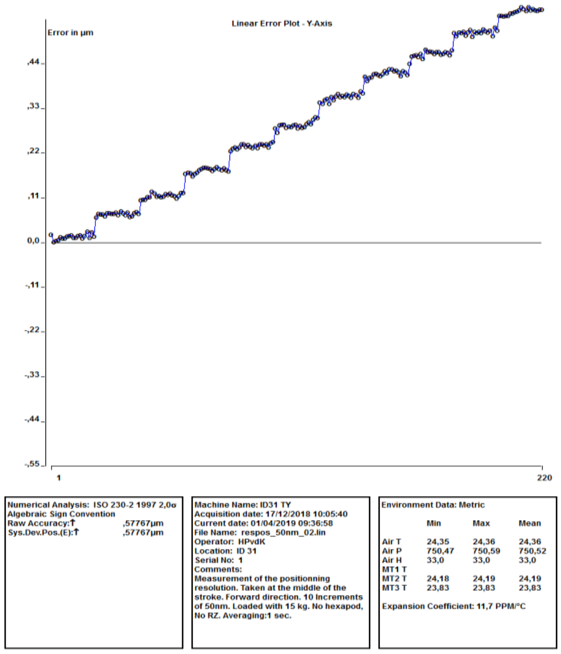
<u>MIM</u> (Minimum Incremental Motion) measurements.



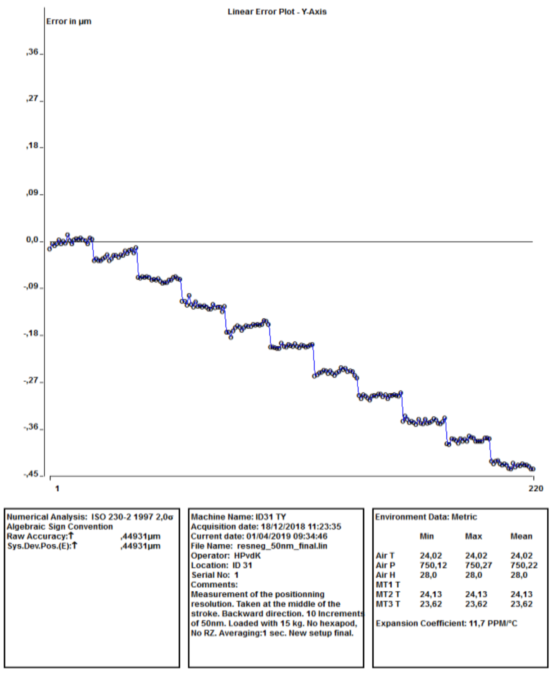
MIM = 150 nm. Forward direction, the hexapod and NTH motors are switched **on**.



MIM = 150 nm. Backward direction, the hexapod and NTH motors are switched **on**.



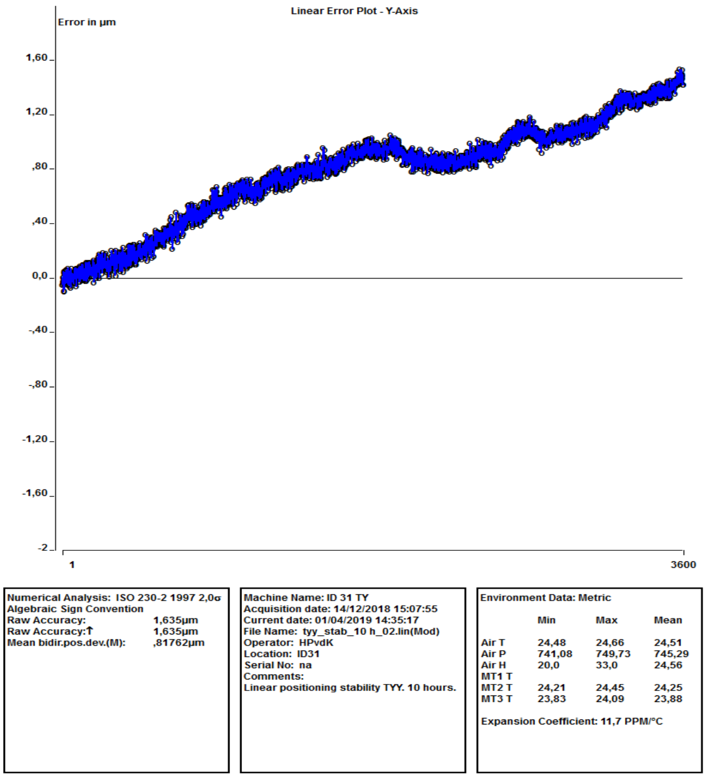
MIM = 50 nm. Forward direction, the hexapod and NTH motors are switched **off**.



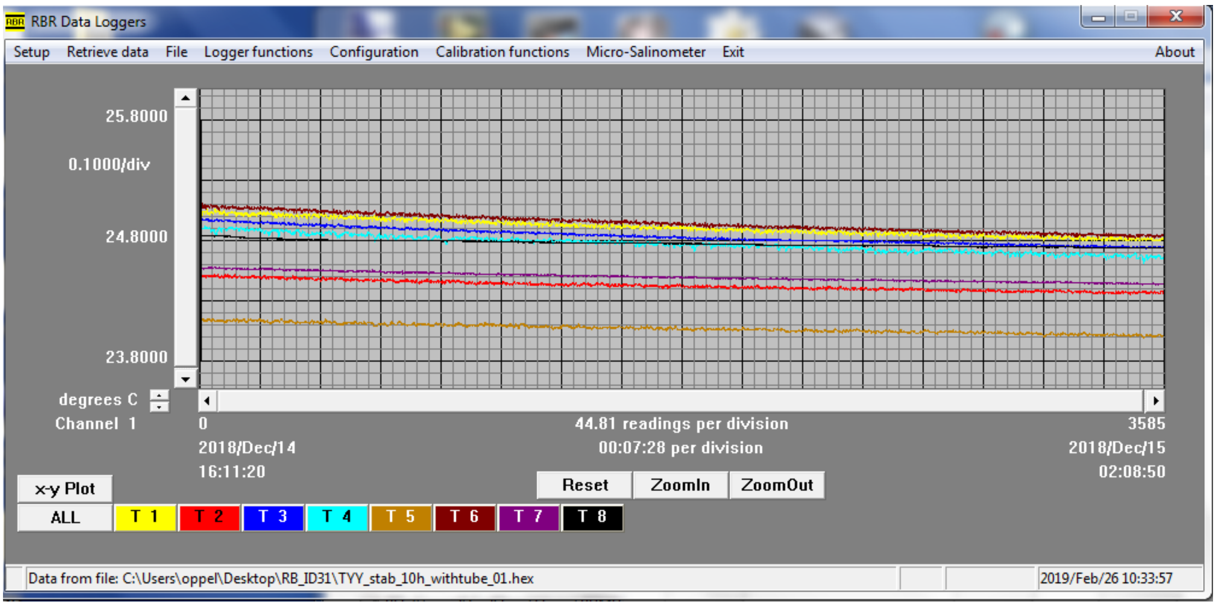
MIM = 50 nm. Backward direction, the hexapod and NTH motors are switched **off**.

<u>TYY stability</u> measurements.

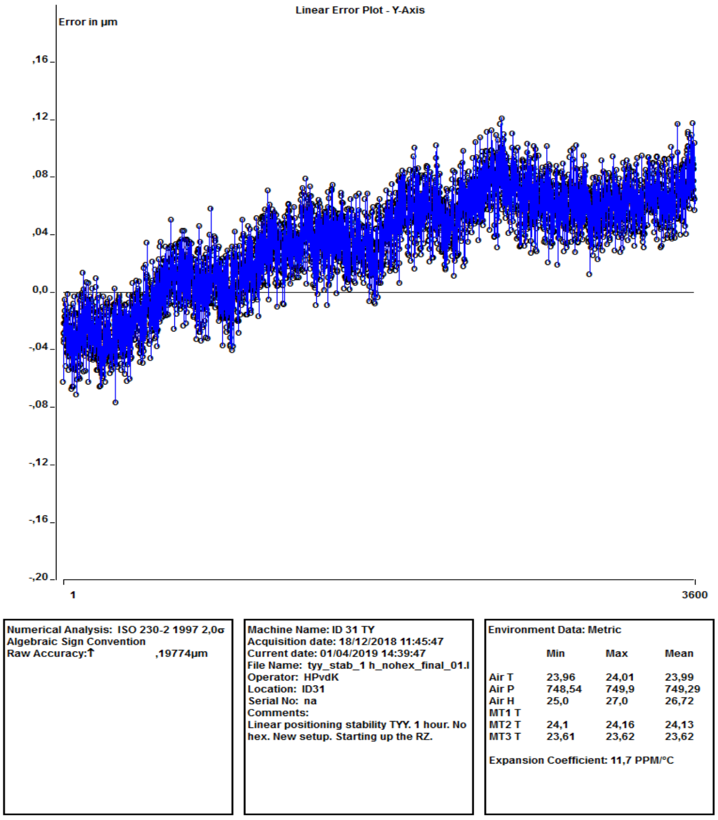
Accuracy = 1.64 µm over 10 hours, all motors on.



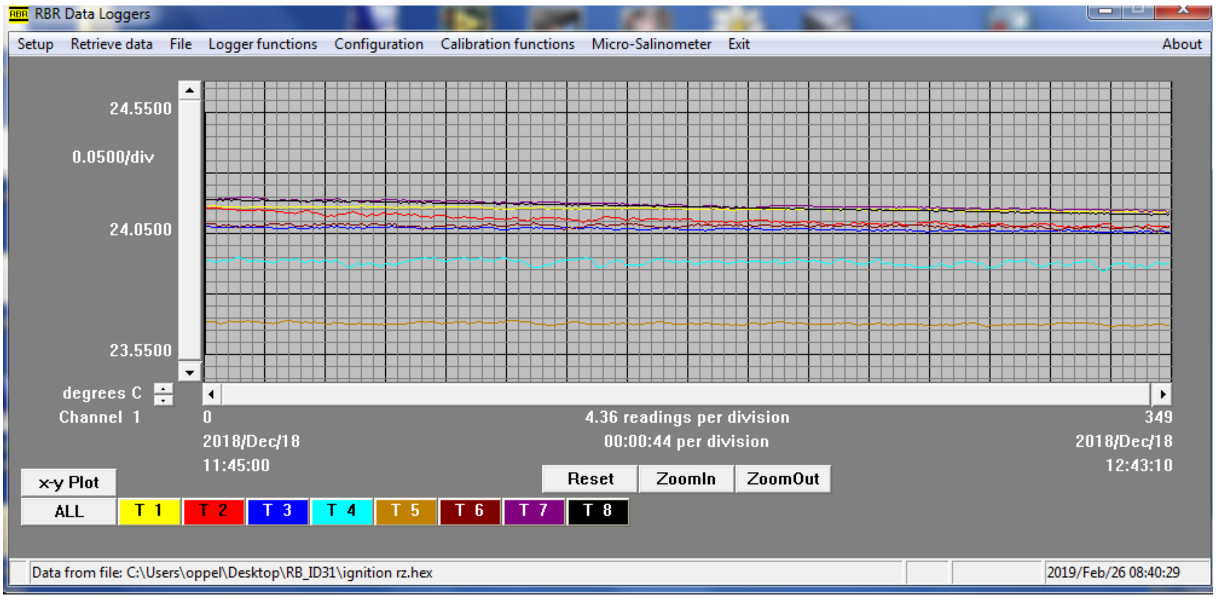
Temperature recording during the above mentioned test. **No air-conditioning**.



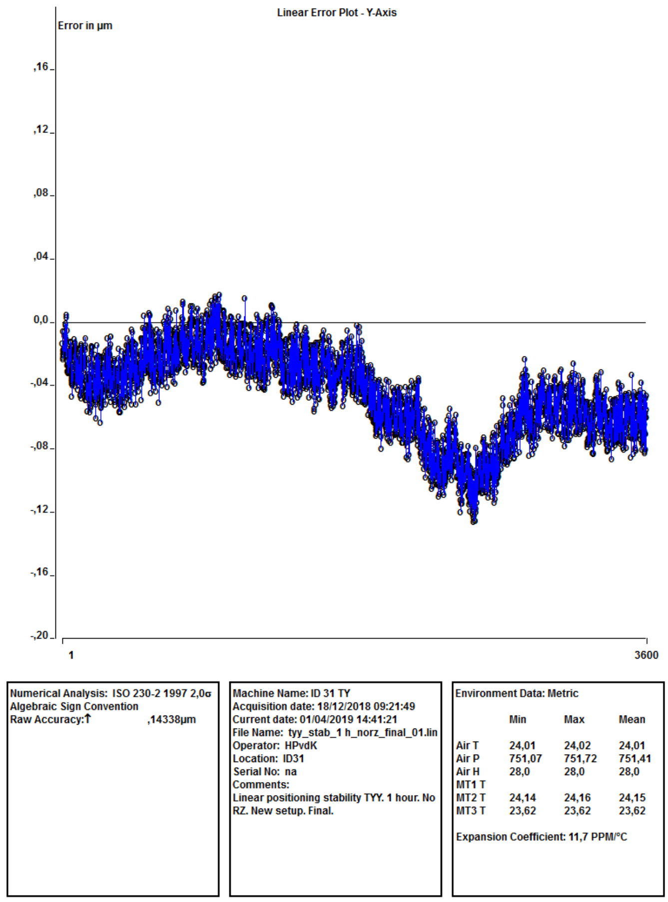
Accuracy = 0.2 µm over 1 hours, hexapod is switched off and the NTH motor is switched on.



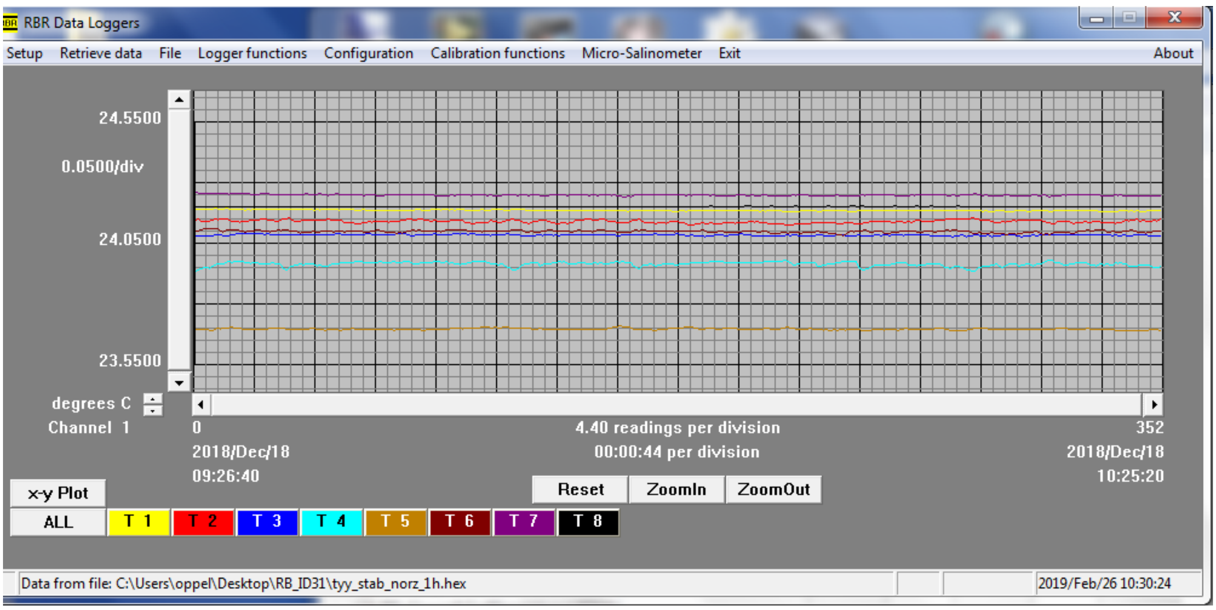
Temperature recording during the above mentioned test.



Accuracy = 0.14 µm over 1 hours, NTH is switched off and the hexapod motors are switched on.

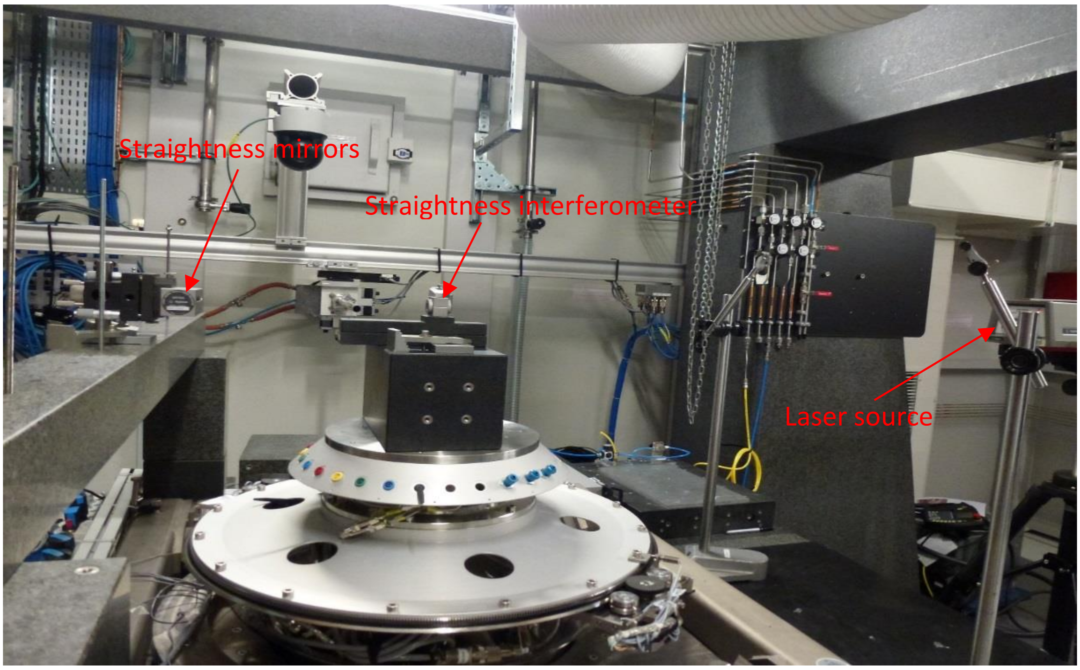


Temperature recording during the above mentioned test.



Linear deviation (straightness):

Measurement setup of the straightness measurement TYX (See picture below). During measurement the set-up is covered with a sheet of bubble plastic.



