Magnetic performance and future upgrades of the new ALBA magnetic Hall probe measurements bench for closed structures

J. Campmany, J. Marcos,

L. Ribó, V. Massana, L. Garcia

Outline

1. Challenge to face out
2. The concept and the design of new bench
3. Fabrication
4. Mechanical performance
5. Magnetic performance
6. Lessons learned
7. Future upgrades

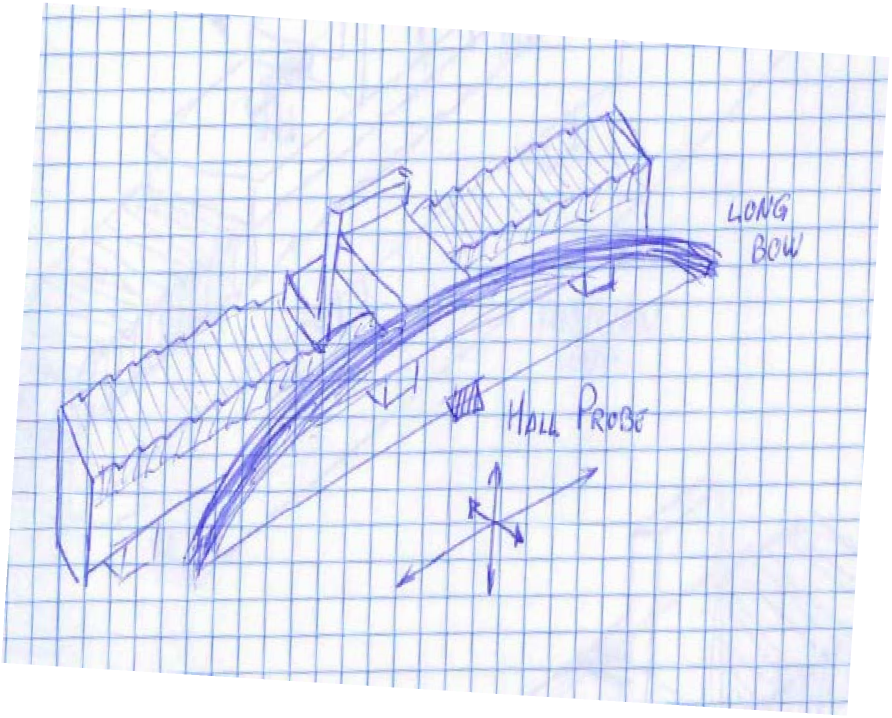
The challenge

- MORE SMALL SPACES TO EVALUATE
- MORE ACCURATE AND 3D
- MORE UNACCESSIBLE
- MORE ENVIRONMENTAL CONDITIONS

- Measurement of closed structures: gaps ~4 to 25 mm
- High accuracy in positioning (~µm) and magnetic field (below 100 ppm)
- 3D field mapping, strokes of few cm in transversal, few m in longitudinal
- Measurements in vacuum (medium vacuum, ~10^{-1} Pa)
- Measurements in cold (down to ~10 K)

The concept and design

Concept: «longbow»



Goals:

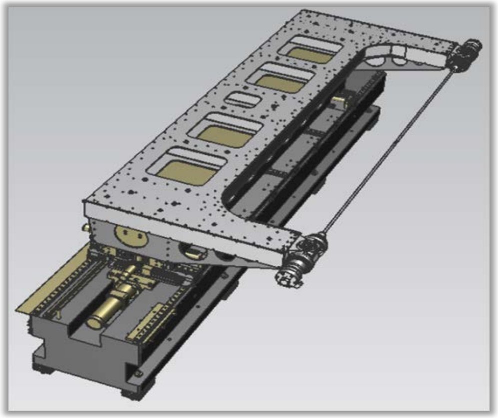
a) Decouple magnetic structure to be measured, from movement. In this way, positioning accuracies rely on external structures, that can be as big as needed.

b) Design a repetitive methodology to be sure that the Hall probe position (spatial and angular) is well known within required accuracy

c) Develop and test a 3D Hall probe able to be introduced in narrow gaps

d) Allow 3D fieldmapping. This is needed to introduce magnetic measurements in tracking codes.