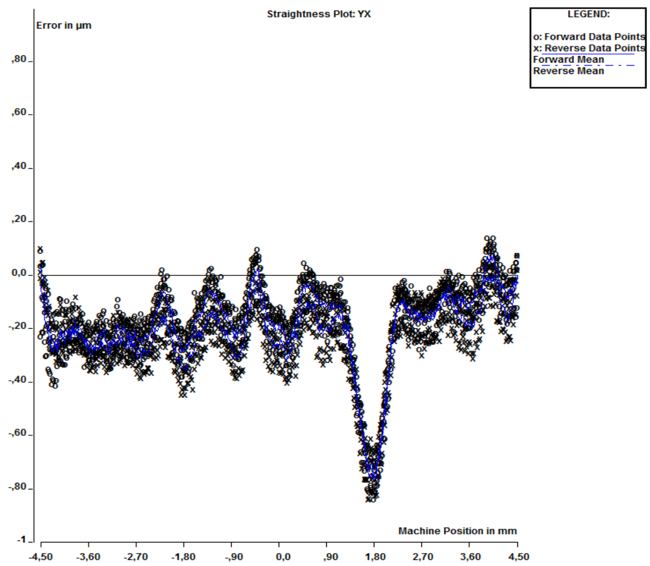
Linear deviation (straightness) TYX. Stroke +/- 4.5 mm.

Accuracy : 0.98 µm

Repeat : 0.33 µm

Repeat↑ : 0.32 µm

Repeat↓ : 0.25 µm



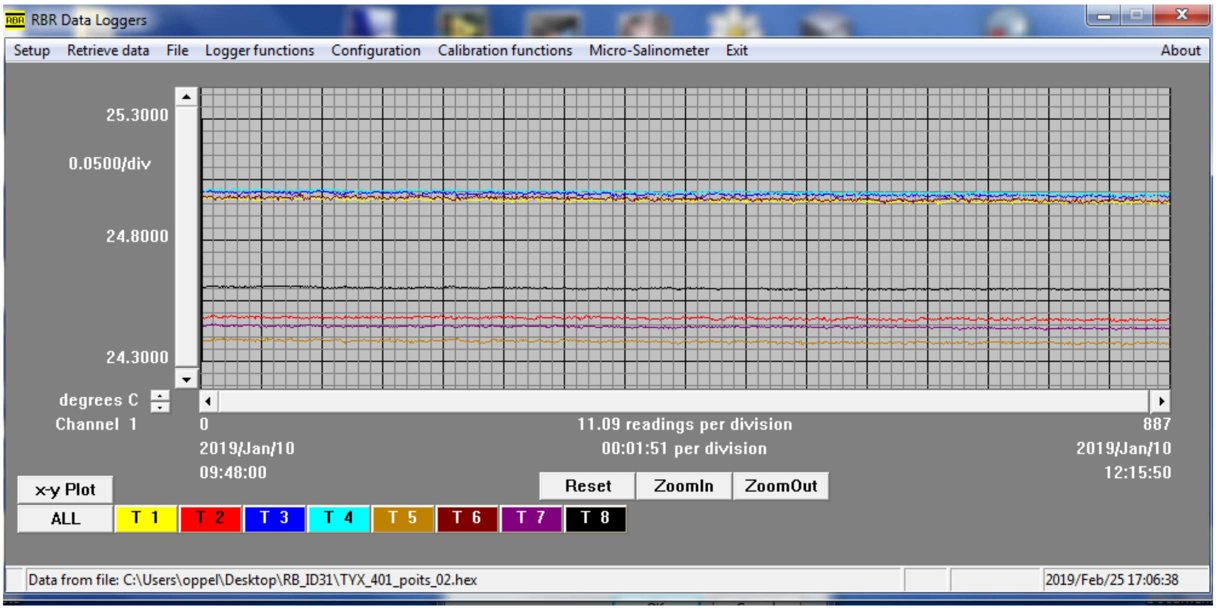
Numerical Analysis: Standard: USER 3,0σ
Raw Accuracy: 0,979441µm
Raw Accuracy:↑ 0,977875µm
Raw Accuracy:↓ 0,940857µm
Raw Repeat: 0,330549µm
Raw Repeat:↑ 0,322174µm
Raw Repeat:↓ 0,249852µm

Machine Name: ID 31 TY
Acquisition date: 10/01/2019 09:42:34
Current date: 01/04/2019 15:37:36
File Name: linear deviation _tyx_401_poin
Operator: HPvdK
Location: ID31
Serial No: na
Comments:
Linear deviation TYX. 401 points, 3 bidir cycles. No backlash routine. All motors activated. Averaging 1 sec.

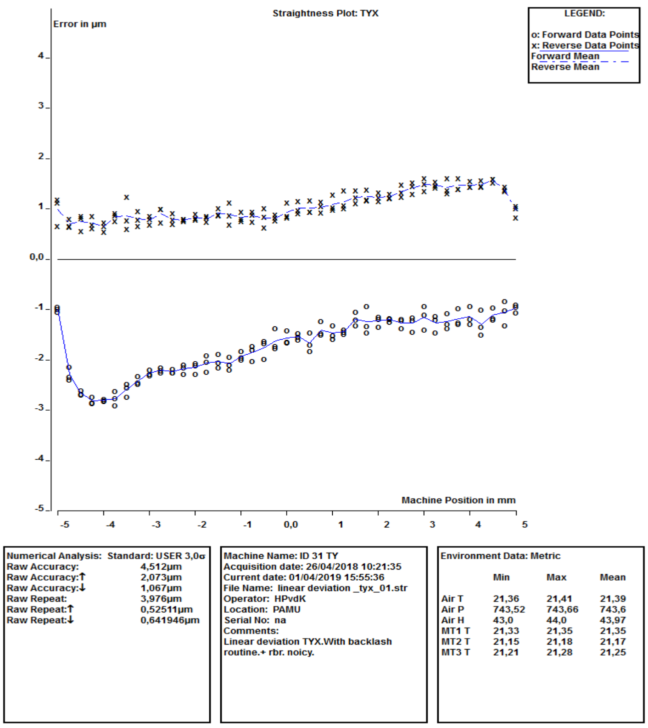
Environment Data: Metric

	Min	Max	Mean
Air T	24,48	24,49	24,49
Air P	746,31	746,96	746,71
Air H	21,0	22,0	21,82
MT1 T			
MT2 T	24,24	24,25	24,25
MT3 T	24,16	24,18	24,17

Temperature recording during the above mentioned test. **No air-conditioning**.



Linear deviationTYX of the NY translation. Stroke +/- 5 mm.
Done at the **PAMU @ 4/2018**, with hexapod and NTH motors switched **off**.



Accuracy : 4.51 µm

Repeat : 3.98 µm

Repeat↑ : 0.53 µm

Repeat↓ : 0.64 µm

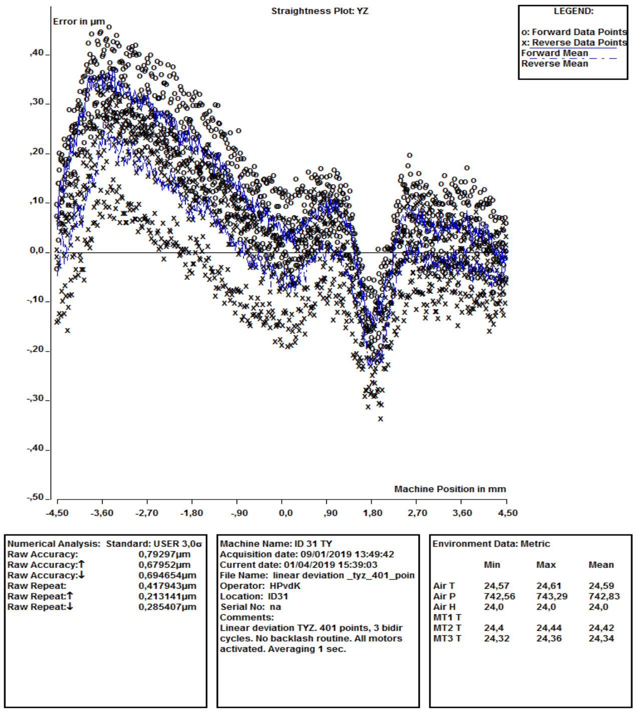
<u>Linear deviation</u> TYZ. Stroke +/- 4.5 mm.

Accuracy : 0.79 µm

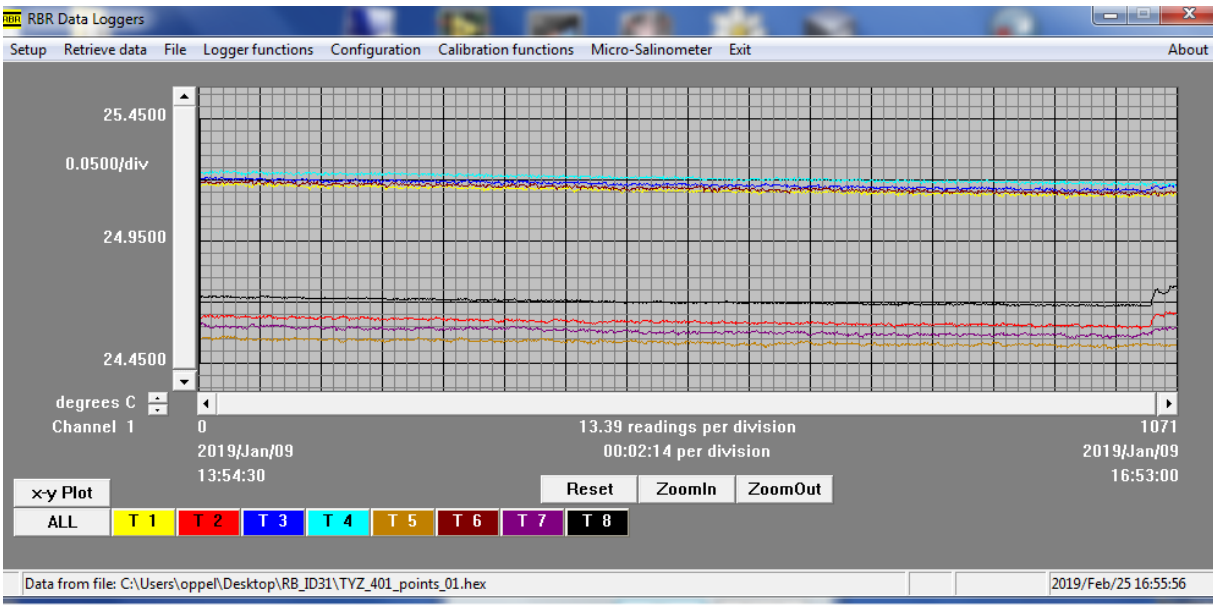
Repeat : 0.42 µm

Repeat↑ : 0.21 µm

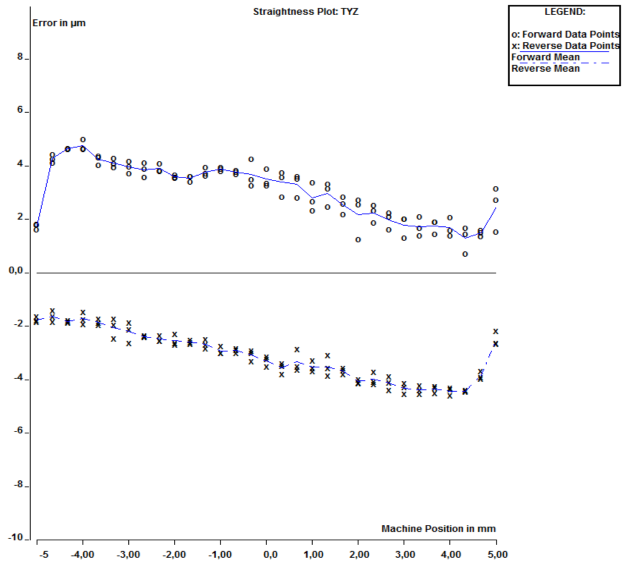
Repeat↓ : 0.29 µm



Temperature recording during the above mentioned test. **No air-conditioning**.



Linear deviationTYX of the NY translation. Stroke +/- 5 mm.
Done at the **PAMU @ 4/2018**, with hexapod and NTH motors switched **off**.



Accuracy: 9.61 µm

Repeat : 7.57 µm

Repeat↑ : 1.6 µm

Repeat↓ : 0.76 µm

Numerical Analysis:	Standard: USER 3,0σ
Raw Accuracy:	9,612µm
Raw Accuracy:↑	4,287µm
Raw Accuracy:↓	3,198µm
Raw Repeat:	7,567µm
Raw Repeat:↑	1,601µm
Raw Repeat:↓	0,764851µm

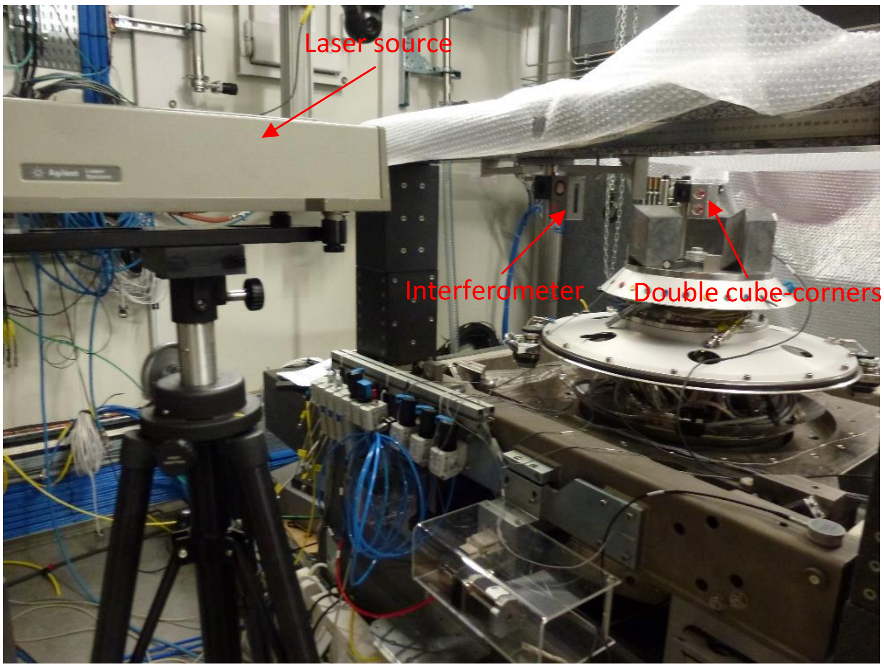
Machine Name: ID 31 TY
Acquisition date: 25/04/2018 17:10:35
Current date: 01/04/2019 15:57:09
File Name: linear deviation _tyz_03.str(M
Operator: HPvdK
Location: PAMU
Serial No: na
Comments:
Linear deviation TYZ.With backlash routine.

Environment Data: Metric

	Min	Max	Mean
Air T	21,34	21,38	21,35
Air P	740,07	740,2	740,16
Air H	45,0	46,0	45,15
MT1 T	21,36	21,39	21,37
MT2 T	21,16	21,19	21,18
MT3 T	21,19	21,24	21,22

Angular deviation:

Measurement setup of the angular deviation measurement RYx (See picture below).



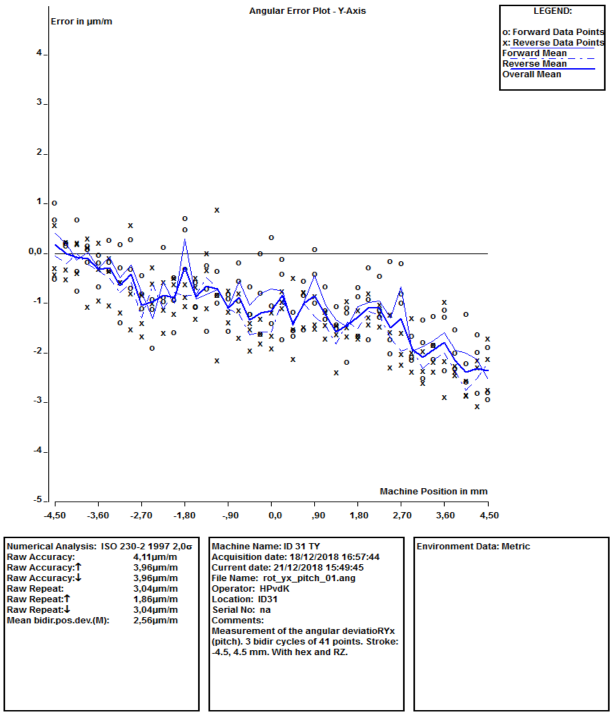
Angular deviation : RYx (pitch). Stroke +/- 4.5 mm.

Accuracy : 4.11 µm/m

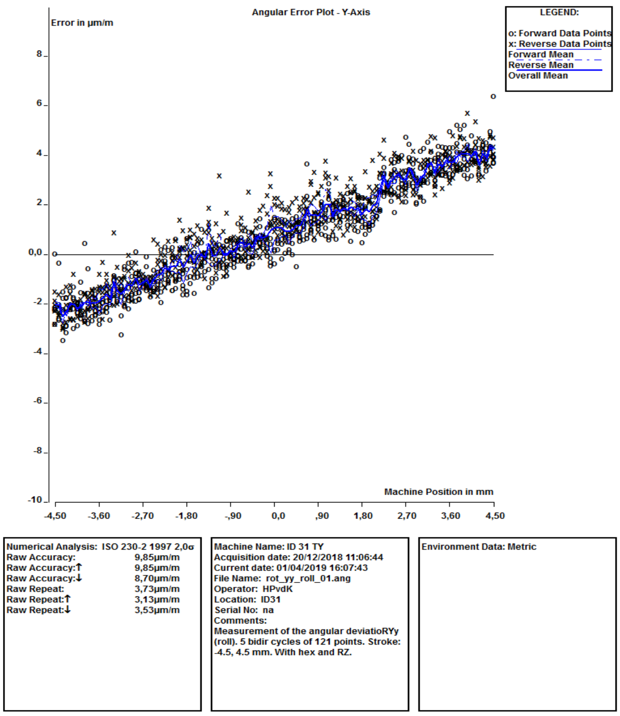
Repeat : 3.04 µm/m

Repeat↑ : 1.86 µm/m

Repeat↓ : 3.04 µm/m



RYy (roll). Stroke +/- 4.5 mm.