DESIGN REQUIREMENTS



Ranges

X : ±125 mm
Y : ±50 mm
Z : 1200 mm
Chamber allowance ("stay clear" area) = 600 mm

MAGNETIC REQUIREMENTS

Maximum error

Field accuracy : $\pm 10^{-4}$ T

Position repetitivity: ±25 µm

Angular error: $\pm 10^{-4}$ rad

Speed

Longitudinal speed ~15 mm/s

MECHANICAL REQUIREMENTS

Repeatability

X, Y, Z ≤ 0,03 mm

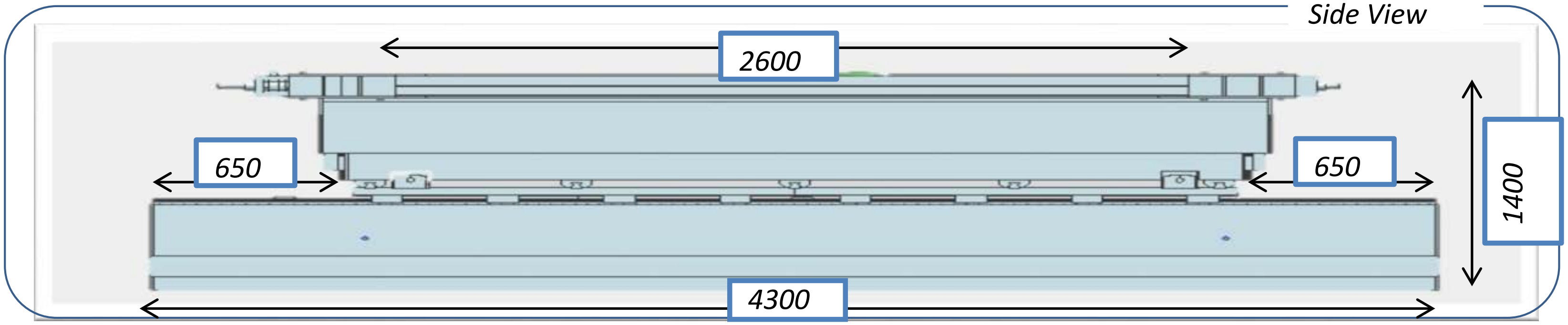
Longitudinal POSITIONING ERROR

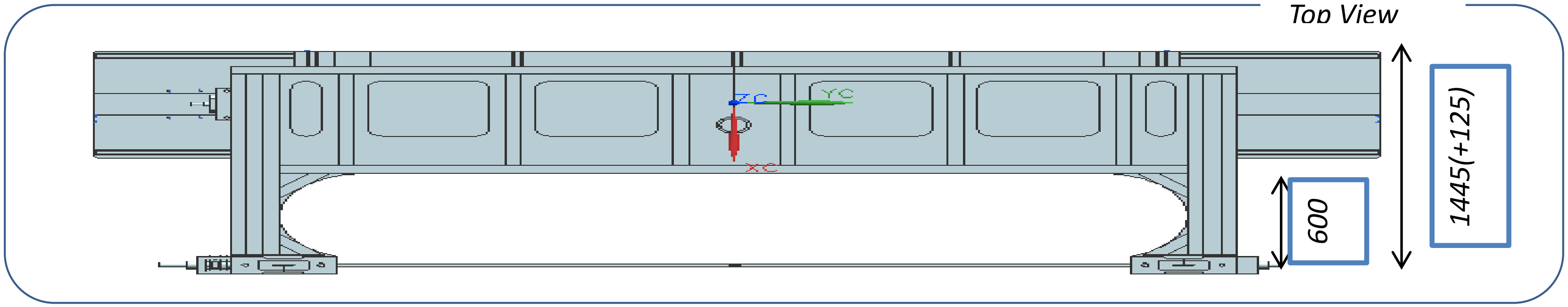
dX, dY, dZ < 0,05 mm

Angular POSITIONING ERROR

Roll dα, Pitch dβ < 0,05 mrad
Yaw dφ < 0,1 mrad