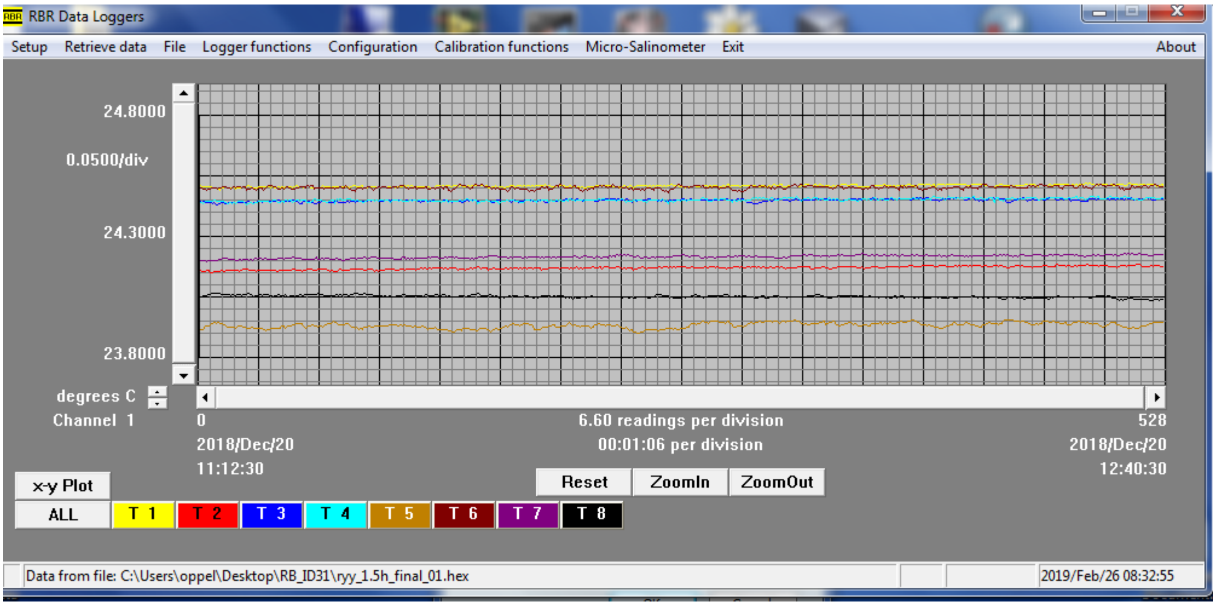
Accuracy : 9.85 µm/m

Repeat : 3.73 µm/m

Repeat↑ : 3.13 µm/m

Repeat↓ : 3.53 µm/m

Temperature recording during the above mentioned test.



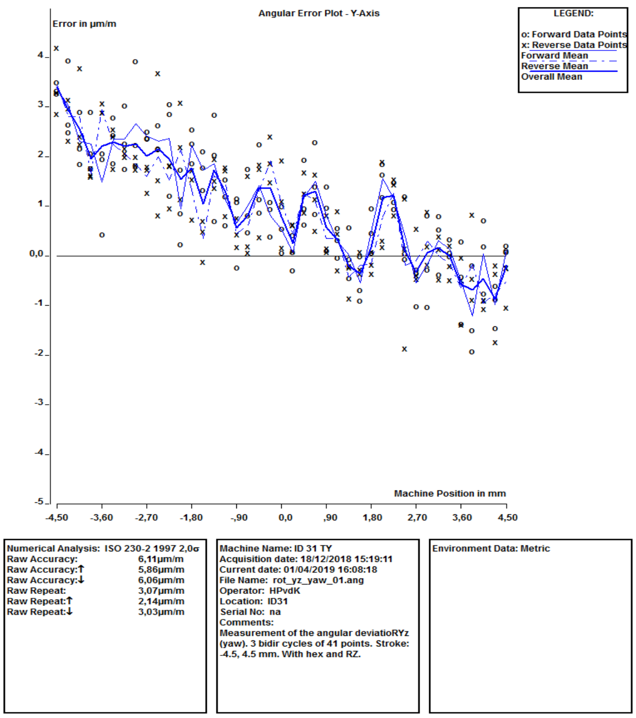
RYz (yaw). Stroke +/- 4.5 mm.

Accuracy : 6.11 µm/m

Repeat : 3.07 µm/m

Repeat↑ : 2.14 µm/m

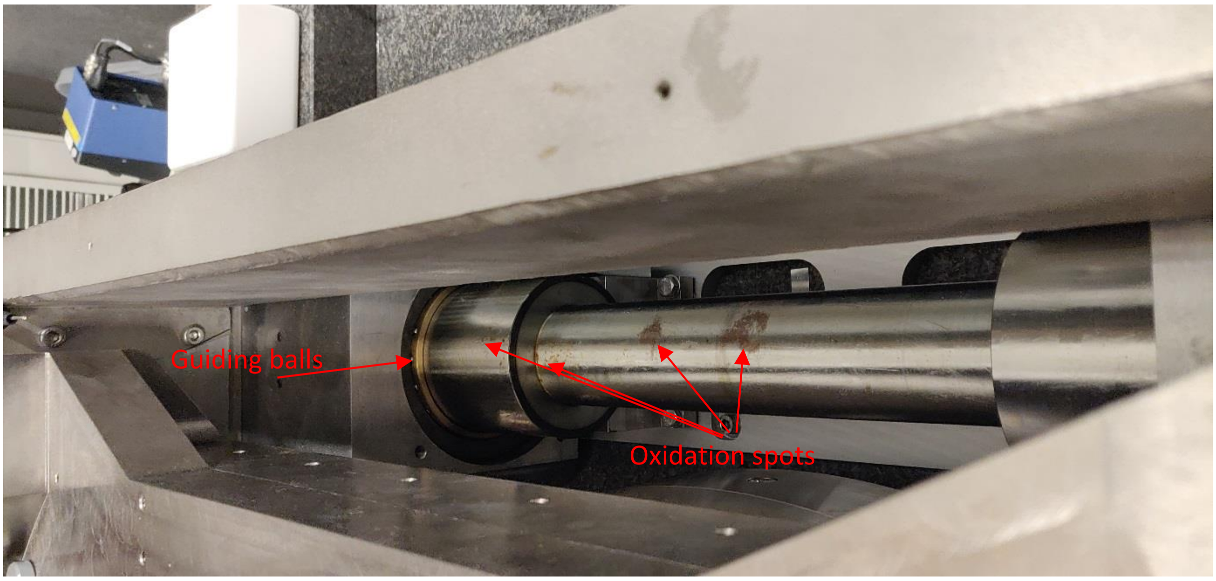
Repeat↓ : 3.03 µm/m



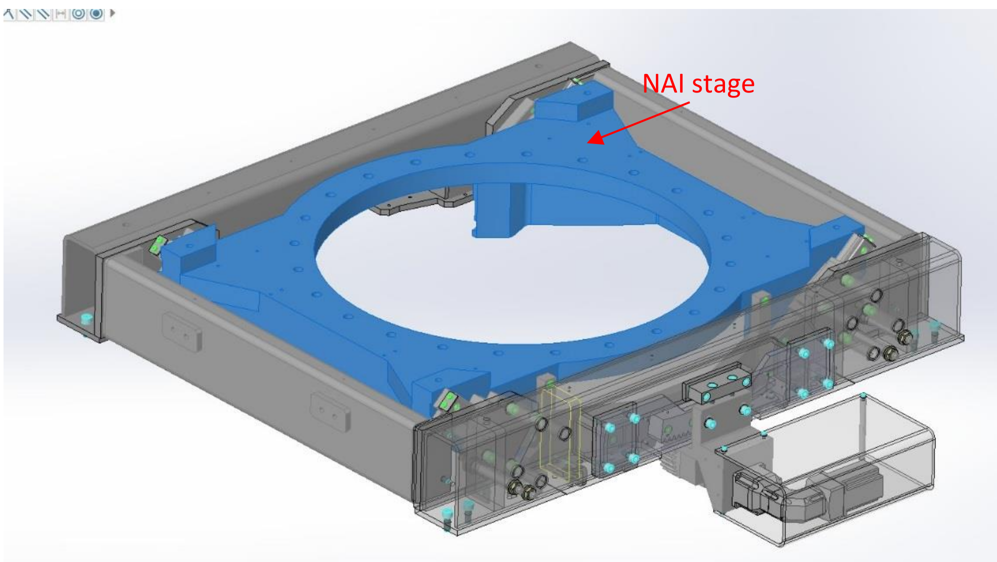
Conclusion and remarks:

The NY stage suffers from an instable closed loop; the reason might be the position of the encoder read head or the stiffness of its support. Another possibility to cure this problem might be to replace the linear motor for a stepper motor.

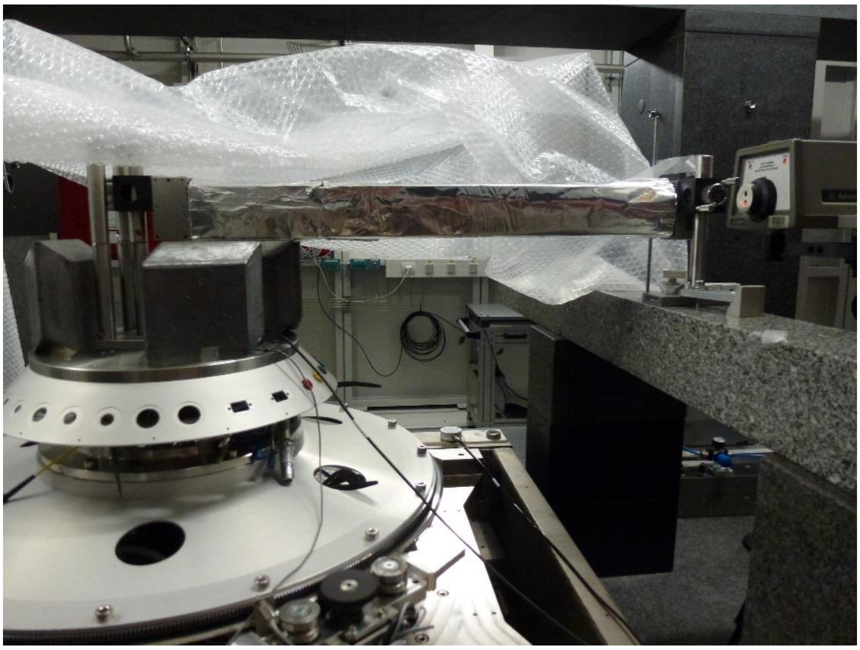
During the last measurement campaign at ID31 we observed a "hard" spot at about 1.8 mm, while measuring the Linear positioning and deviation. This spot was not present during the measurement campaign @ 4/2018 at the PAMU. I joined the graphs from these test in this report.
The reason for this "hard "spot could be: an alien particle, oxidation, damage of the Mahr guiding's or the wrong positioning of the outer guiding regarding the inner guiding. (at 1.8 mm you can see that, a row of guiding balls is just entering or leaving the guiding.)
The guiding's are too much exposed; If I am right a cover is foreseen.



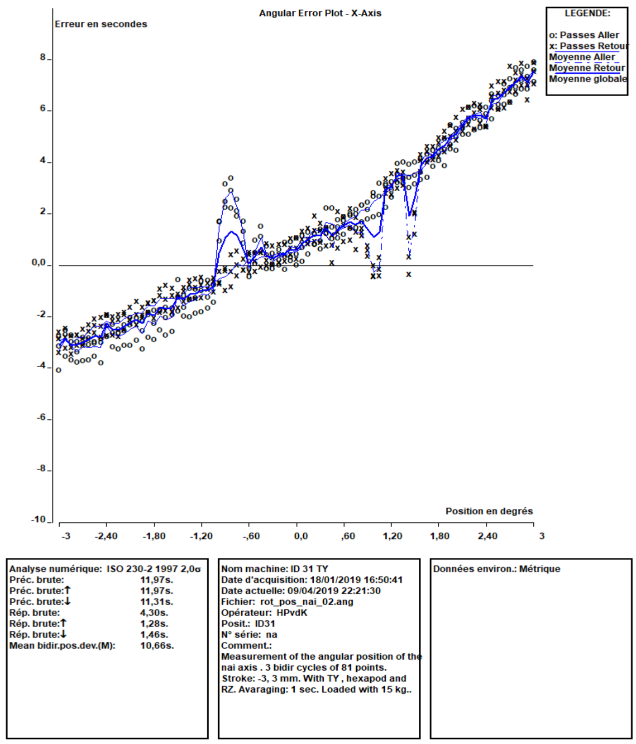
Part 2) NAI (tilt around Y axis)



Measurement setup of the angular positioning calibration of the NAI axis (See picture below).



<u>Angular positioning</u> of the NAI rotation. Stroke +/- 3 deg.



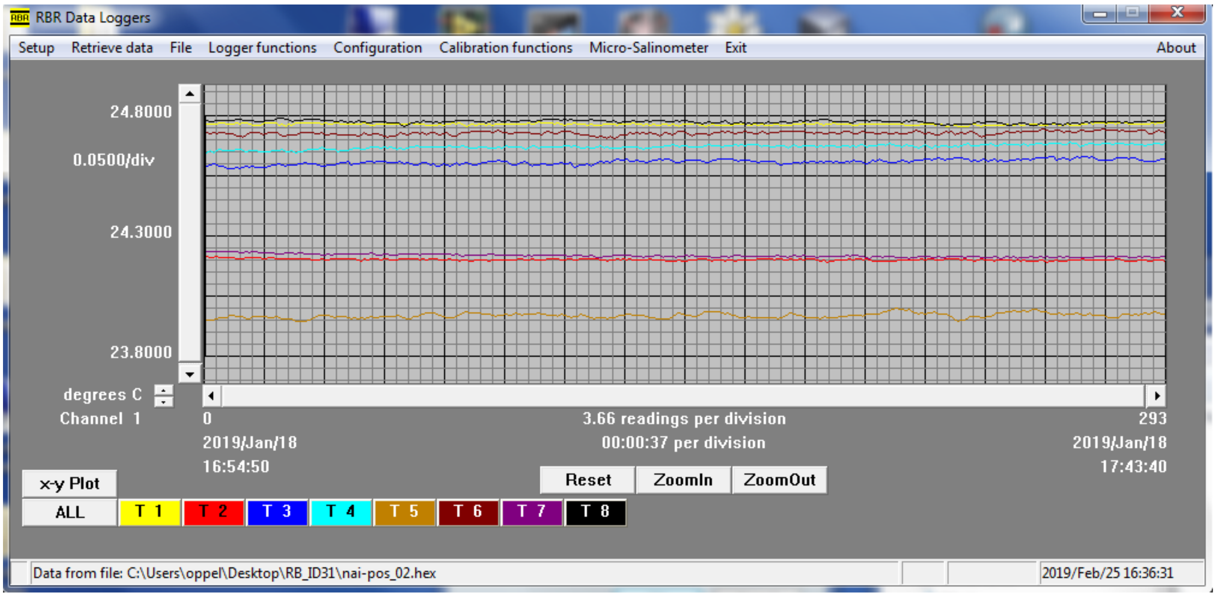
Accuracy : 11.97 arcsec x 4.85 = 58.05 µm/m

Repeat : 4.3 arcsec x 4.85 = 20.86 µm/m

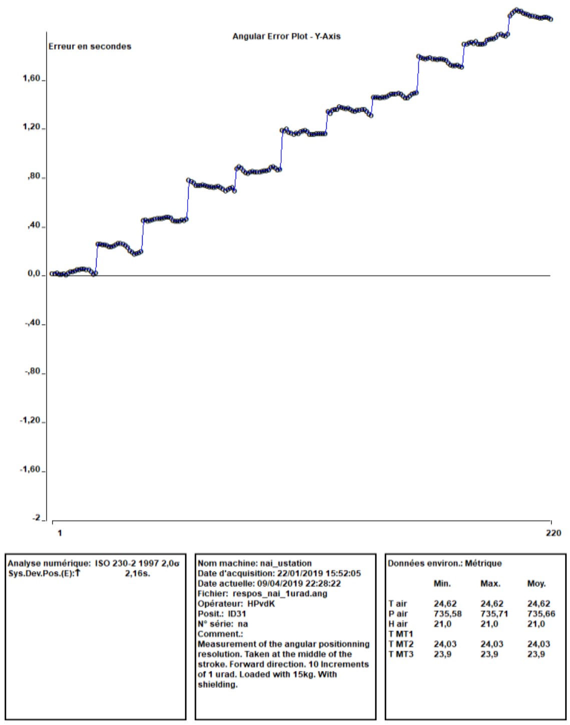
Repeat↑ : 1.28 arcsec x 4.85 = 6.2 µm/m

Repeat↓ : 1.46 arcsec x 4.85 = 7.08 µm/m

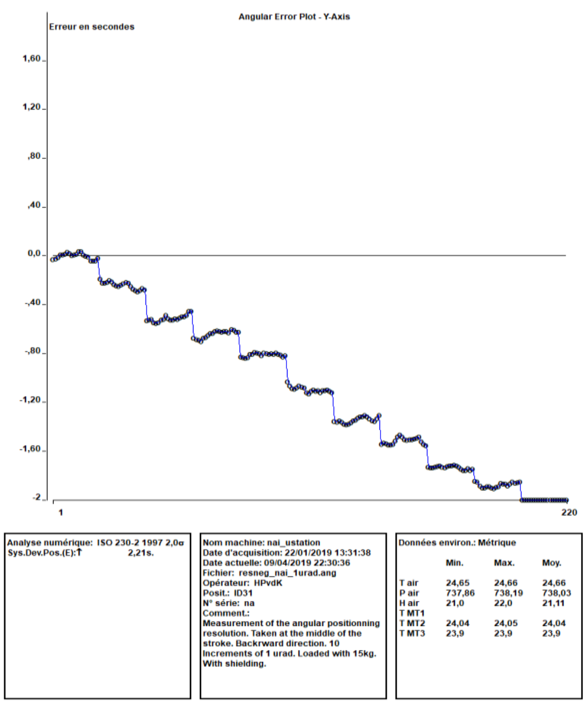
Temperature recording during the above mentioned test.



<u>MIM</u> (Minimum Incremental Motion) measurements.



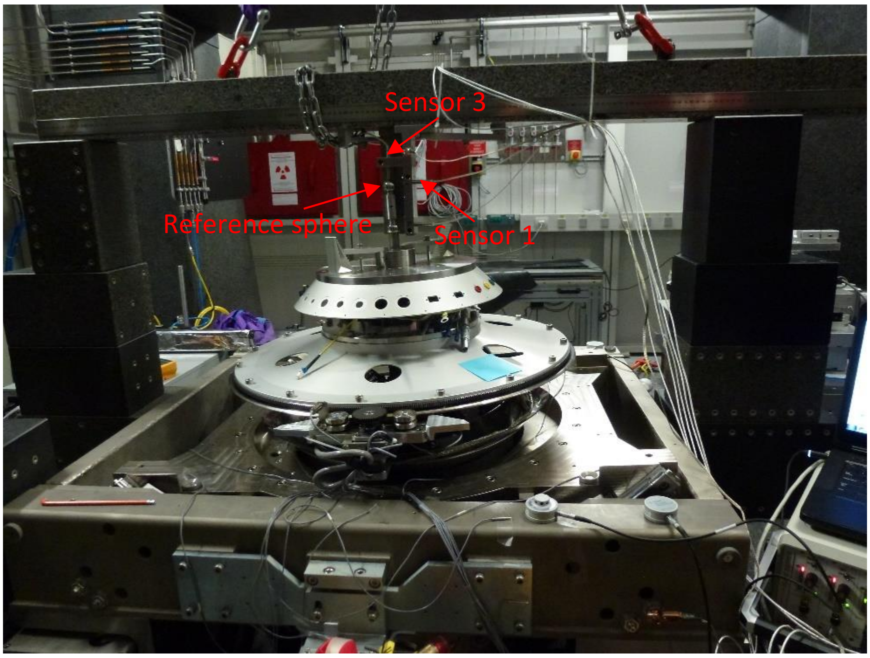
Forward direction
MIM = 0.216 arc sec x 4.85 = 1.05 µm/m.



Backward direction
MIM = 0.22 arc sec x 4.85 = 1.07 µm/m.

Determination of the center of rotation:

Determination of the center of rotation of the NAI stage, using a PIC reference sphere and a capacitive sensor system from the Lion company (see picture below). We come back later on to this equipment with the measurements of the NTH spindle.



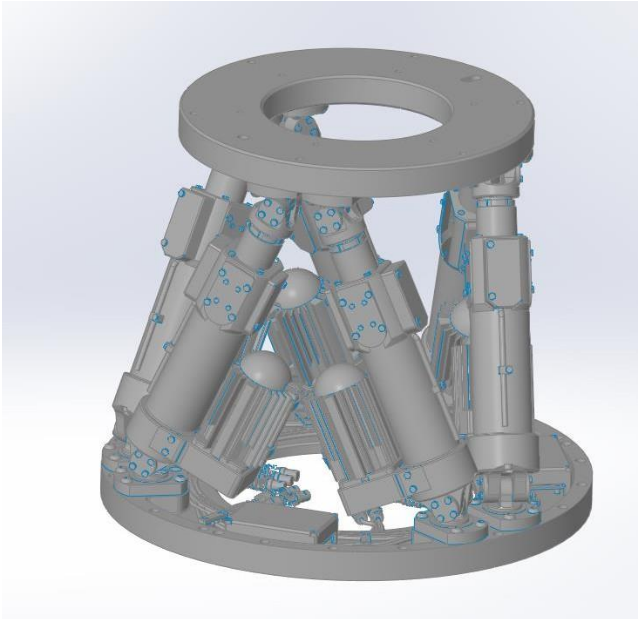
The distance (height) between the top plate of the hexapod and the center of rotation of the NAI stage ≈ **142.857 mm**, with NHZ at **5.4916 mm***[1]

Conclusion and remarks:

The NAI is performing quite well, except a few small spots at -0.9, 0.9 and 1.5 deg. Regarding the, in my opinion, difficulty to assemble and adjust the 4-independent guiding's of the rotary stage, the PAMU did a good job.

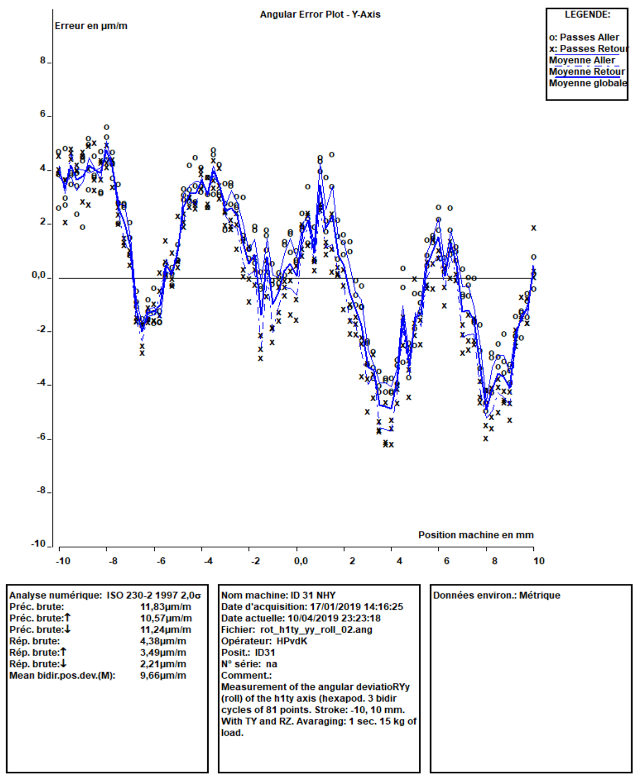
*[1]I had no time to double check this value, while at the end the stage stopped working. The lack of correct tightening of the link between motor and reducer seems to be the reason (factory assembly error).
In the meantime, this problem is probably solved, a future measurement campaign will confirm this value.

Part 3) hexapod from Symetrie (NHY movement only)



Measurement setup of the angular deviation measurement RYy (See picture below).

Angular deviation measurement RYy (roll). Stroke +/- 10 mm.



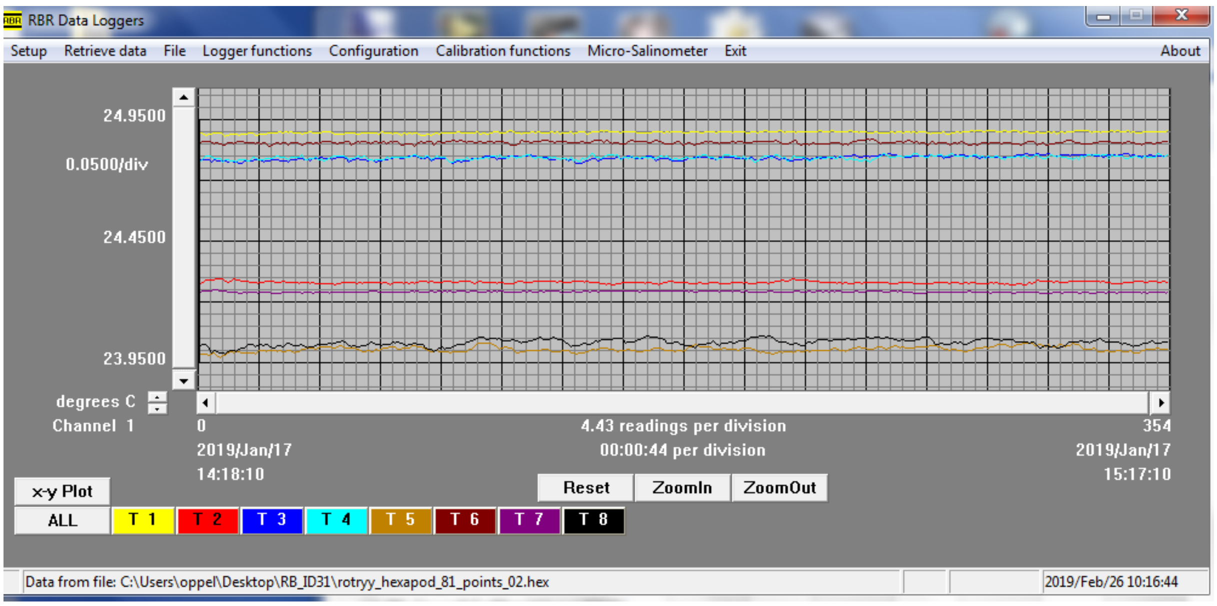
Accuracy : 11.83 µm/m

Repeat : 4.38 µm/m

Repeat↑ : 3.49 µm/m

Repeat↓ : 2.21 µm/m

Temperature recording during the above mentioned test.



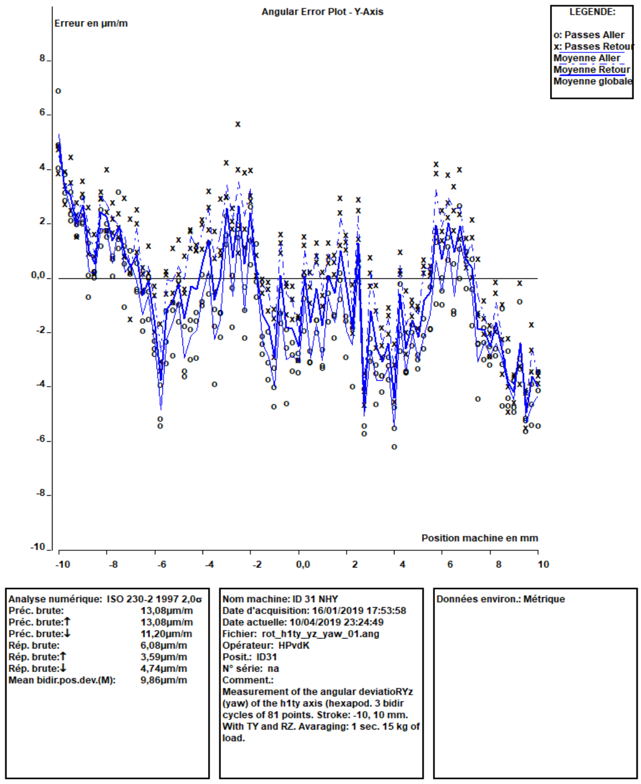
Angular deviation measurement RYz (yaw). Stroke +/- 10 mm.

Accuracy : 13.08 µm/m

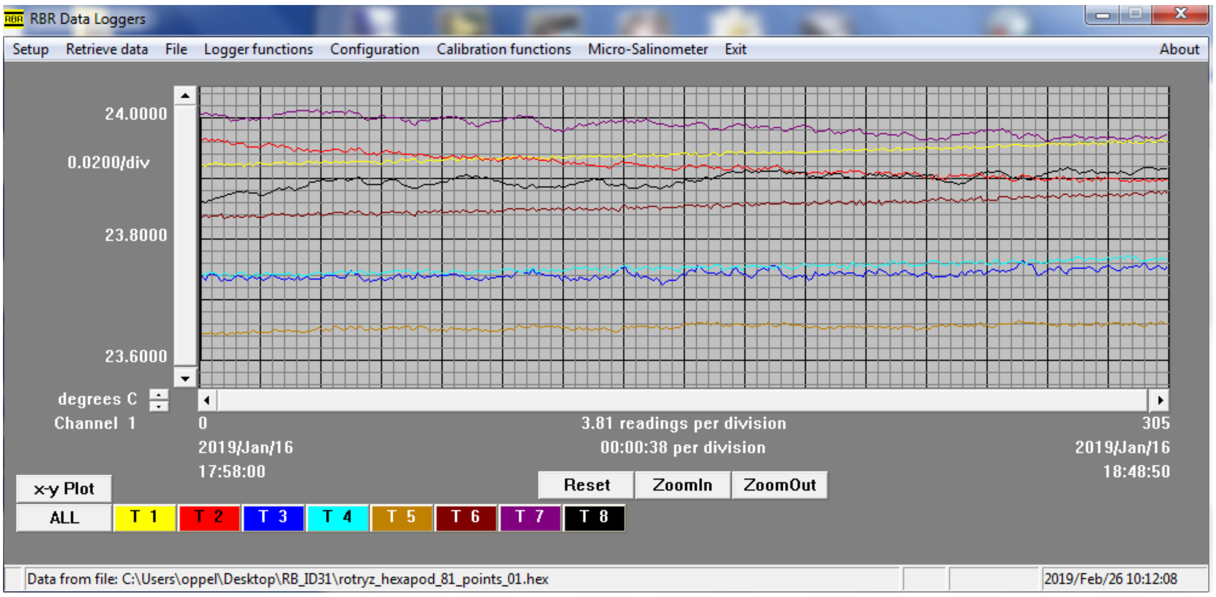
Repeat : 6.08 µm/m

Repeat↑ : 3.59 µm/m

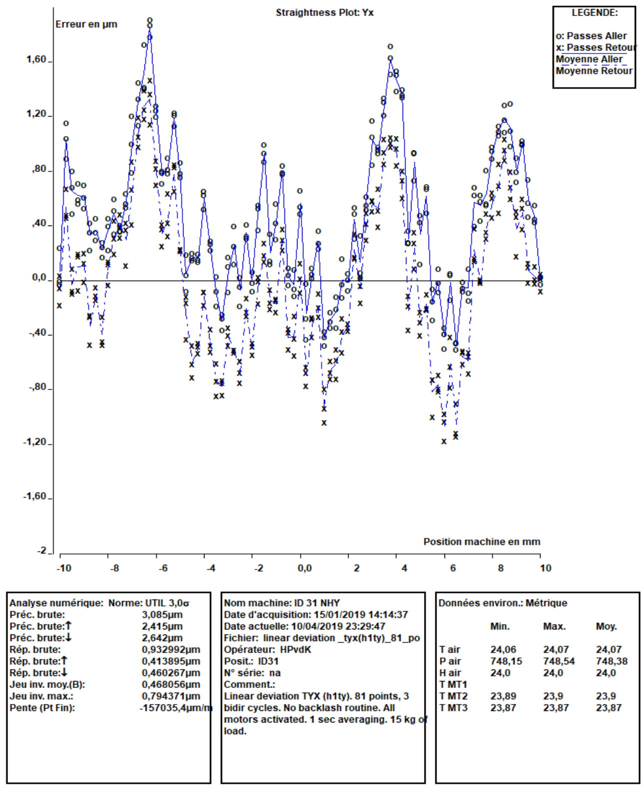
Repeat↓ : 4.74 µm/m



Temperature recording during the above mentioned test.



Linear deviation (straightness) measurement TYX. Stroke +/- 10 mm.



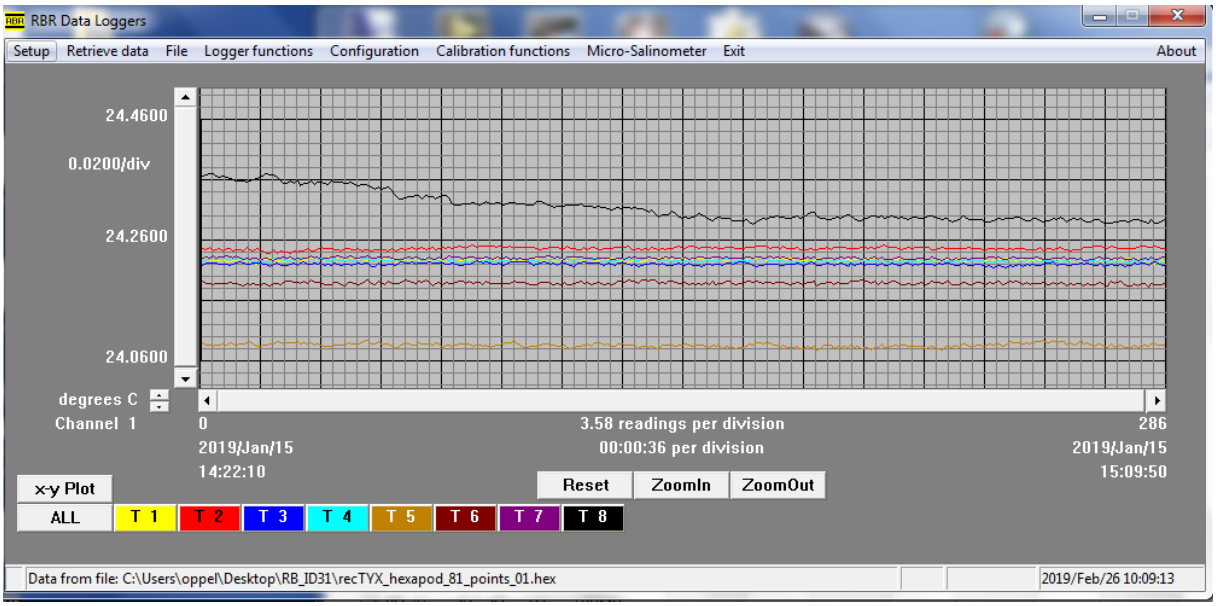
Accuracy : 3.09 µm

Repeat : 0.93 µm

Repeat↑ : 0.41 µm

Repeat↓ : 0.46 µm

Temperature recording during the above mentioned test. **No air-conditioning**.



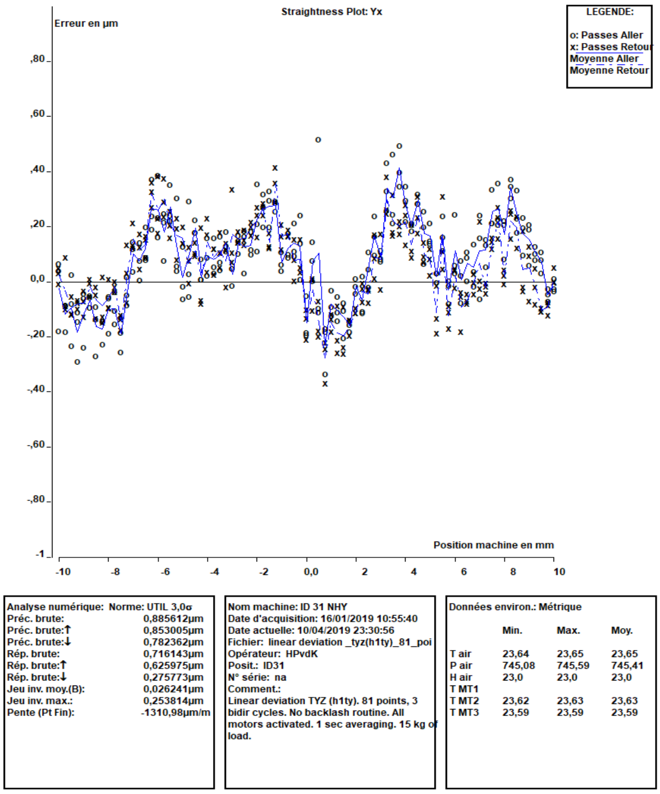
Linear deviation (straightness) measurement TYZ. Stroke +/- 10 mm.