Bench overview





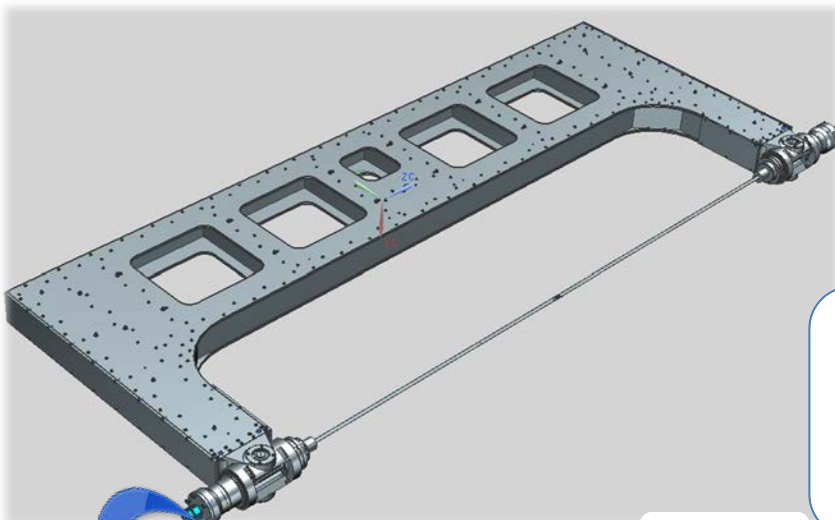
Critical points

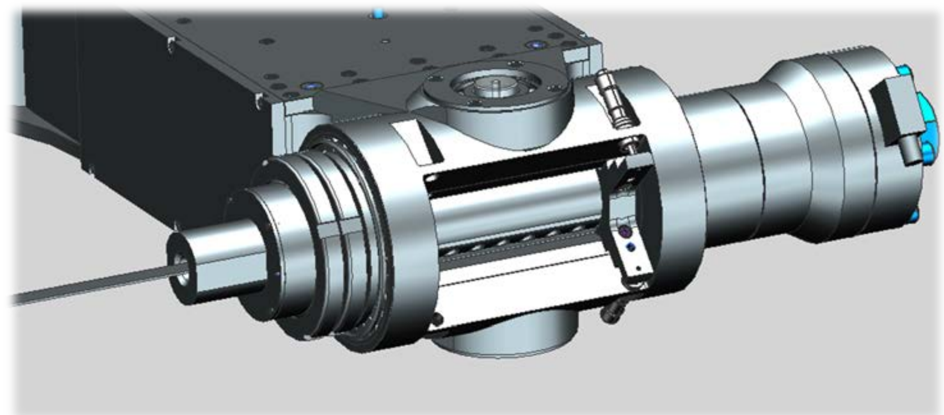
- Positioning errors (angular and spatial)
- Vibrations (eigen-values of string structure)
- Repetitivity of the assembly (attach and dettach)

Arc structure

Arc structure

- Aluminium profile structure
- Two tensioning blocks one with stretching gauge
- Mass arround 400 Kg





Strip dimensioning

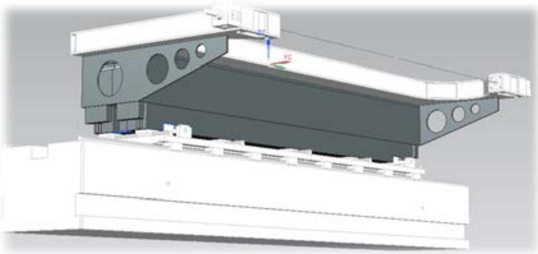
- Area 16x1,6mm^2
- Vibrating length **2600 mm**
- d = 1600 Kg/m^3
- Tensioning force **0.5 TN**