Accuracy : 0.89 µm

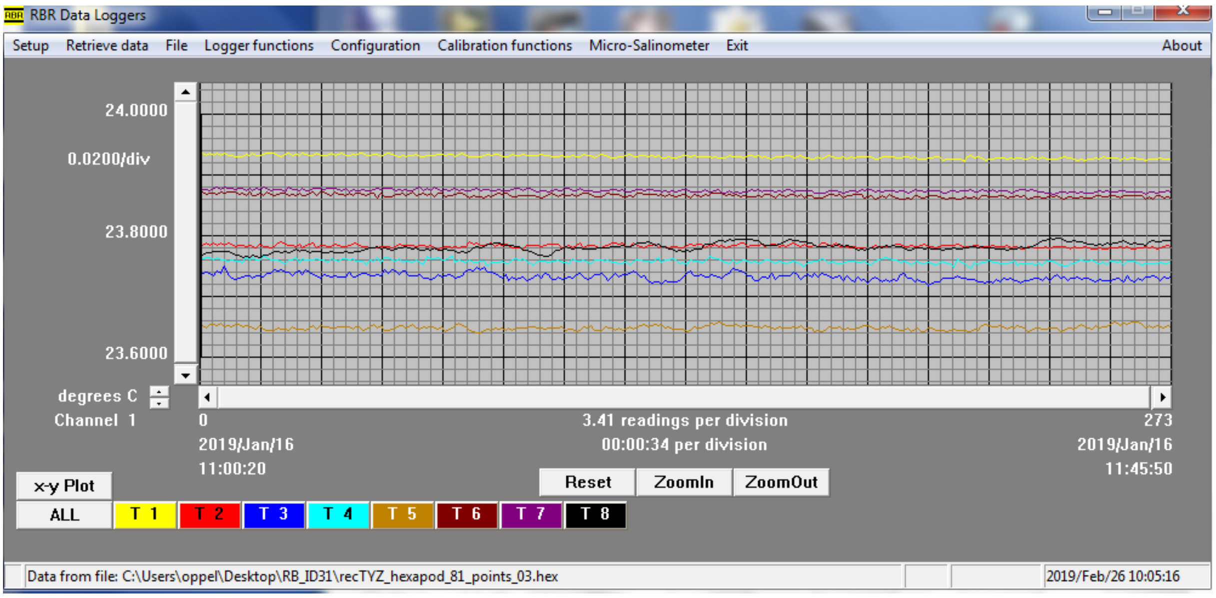
Repeat : 0.72 µm

Repeat↑ : 0.63 µm

Repeat↓ : 0.28 µm



Temperature recording during the above mentioned test.

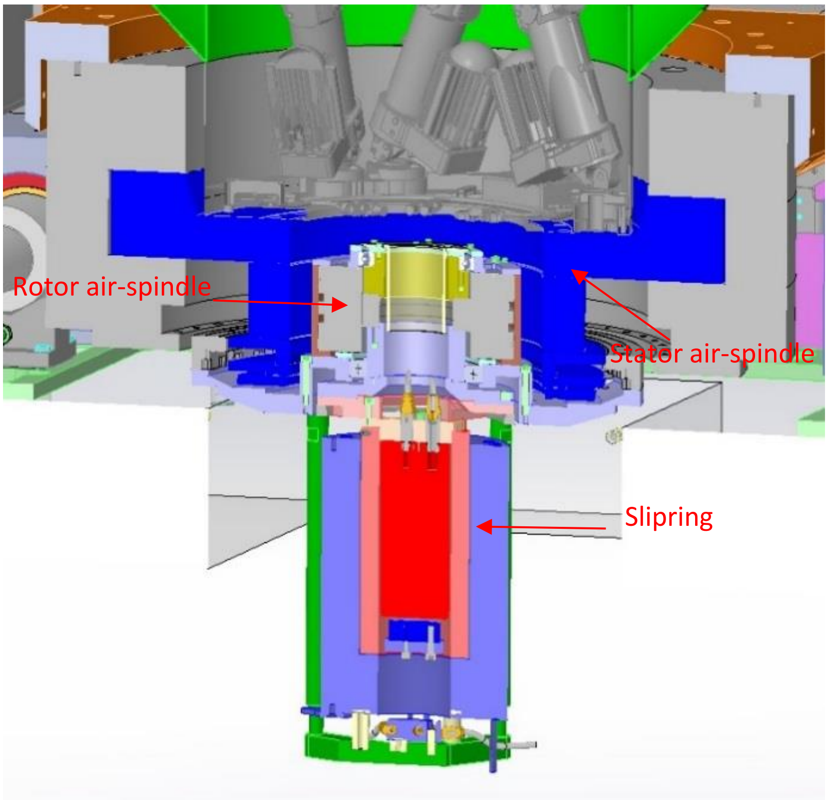


Conclusion and remarks:

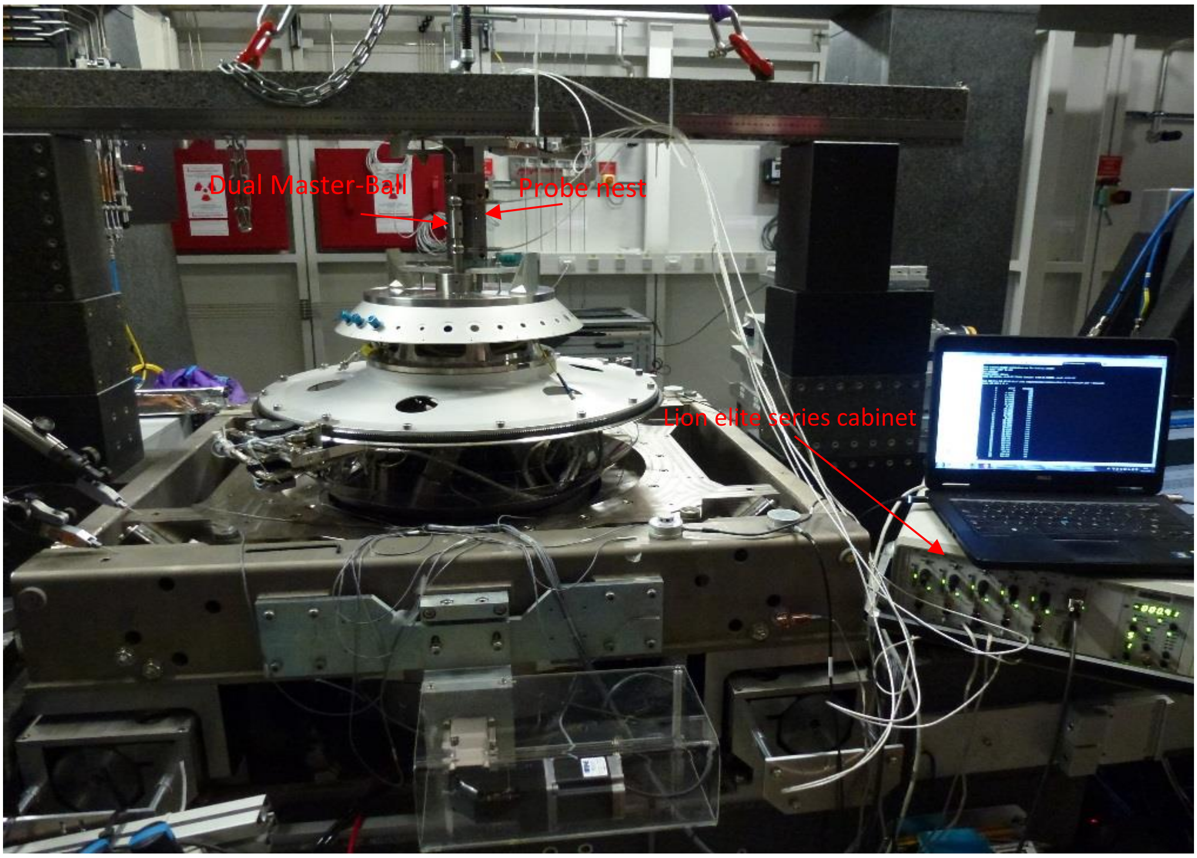
The results of the measurements are more or less in spec.
An electrical problem occurs from time to time in one of the legs, preventing the hexapod to move. This could be a bad contact in the slipring.

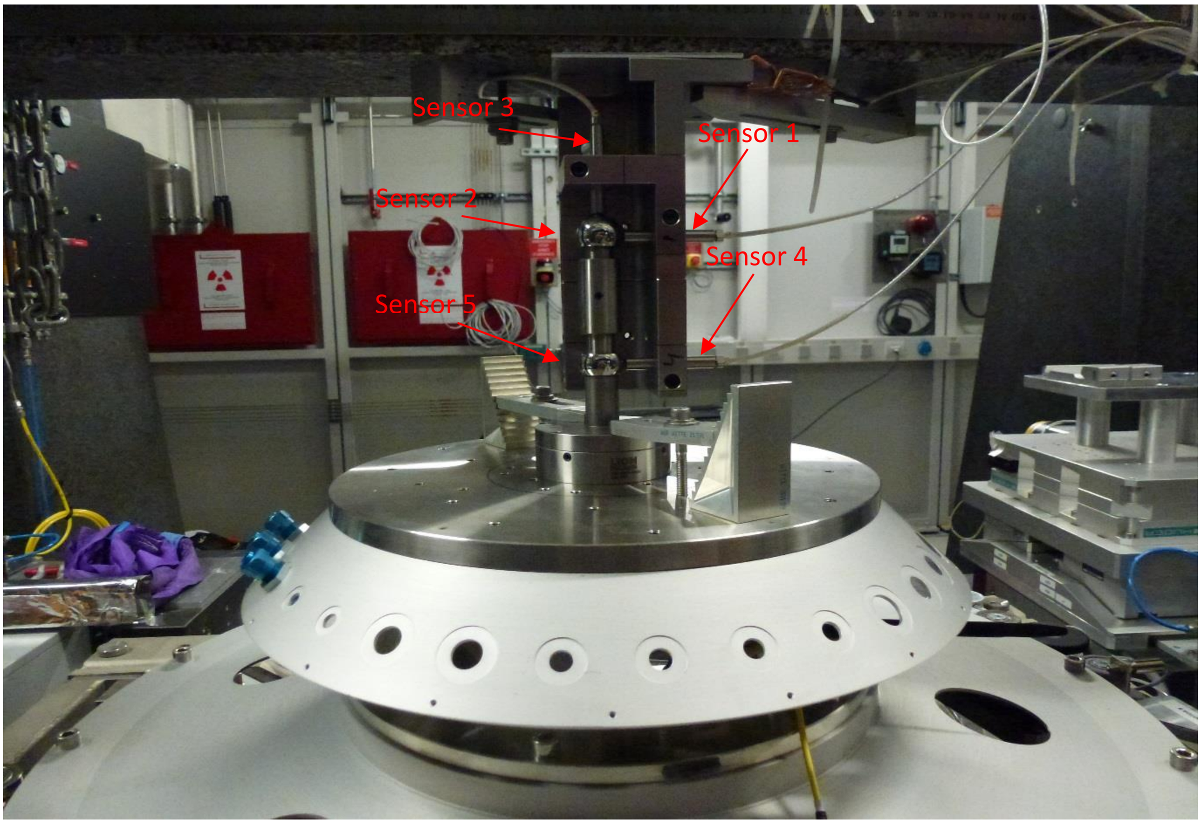
Part 4) NTH (Air spindle from LAB)

Spindle + slipring



Measurement setup for the axial, radial and tilt measurements (See pictures below).



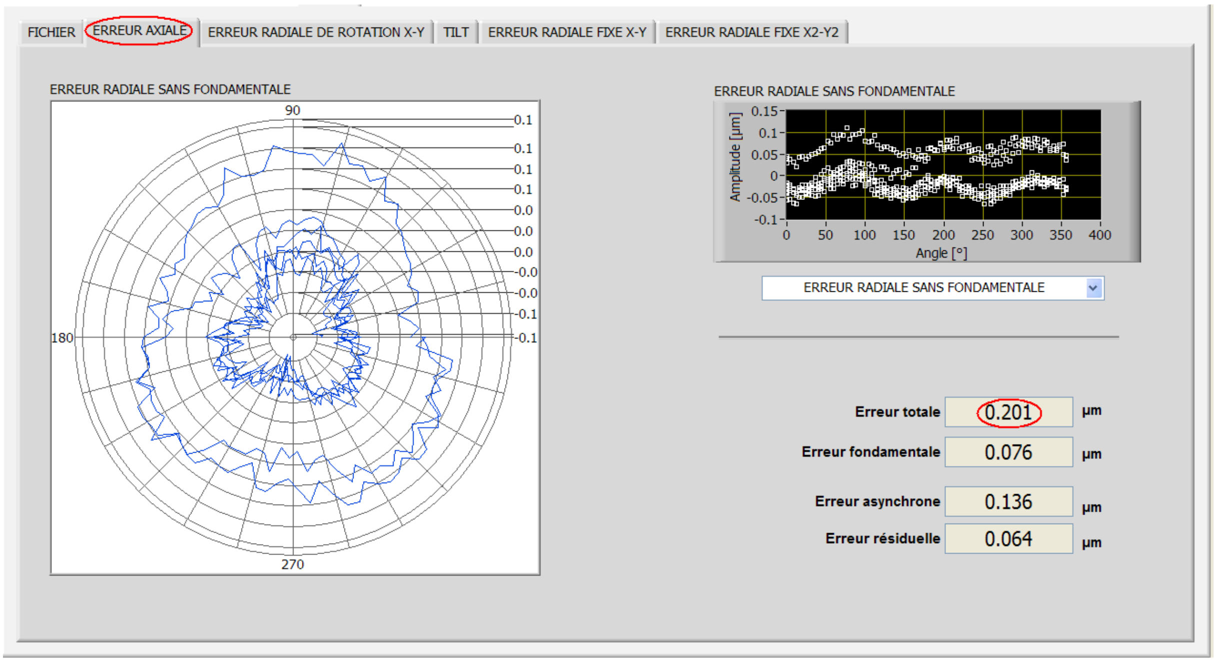


- The (static) measurement was performed in 3 bidirectional cycles, from 0 to 360 deg, every 2 deg. No drift compensation.

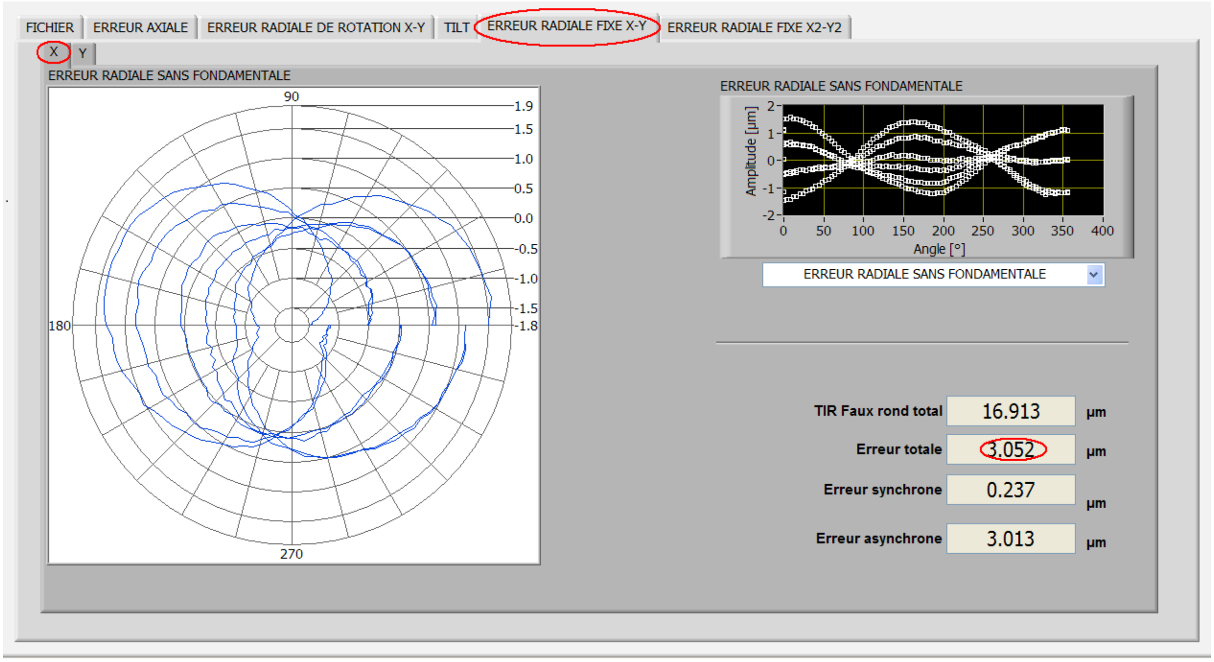
- A dual Master-Ball (25.4mm) target was mounted on the rotor, used as reference surface for the measurement, and aligned at the center of the spindle. The master ball roundness is <25nm and it is considered negligible. The upper master ball is at sample height, ≈142.857 mm.

- The measurement has been performed with a low resolution (80mV/µm) capacitive sensor set from Lion Precision, composed of 5 sensors conditioned by a CPL290 driver and mounted on a probe nest (i.e appendix for the datasheets).

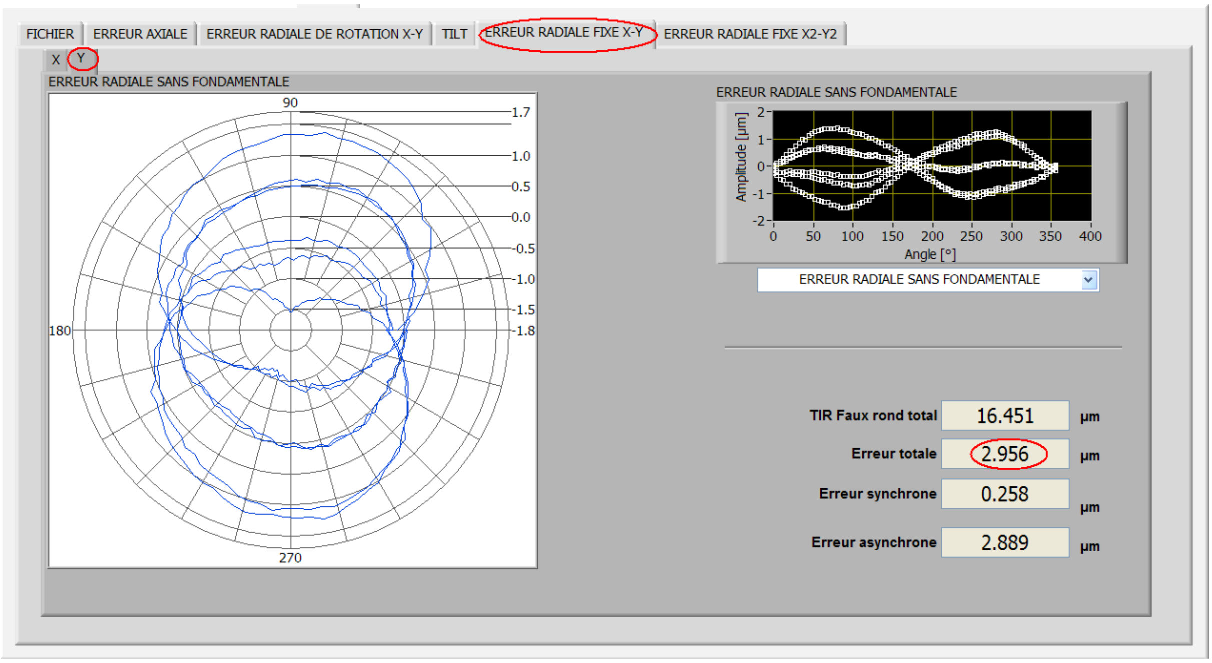
The results of the measurement done at the PEL on 4/2017 are written in Red.