Results

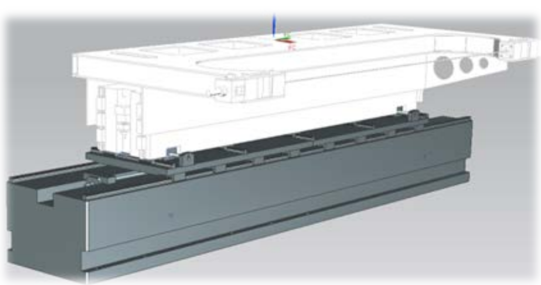
- Stress = 223 Mpa
- Security factor = 13
- f_0 **= 71 Hz**
- Elongation ~ 4 mm

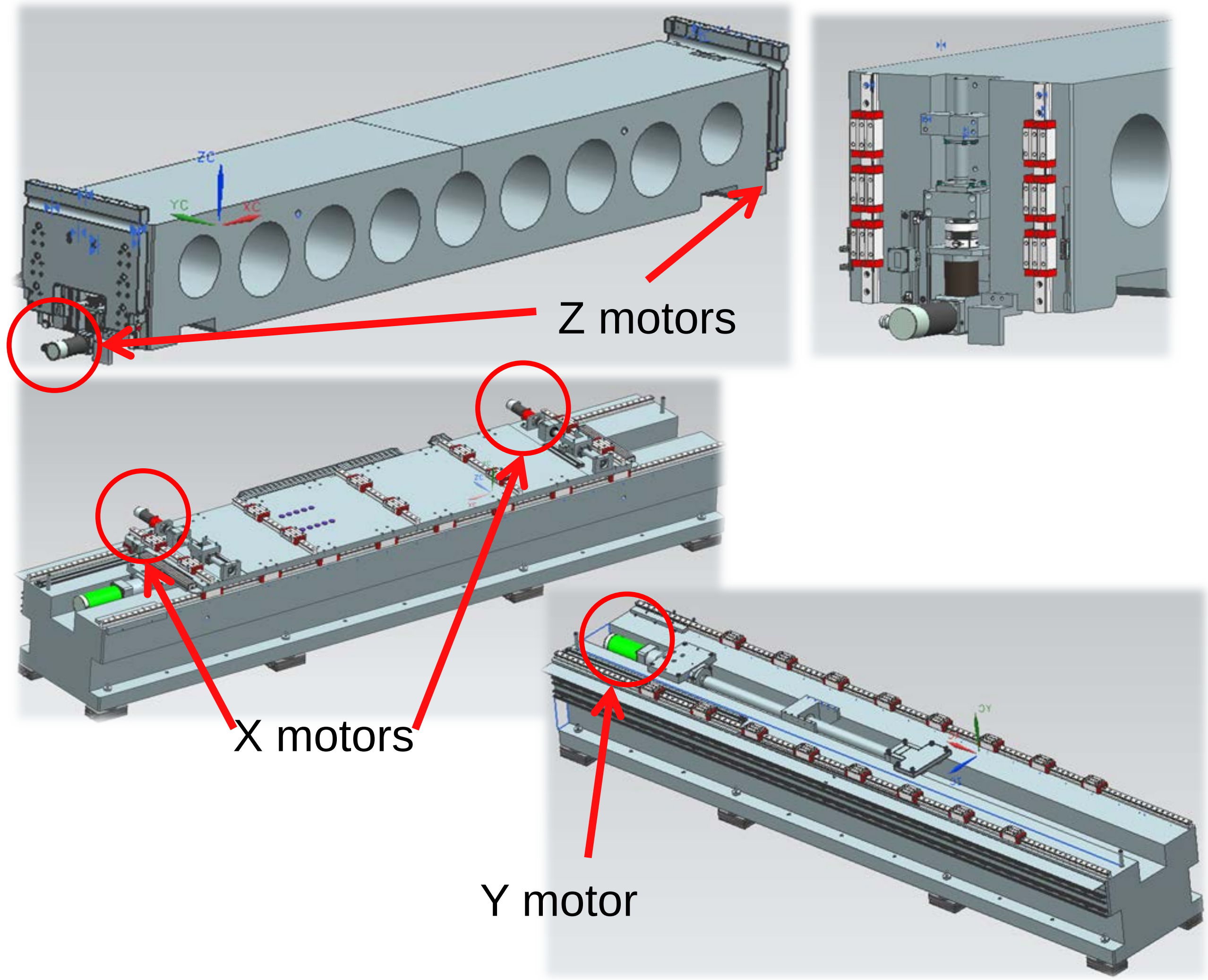
Stages

Z stage



XY stage





Points to remark

a) Belt is made on carbon-fiber and stretched to 500 kg

b) Motion driven by step-motors.

c) Motion controller is ESRF's ICEPAP

d) X and Z motors are linked at low-level (electronically) and moved as one (special ICEPAP feature)

e) Granite basis is dimensioned to guarantee that irregularities on lineal guides does not induce angular errors in the belt higher than specified (±25 µrad)