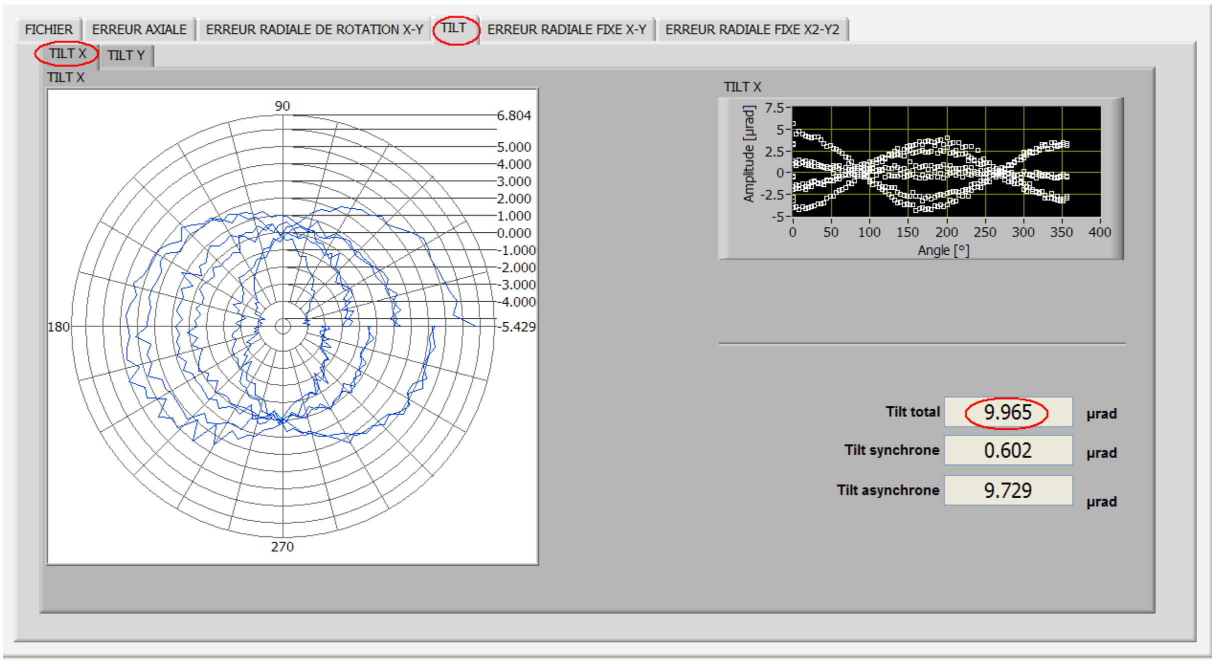
Axial error: 201 nm



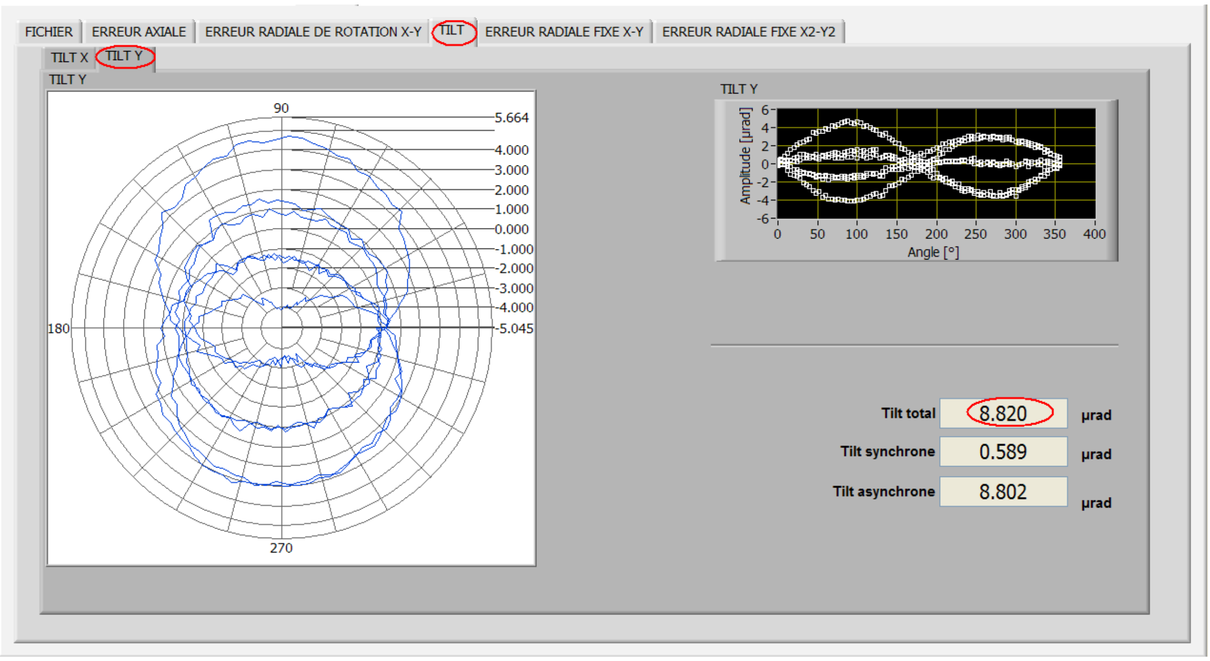
Radial error in X: 3.052 µm



Radial error in Y: 2.956 µm

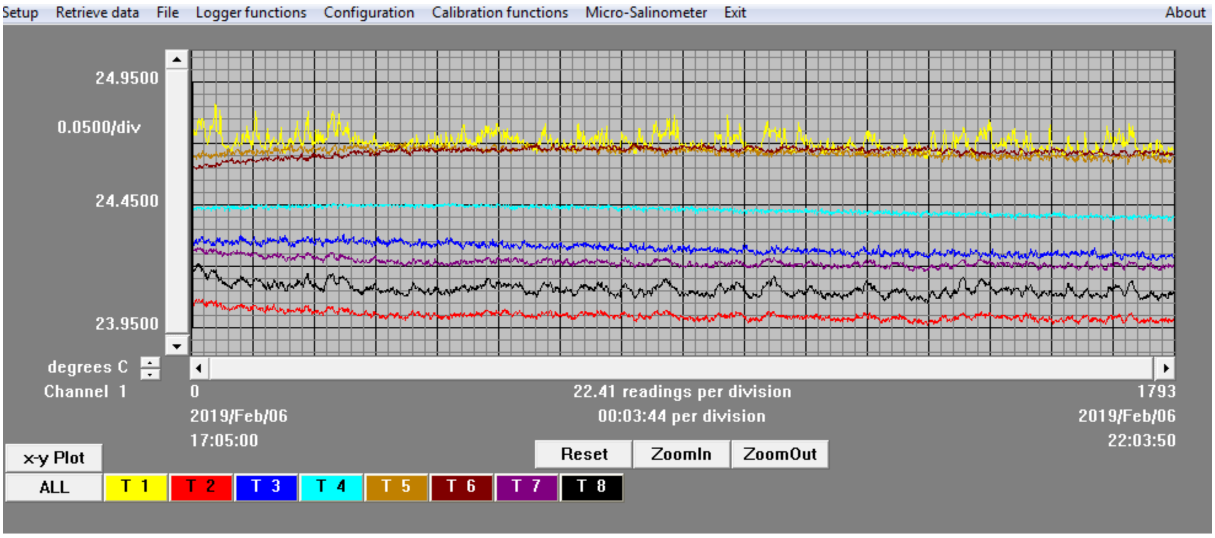


Tilt error in X: 9.965 µm/m



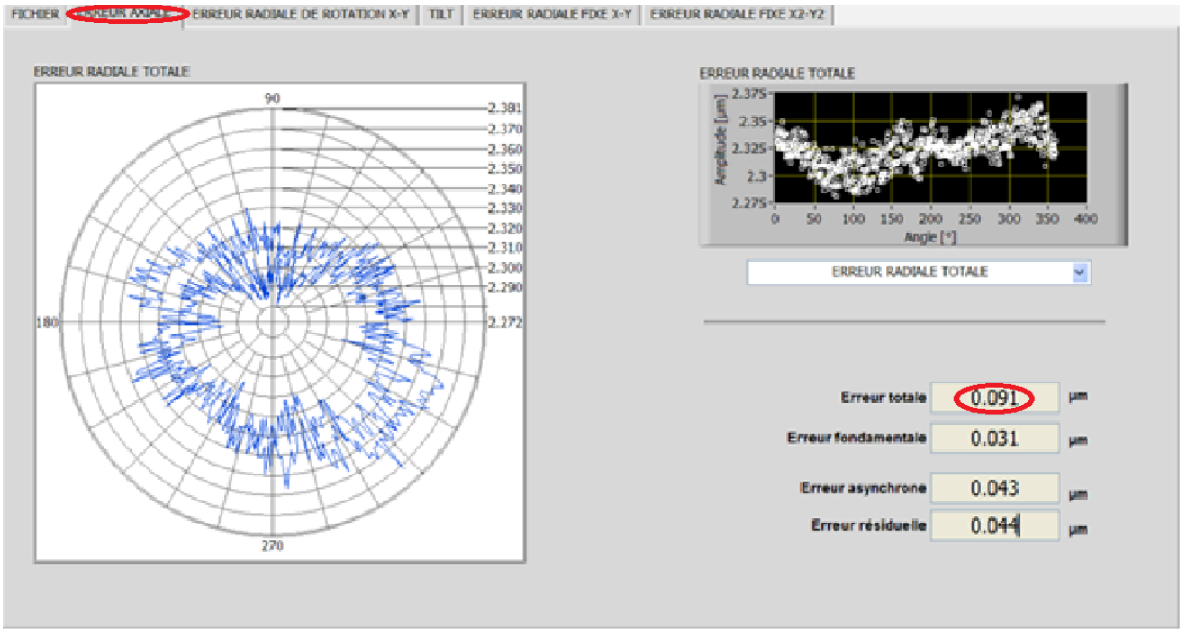
Tilt error in Y: 8.82 µm/m

Temperature recording during the above mentioned test. Time duration is 5 hours.

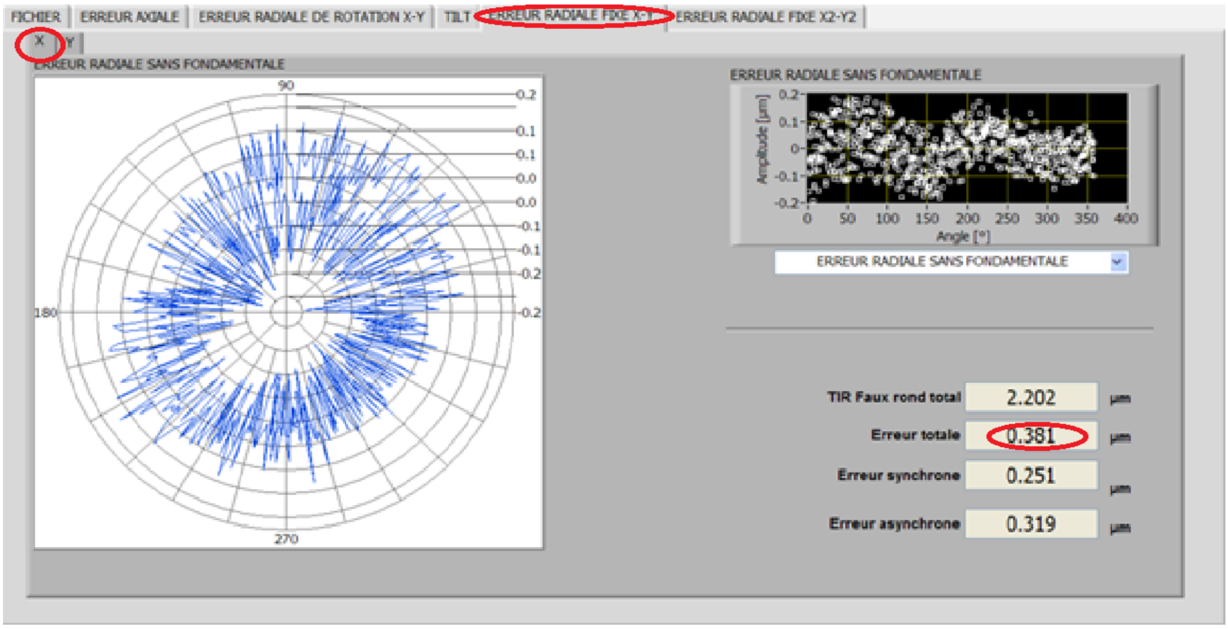


Measurements done at the PEL @ 4/2017

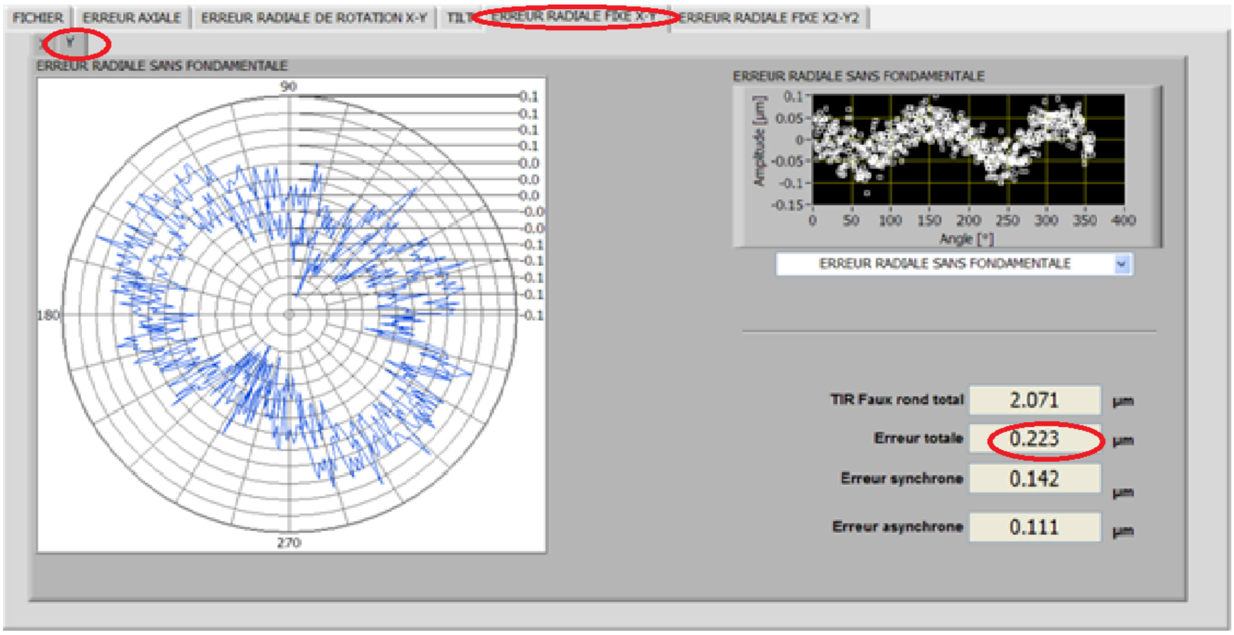
The (static) measurement was performed in 3 bidirectional cycles, from 0 to 360 deg, every 2 deg, with **only** the motorized air-bearing, no NY stage, hexapod, NAI stage and slipring.
With drift compensation.



Axial error: 91 nm

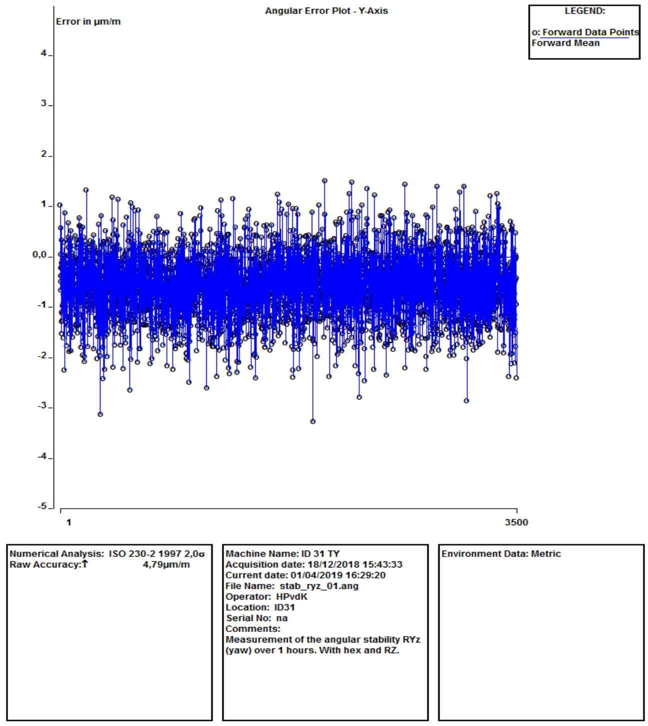


Radial error in X: 0.381 µm



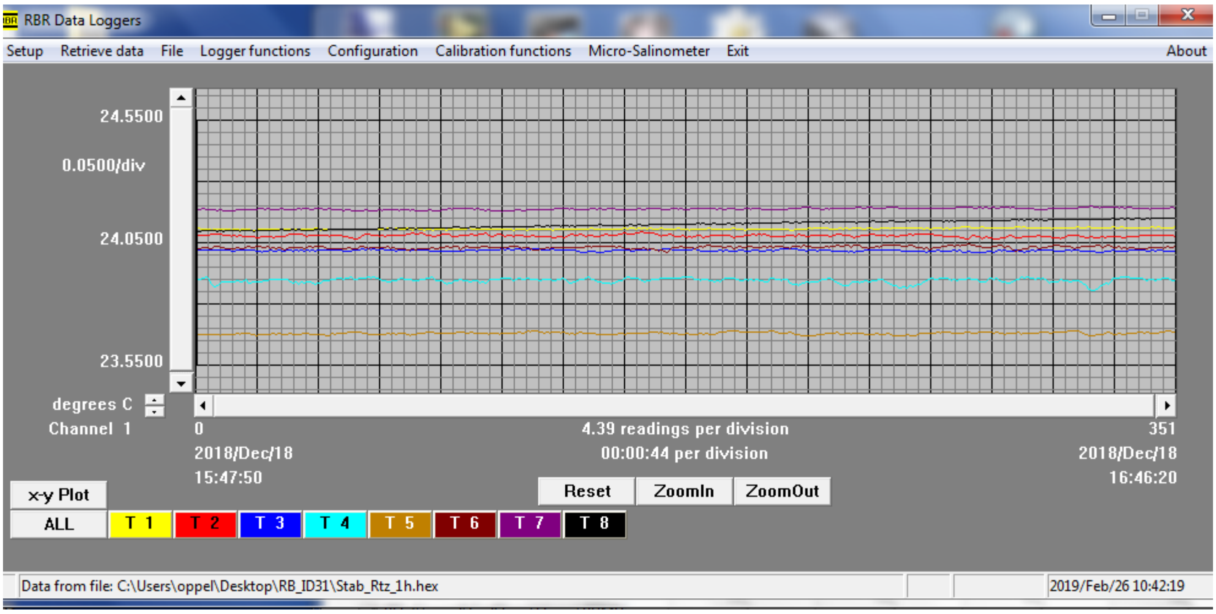
Radial error in Y: 0.223 µm

<u>RYz stability</u> measurements.

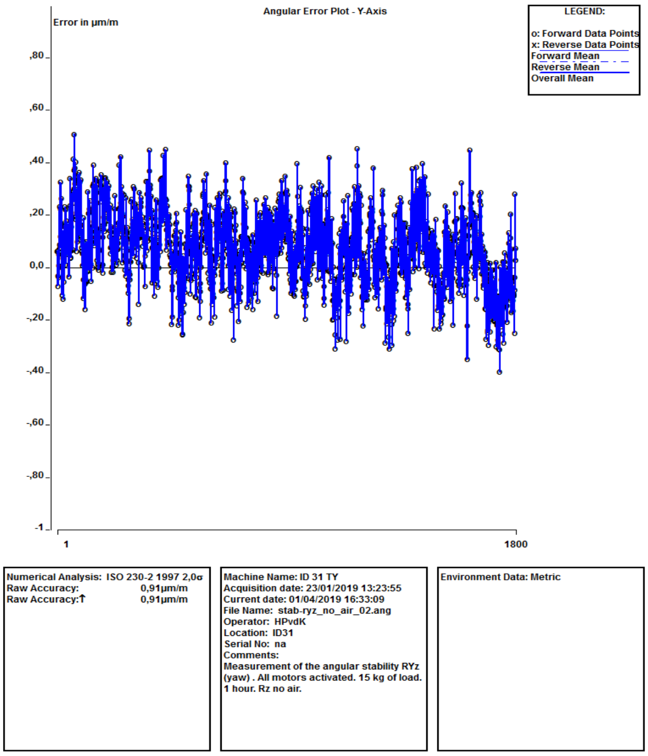


Accuracy = 4.79 µm/m over 1 hours. Both NTH and hexapod motors are switched on.

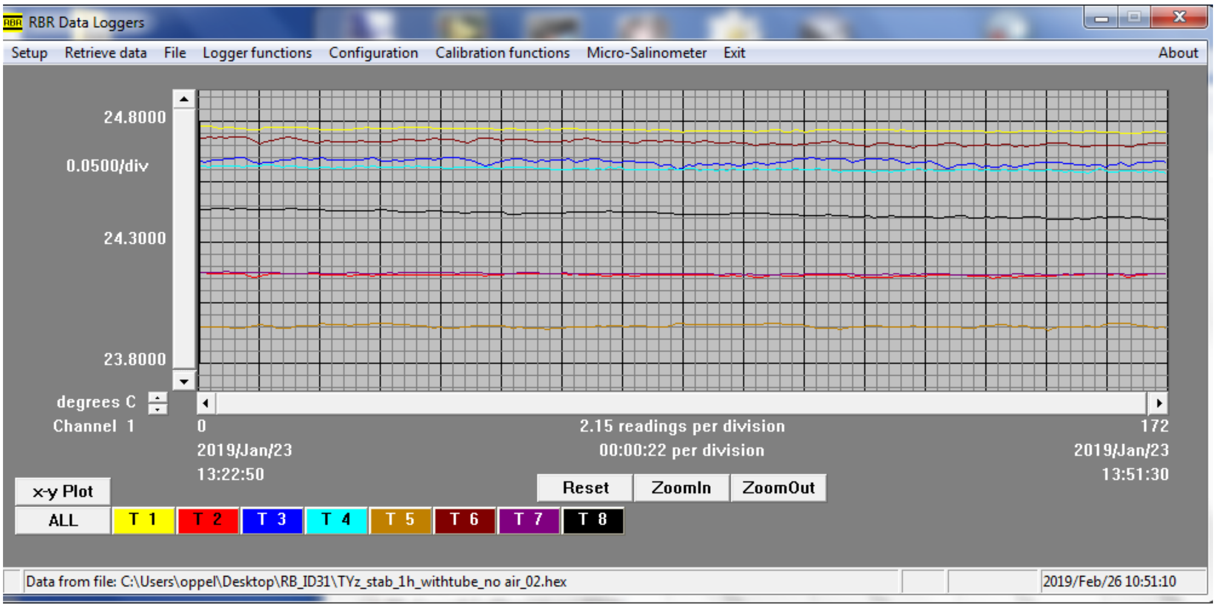
Temperature recording during the above mentioned test.

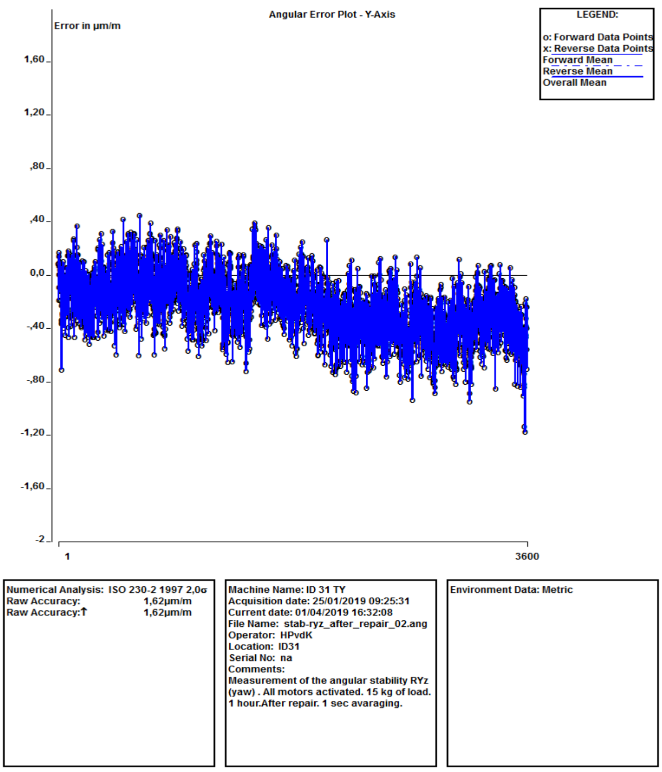


Accuracy = 0.91 µm/m over 1 hours. Hexapod motors are switched on. NTH switched off, no air.



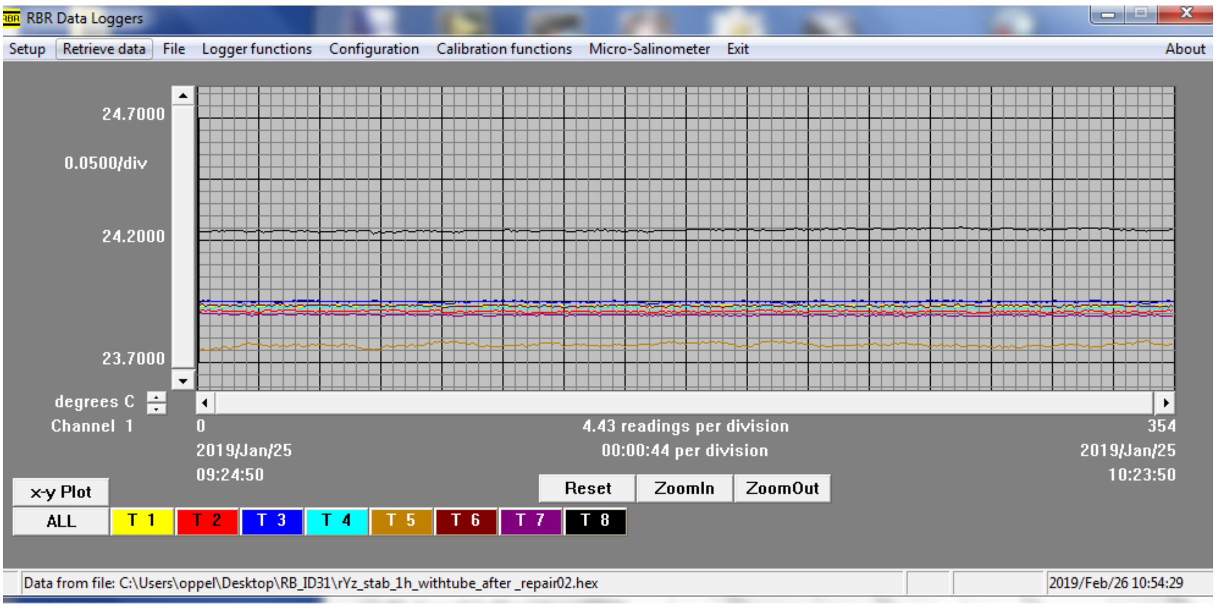
Temperature recording during the above mentioned test.





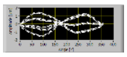
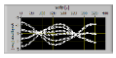
Accuracy = 1.62 µm/m over 1 hours. Both NTH and hexapod motors are switched on. After intervention of MJC.

Temperature recording during the above mentioned test.



Conclusion and remarks:

-The difference between the axial and radial errors resulting from the measurements done at ID31 and the measurements done at the PEL on 4/2017 are inexplicable. The radial error is almost multiplied by 10.

If we look at the Cartesian plots of the measurement done at ID31   , we remark the unusual shape of these graphs, they looks like if there is something preventing the spindle to rotate freely (pushing or pulling the spindle and degrading its stiffness). Could this be the slipring, slipring synchronisation or a cable issue?

-The NTH spindle position where the NY axis and the nhy axis from the hexapod are parallel ≈ +82.45 degree.

The procedure to determinate the position of the NTH spindle where the nhy axis from the hexapod and the NY axis are parallel, was not finished. At the last moment the NY stage became too instable and started to enter in resonance, each time it passed the 1.8 mm position. I was not able to finalize the measurement. The value I found was about +82.45 degree, but I can't guaranty this value. A future measurement campaign will confirm the right value.

-The RYz stability measurements shows that the NTH spindle generates quitte a lot of noise. This is manly due to the pid of the spindle, also the important distance between the encoder of the spindle and the optics at sample position will not help.
By putting a very aggressive pid, JMC could devide the noice by 3, but then other problems occurred, preventing the spindle to rotate smoothly.
Due to the poor performance of the spindle we decided that dynamic measurements had to wait till the NTH works correctly.

Results:

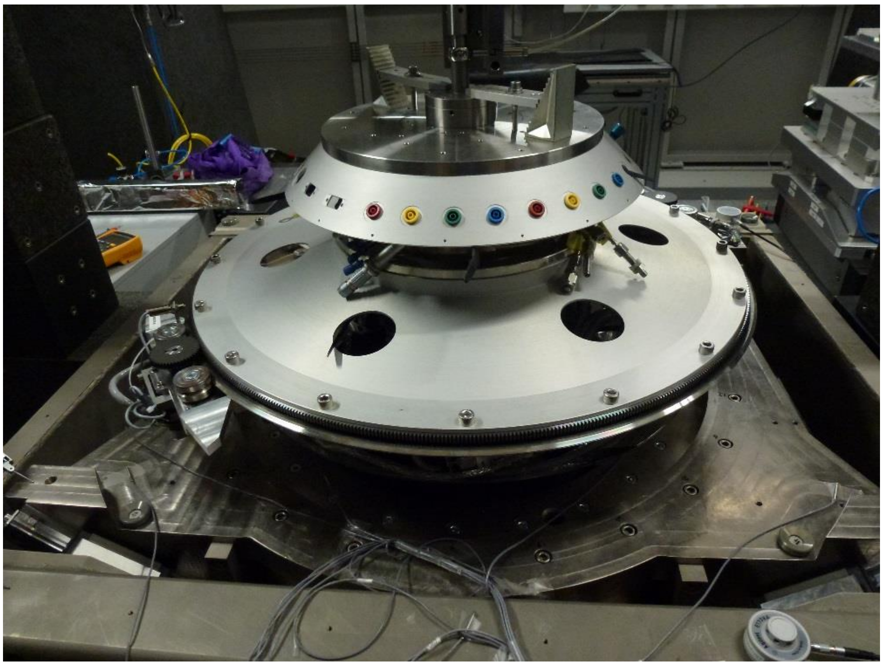
Results of the measurement campaign on the ID31 µ-station, from 18/12/2018 till 28/02/2019						
Y translation:ny	stroke = +/- 4.7 mm	Specificatio between()				
	accuracy (µm)	repeatability (µm)	repeatability↑(µm)	repeatability↓(µm)	MIM (nm)*1	MIM (nm)*2
Linear positioning TYY	2,827	1,195 (0.02)	0,688	0,588	150	50(5)
Linear deviation TYX	0,979 (0.02)	0,331	0,322	0,25		
Linear deviation TYZ	0,793 (0.01)	0,418	0,213	0,285		
	accuracy (µrad)	repeatability (µrad)	repeatability↑(µrad)	repeatability↓(µrad)		
Angular deviation RYx (pitch)	4,11	3,04	1,86	2,04		
Angular deviation RYy (roll)	9,85 (1.7)	3,73	3,31	3,53		
*Angular deviation RYz (yaw)**2	6,11	3,07	2,14	3,03		
Stability RYz (Yaw)	Over 1 hour, **with** hexapod and NTH (RZ). 4,79 µrad.					
	Over 1 hour, **NO** hexapod and **NO** NTH (no air). 0,91 µrad.					
	Over 1 hour, **with** hexapod and NTH (RZ). After intervention of JMC. 1,62 µrad.					
NAI (craddle)	stroke = +/- 3 deg					
	accuracy (µrad)	repeatability (µrad)	repeatability↑(µrad)	repeatability↓(µrad)	MIM (µrad)	
Angular position RY	57,456	20,64 (5)	6,144	7,008	1	
Hexapod (nhy axis)	stroke = +/- 10 mm					
	accuracy (µm)	repeatability (µm)	repeatability↑(µm)	repeatability↓(µm)		
Linear deviation TYX	3,024	0,933	0,414	0,46		
Linear deviation TYZ	0,887	0,716	0,626	0,276		
	accuracy (µrad)	repeatability (µrad)	repeatability↑(µrad)	repeatability↓(µrad)		
Angular deviation RYy (roll)	11,83 (1.7)	4,38	3,49	2,21		
Angular deviation RYz (yaw)	13,08 (1.7)	6,08	3,59	4,74		
NTH (RZ)						
Axial error	0,2 µm (0.01)					
Radial error	3,004 µm (0.02)					
Tilt error	9,39 µrad (1.7)					
*1 Hexapod and NTH actif.						
*2 No Hexapod and no NTH (no air).						
All measurements done with a load of 15 kg, exept the NTH axial, radial and tilt measurements.						
Specification (). Out of spec in red.						

Appendix

-Motor (pid) settings:

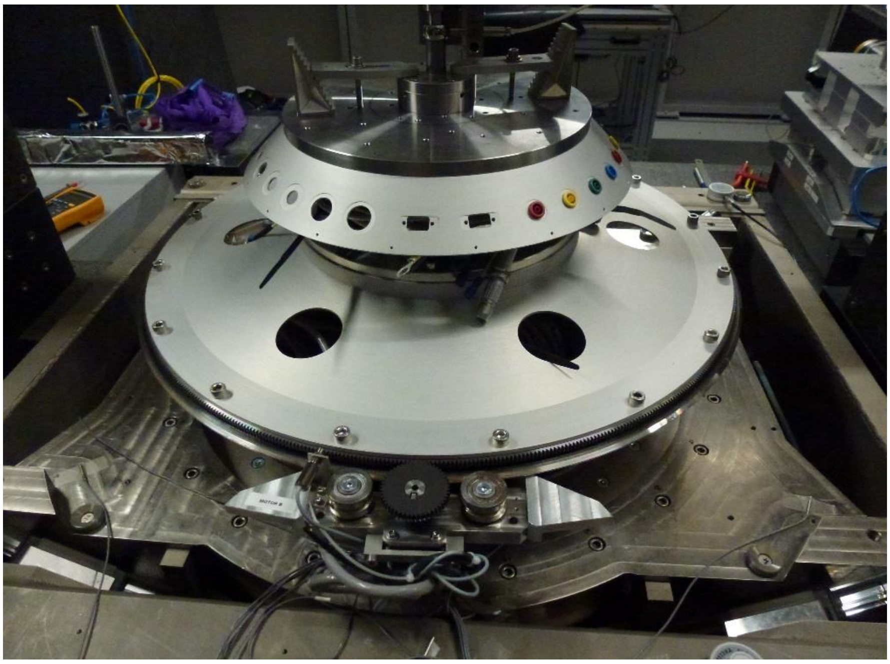
For the Motion controller configurations. We have to refer to P. got or M.J. Clement

-NTH position @ 0 and 53 deg:



NTH @ 0 deg

NTH @ 53 deg



-Specifications of the Keysight Dynamic Calibrator

Specifications

Laser Characteristics

Type: Helium-Neon with automatically tuned Zeeman-split two-frequency output

Output Power: ≥ 180 µW
(< 1 mW per Class II Laser Product)

Safety Classification:
Class II Laser Product conforming to U.S. National CDRH Regulations 21CFR 1040.10 and 1040.11.