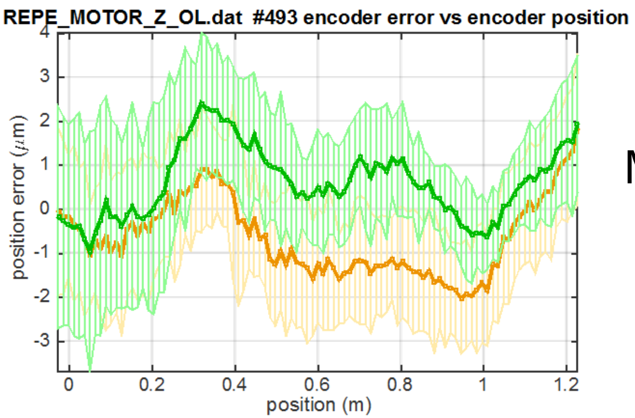
f) Motion controller allows both point-to-point and on-the-fly scans. Maximum velocity 13 mm/s

g) Motion controller triggers data acquisition

Magnitudes on top of Hall probe	Values
X stroke	0.233 m
Y stroke	0.092 m
Z stroke	1.282 m
On-the-fly velocity	$13 \cdot 10^{-3}$ m/s

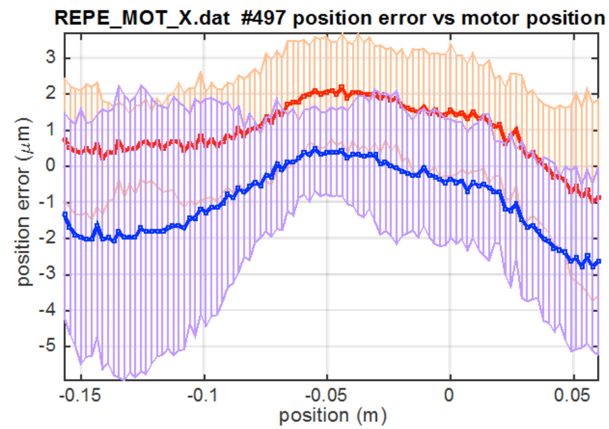
Mechanical performance

Positioning



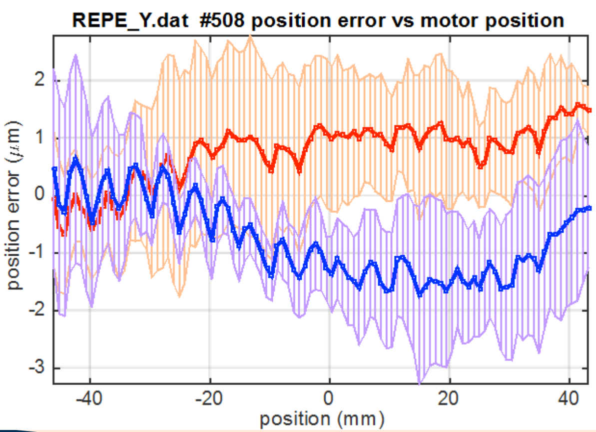
Maximum error: ±4 µm

Y positioning (longitudinal)