Warm-up Time: Less than 10 minutes
(4 minutes typical)

Vacuum Wavelength: 632.991354 nm

Wavelength Accuracy: ± 0.1 ppm
(± 0.02 ppm of measured wavelength wavelength with factory calibration, Option A6J)

Wavelength Stability (typical):
short term (1 hour): ± 0.002 ppm
long term (lifetime): ± 0.02 ppm

Beam Diameter: 6 mm (0.24 in)

Beam Centerline Spacing:
11.0 mm (0.44 in) (input to output aperture)

Linear Distance, Diagonal, and Velocity Measurement Specifications

Measurement Range
Up to 40 m (130 ft) with Linear Optics;
Up to 80 m (260 ft) with Long Range Option

Linear Distance and Diagonal Measurement Accuracy

Temperature Range, °C [°F]	E1738A Air Sensor	In Vacuum[1]
0 – 40° [32° – 104°]	± 0.4 ppm	± 0.1 (± 0.02) ppm

1. † Vacuum accuracy is ± 0.02 ppm if the laser head is calibrated to MIL-STD 45662A.

Velocity Measurement Accuracy

$$\left[\frac{2\ \text{mm/s}}{\text{Velocity}} + 0.01\right] \%\ \text{of displayed value}$$

Linear Distance and Diagonal Measurement Performance

OPTICS	RESOLUTION	MAXIMUM AXIS VELOCITY 5519A	MAXIMUM AXIS VELOCITY 5519B
Linear Optics (10766A)	1 nm (0.04 µin)	± 0.7 m/s (± 28 in/s)	± 1 m/s (± 40 in/s)
Plane Mirror Optics (10706A/B)*	0.5 nm (0.02 µin)	± 0.35 m/s (± 14 in/s)	± 0.5 m/s (± 20 in/s)
High Resolution Plane Mirror Optics (10716A)*†	0.25 nm (0.01 µin)	± 0.18 m/s (± 7 in/s)	± 0.25 m/s (± 10 in/s)

* Requires the 10724A Plane Mirror Reflector. Since alignment of these optics is much more sensitive than for linear optics, linear optics are recommended for general use.
† Aperture distance of 10716A is 12.7 mm, whereas 5519A is 11 mm.

Angular Measurement Specifications

Angle Measurement Accuracy
± 0.2% of displayed value
± 0.05 arc-seconds per meter of distance traveled by the linearly moving optic.

Maximum Distance Between Laser Head and Reflector
Up to 15 m (50 ft)

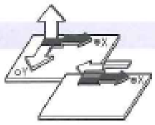
Angle Measurement Resolution
0.005 arc-seconds

Measurement Range
± 10° (rotated about base of optic)
± 20° (rotated about center of optic)

Measurement Type
Pitch and yaw

Specifications

Straightness and Parallelism Measurement Specifications



Straightness Measurement Accuracy[1]
Overall Accuracy = Optical Reference Accuracy
+ Measurement Accuracy

1. This is analogous to the traditional straightedge and indicator method of measuring straightness, where Optical Reference Accuracy corresponds to the straightedge accuracy, and Measurement Accuracy corresponds to the indicator accuracy.

Optical Reference Accuracy
Optical reference inaccuracy can be eliminated by using straightedge (mirror) reversal techniques.

Short Range Optics:
Metric units mode: ± 0.15 $(M)^2$ µm
English units mode: ± 0.5 $(F)^2$ µin

Long Range Optics:
Metric units mode: ±0.015 $(M)^2$ µm
English units mode: ±0.05 $(F)^2$ µin
where:
M = distance of travel of the moving optic in meters
F = distance of travel of the moving optic in feet

Straightness Measurement Range (Orthogonal to Axial Travel)
± 1.5 mm (0.060 in)

Axial Separation (Travel)
(distance between the interferometer and the reflector, typical, with proper alignment, 15 - 25 °C):
Short Range Optics: 0.1 – 3m (4 – 120 in)
Long Range Optics: 1 – 30m (3 – 100 ft)

Measurement Accuracy[2]

Short Range Optics

Temperature Range	Displayed Value 0 - 10 µm (0 - 400 µin)	Displayed Value 10 - 1,500 µm (400 - 60,000 µin)
0 – 40 °C	± 3.5%	± 1% ± 0.25 µm (10 µin)

Long Range Optics:

Temperature Range	Displayed Value 0 - 100 µm (0 - 4000 µin)	Displayed Value 100 - 1,500 µm (4000 - 60,000 µin)
0 – 40 °C	± 5%	± 2.5% ± 2.5 µm (100 µin)

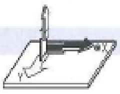
2. Measurement Accuracy specifications are not applicable to Timebase Straightness Measurements.

Straightness[3] **Measurement Resolution**

Short Range	0.01 µm (0.4 µin)
Long Range	0.1 µm (4 µin)

3. Straightness Measurement Resolution specifications are not applicable to Timebase Straightness Measurements.

Squareness Measurement Accuracy



Short Range Optics:
Metric Units Mode:
± (1.0 + 0.1 M) arc-seconds ± 0.01 θ
English Unit Mode:
± (1.0 + 0.03 F) arc-seconds ± 0.01 θ

Long Range Optics:
Metric Units Mode:
± (1.0 + 0.01 M) arc-seconds ± 0.025 θ
English Units Mode:
± (1.0 + 0.003 F) arc-seconds ± 0.025 θ

where:
θ = calculated out-of-square angle in arc-seconds
M = distance of travel of the moving optic in meters
F = distance of travel of the moving optic in feet

Specifications

Environmental Compensation[1] and A-quad-B Input

1. Compensation values may be manually entered by user via keyboard.

E1738A Air Sensor[2]

2. Refer to the E1738A Air Sensor Data Sheet, 5989-8456 for more specifications.

Wavelength of Light (WOL) in Air Compensation
The E1738A Air Sensor provides for the automatic display of pressure, temperature, relative humidity, and computed WOL.

Operating Range

Temperature:	0 – 40 °C (32 – 104 °F)
Relative Humidity:	10% – 90%
Absolute Pressure:	70 – 110 kPa (~10 – 16 psia)
Heat Dissipation:	2 mW typical
Time Constant:	5 min typical (temperature)

Accuracy[4]

Temperature:	± 0.1°C (± 0.2°F)
Relative Humidity:	± 5%
Absolute Pressure:	± 50 Pa (± 0.008 psi)
Heat Dissipation:	1 mW typical Time

4. 12 month calibration interval

E1737A Material Temperature Sensor[3]

3. Refer to the E1737A Material Sensor Data Sheet, 5989-8455 for more specifications.

Material Temperature Compensation
The E1737A Material Temperature Sensor provides for the automatic display of the temperature of the device under test. One to three sensors may be used.

Operating Range

Temperature:	0 – 40°C (32 – 104°F)
Material Expansion Coefficient:	
range:	–100.0 to +100.0 ppm per °C or °F, manually entered.
Constant:	60s typical

Accuracy[4]

Temperature:	± 0.1 °C (± 0.2 °F)

4. 12 month calibration interval

Shared Sensor Characteristics

Maximum Compensation Update Rate
per 15s (combined WOL and material temperature compensation)

Cable Lengths:
E1739A–5m (16 ft)
E1739B–10m (33 ft)
E1739C–15m (49 ft)
E1739D–25m (82 ft)

A-quad-B Input

Differential Input Threshold
± 0.5V minimum, ± 7.0V maximum

Differential Input Impedance
100W

Input Rate
> 2 ns edge-to-edge, or < 10 MHz information rate
Example: at maximum speed, A and B both must be < 2.5 MHz.

-Specification of the capacitive probes c7-c from Lion.

LION PRECISION

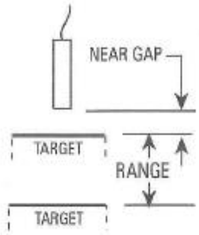
CALIBRATION REPORT

Calibration Report for ESRF

Order ID: 17090
Customer ID: 1066
Calibration Date: 12/7/2016
Calibration Due Date: 12/7/2017
Calibration Number: 163420818130
Calibration Type=Single-Ended

System Components

Driver Model:	CPL290
Driver Serial:	060259-01
Probe Model:	C7-C
Probe Serial:	060284-01
Channel:	1
Sensitivity:	LO



Calibration Parameters

Near Gap:	125 µm
Range:	250 µm
Target:	100 - flat target
Output:	10 to -10 VDC
Sensitivity:	80.000 mV/ µm
Bandwidth:	15000Hz

See definition of terms on the back of this sheet

Peak to Peak Resolution:	38.69 nm	(Spec: 100 nm)
RMS Resolution:	4.47 nm	(Spec: 10 nm)
Bandwidth: (-3dB):	15284 Hz	(Spec: +30% / -10%)

Linearity Error:	0.05%	(Spec: ±0.3%)
Error Band:	0.05%	(Spec: ±0.3%)

★ denotes out of spec condition

Distance to Target µm	Distance to Near Gap µm	Output Volts	Output Converted µm	Error µm
125.000	0.000	10.002	-0.029	-0.029
140.625	15.624	8.759	15.519	-0.106
156.250	31.250	7.505	31.182	-0.068
171.875	46.875	6.252	46.845	-0.030
187.500	62.499	5.001	62.482	-0.017
203.125	78.125	3.751	78.117	-0.008
218.750	93.750	2.501	93.742	-0.008
234.375	109.375	1.250	109.374	-0.001
250.000	124.999	0.000	125.000	0.001
265.625	140.624	-1.250	140.629	0.005
281.250	156.250	-2.502	156.270	0.020
296.875	171.874	-3.753	171.907	0.032
312.500	187.500	-5.005	187.558	0.058
328.125	203.125	-6.257	203.212	0.087
343.750	218.750	-7.509	218.864	0.114
359.375	234.375	-8.759	234.485	0.110
374.999	249.999	-9.996	249.955	-0.044

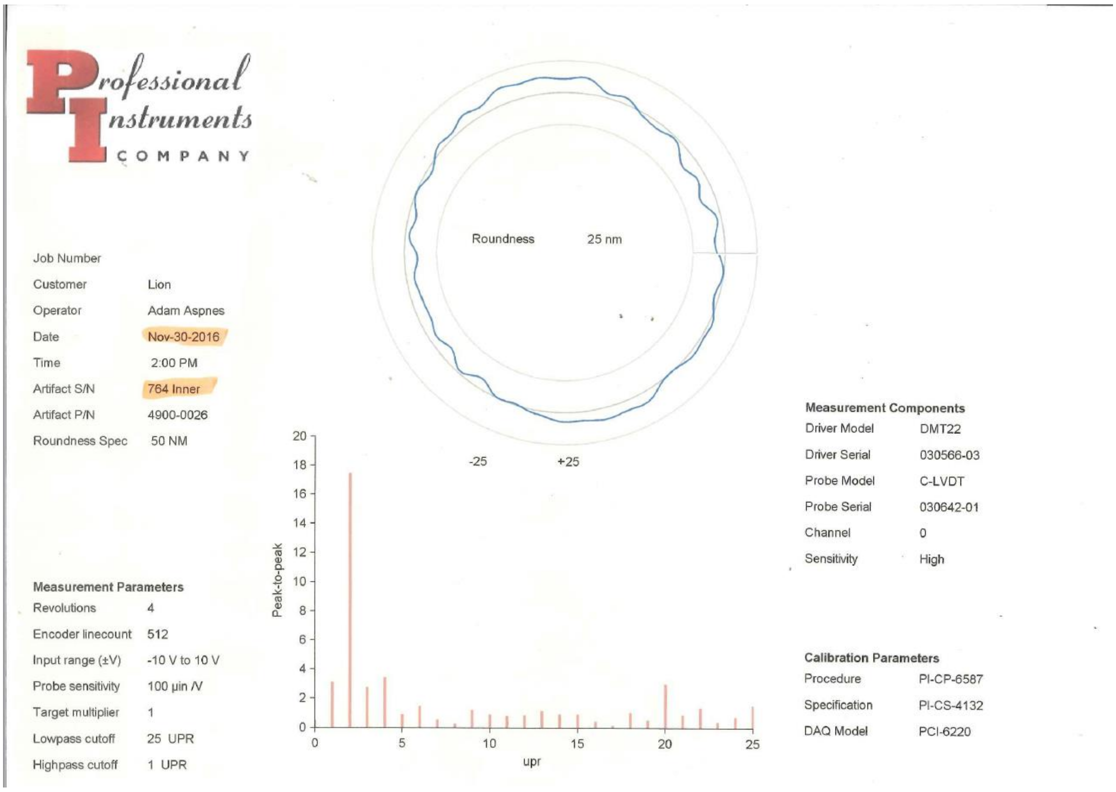
Uncertainty in Distance to Target 12.7 nm plus 12.9 nm/mm of range
Environmental Conditions: Temperature: 21.9 °C Humidity: 24 %RH
Mechanical Calibrator: ID# 130 **Signal Acquisition:** ID# 192
Calibration Procedure ID: T016-0340 **Calibration Spec ID:** 1207

This certificate conforms to ISO 10012-2003, Section 7.1.4
All Lion Precision calibrations are NIST traceable.
Detailed traceability information available upon request.

Standard Calibration Report rev06
Lion Precision 7166 4th Street North Oakdale, MN 55128 USA
Phone: (651) 484-6544 • Fax: (651) 484-6824 • support@lionprecision.com • www.lionprecision.com

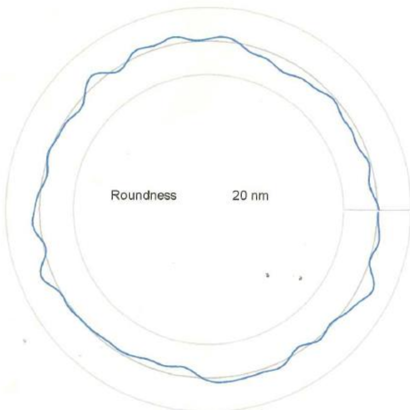
Technician: Mao Lee

-Calibration chart of the 1 inch dual master ball from PIC, no.764.



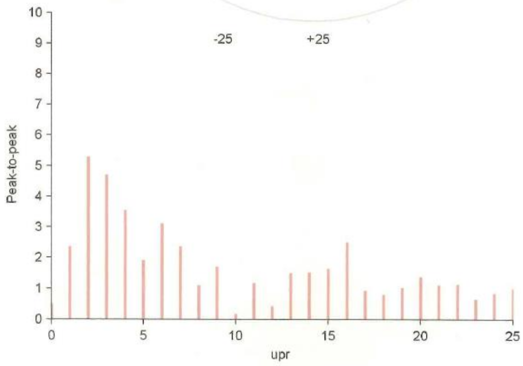
Professional Instruments COMPANY

Job Number	
Customer	Lion
Operator	Adam Aspnes
Date	Nov-30-2016
Time	11:00 AM
Artifact S/N	764 Outer
Artifact P/N	4900-0023
Roundness Spec	50 NM



Measurement Parameters

Revolutions	4
Encoder linecount	512
Input range (±V)	-10 V to 10 V
Probe sensitivity	100 µin /V
Target multiplier	1
Lowpass cutoff	25 UPR
Highpass cutoff	1 UPR



Measurement Components

Driver Model	DMT22
Driver Serial	030566-03
Probe Model	C-LVDT
Probe Serial	030642-01
Channel	0
Sensitivity	High

Calibration Parameters

Procedure	PI-CP-6587
Specification	PI-CS-4132
DAQ Model	PCI-6220

-Specifications of the RBR XR-420 temperature data logger.

RBR

Your Path Through the Sea

MARINE | FRESHWATER | CRYOSPHERIC

Submersible Multichannel Data Logger — Model XR-420/620

XR-420/620 Series
Multichannel Loggers

Features:

- Highest accuracy
- Large Memory (up to 2GB)
- Up to 3 years on one battery set
- High-speed Data Download
- Custom Configuration

The XR-420 and XR-620 are small, autonomous 24-bit profiling loggers with 1Hz (6Hz for the XR-620) sampling and capacity to support up to six sensors in the standard enclosure and up to 11 in custom configurations. These include Conductivity, Temperature, Depth, pH, ORP, Dissolved Oxygen, Fluorescence, Turbidity, Transmittance, PAR, etc. in any combination. All calibration constants are stored in the logger and recalibration is possible by the end-user under suitable conditions.

Conductivity, Temperature and Depth are measured using RBR sensors calibrated to NIST traceable standards. Please see the other side of this sheet for a listing of some of the third party sensors available for the XR-Series logger platform.

Real time clock accuracy is ±32 seconds/year. 8MB of nonvolatile flash provides sufficient memory for 2,400,000 readings which can be logged using one set of high-powered 3V lithium cell batteries. A 2GB memory upgrade is available.

Software

The XR-420 and XR-620 use fully integrated RBR Windows® compatible software. The XR-620 contains profiling software, and includes a programmable "wet-switch" that may be assigned to any channel.

Technical

General

Internal Power:	QTY 4, 3V CR123A cells
Communications:	RS-232/485 cable, telemetry, USB
Download Speed:	~115,000 samples/minute
Clock Accuracy:	±32 seconds/year
Size:	310mm x 64mm diameter
Memory:	8MByte Flash (2,400,000 samples) 2GByte option
Body Weight:	1.2kg in air, 389g in water (Delrin®) 2.5kg in air, 1.6kg in water (titanium)
Calibration:	NIST traceable standards

See the Loggers for CT and CTD data sheet for full specifications.

Temperature

Range:	-5°C to 35°C
Accuracy:	±0.002°C
Resolution:	<0.00005°C
Time Constant:	~3 sec (standard); option ~0.1 sec
Drift:	~0.002°C/year

Depth

Range:	10/20/50/100/200/500/740/1000/2000/4000/6000m (dBar)
Accuracy:	±0.05% full scale
Resolution:	<0.001% full scale
Time Constant:	<10 msec
Drift:	~0.1%/year

Conductivity

Range:	0-2mS/cm (freshwater) or 0-85mS/cm (marine)
Accuracy:	±0.003 mS/cm at 35psu 15°
Drift:	~1 µS/cm/month
Resolution:	~0.01µS/cm (freshwater) and ~1µS/cm (marine)
Time Constant:	Depends on cast rate. Cell length is ~60mm

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10/09

<u>All the obtained measurement results can be consulted at the PEL.</u>