X positioning (horizontal)

Maximum error: ±5 µm

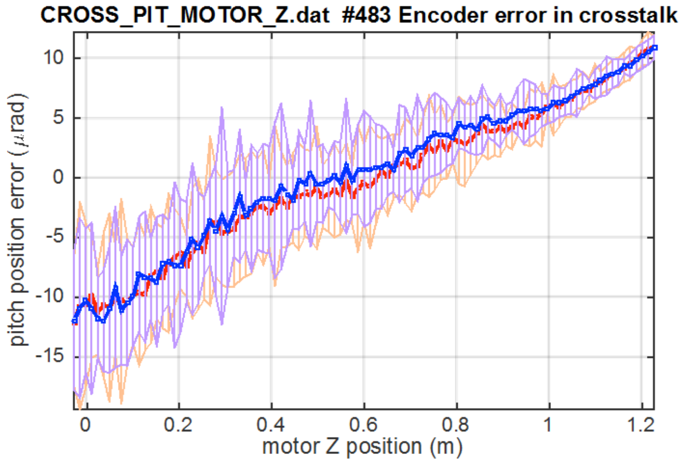


Maximum error: ±3 µm

Z positioning (vertical)

Mechanical performance

Angle

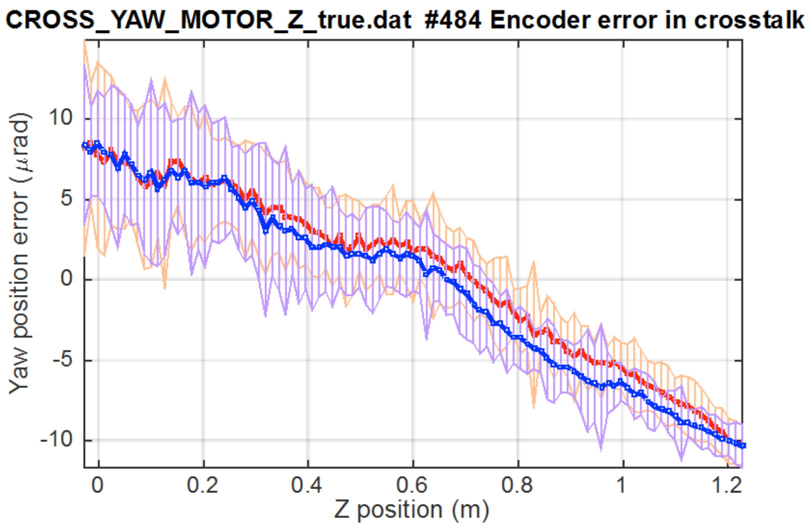


y-motion guidance error - pitch

Maximum error: ±10 µm ±15 µrad

z-motion guidance error - yaw

Maximum error: ±12 µm ±15 µrad

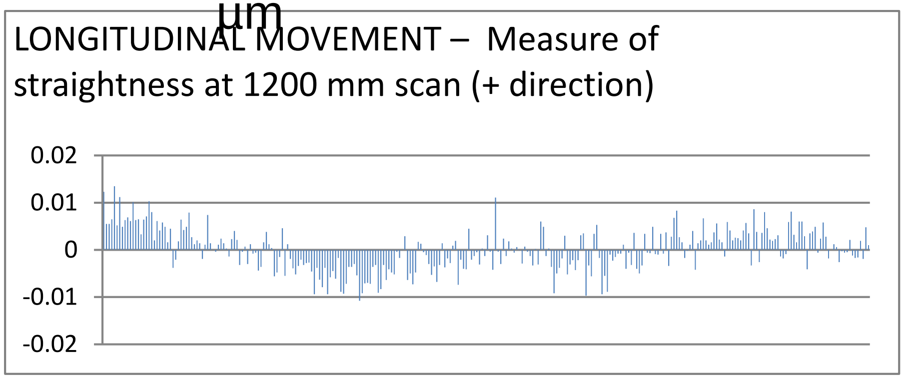


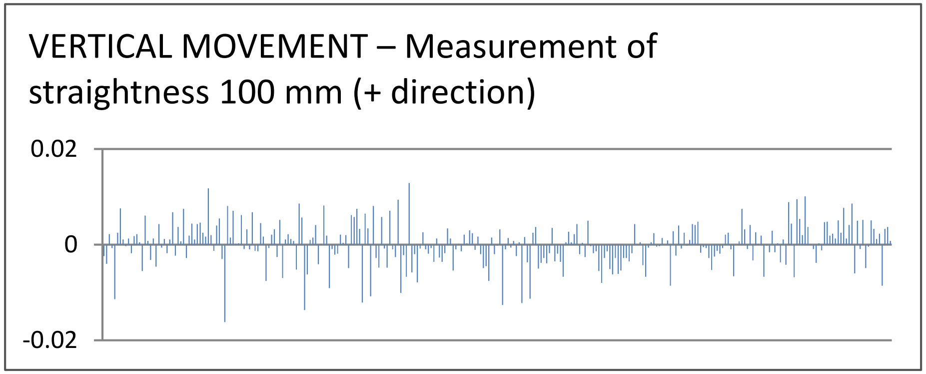
Mechanical performance

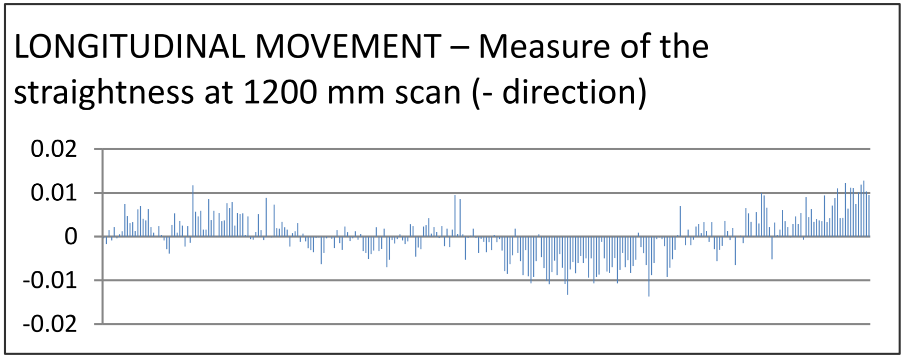
Straighness & roll angle

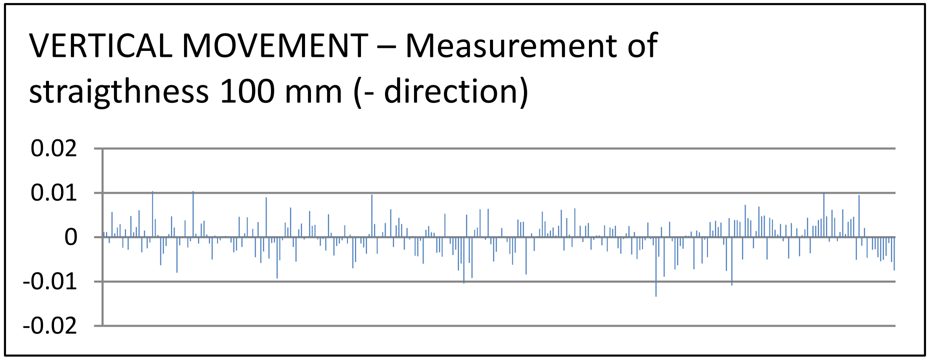
Maximum error: ±12 µm

Maximum error: ±12 µm









Roll angle error: ±3.5 µrad

Specifications

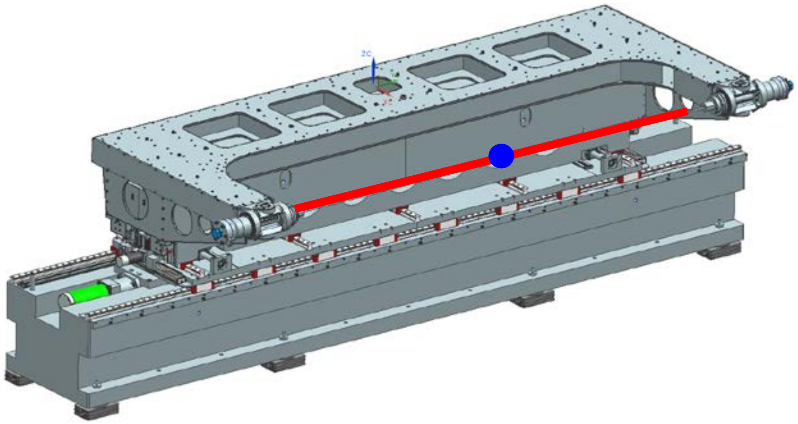
Magnitudes on top of Hall probe	Values
X stroke	0.2 m
Y stroke	0.1 m
Z stroke	1.2 m
X positioning tolerance	$\pm 25 \cdot 10^{-6}$ m
Y positioning tolerance	$\pm 25 \cdot 10^{-6}$ m
Z positioning tolerance	$\pm 10 \cdot 10^{-6}$ m
Z positioning resolution	$10 \cdot 10^{-6}$ m
Pitch angle tolerance	$\pm 50 \cdot 10^{-6}$ rad
Yaw angle tolerance	$\pm 100 \cdot 10^{-6}$ rad
Roll angle tolerance	$\pm 50 \cdot 10^{-6}$ rad
Eigenfrequency (Z direction)	> 50 Hz
On-the-fly velocity	$\sim 15 \cdot 10^{-3}$ m/s

Performances

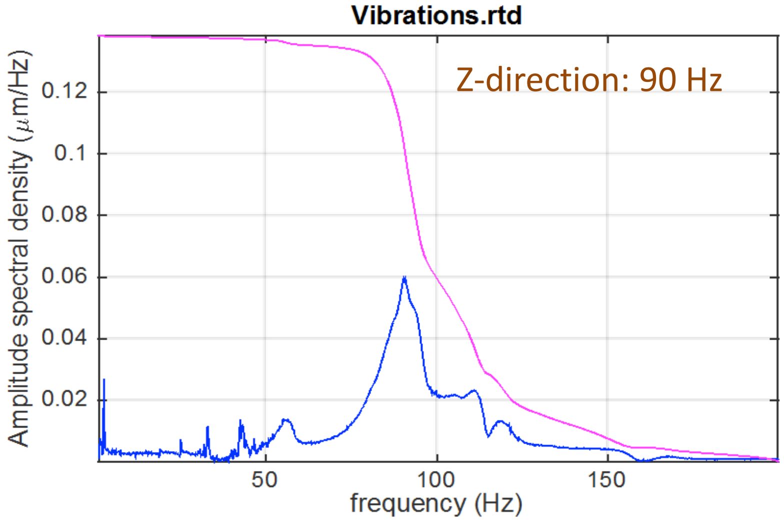
Magnitudes on top of Hall probe	Values
X stroke	0.233 m
Y stroke	0.092 m
Z stroke	1.282 m
X positioning error (wrt encoder)	$7 \cdot 10^{-6}$ m
Y positioning error (wrt encoder)	$5.41 \cdot 10^{-6}$ m
Z positioning error (wrt encoder)	$10 \cdot 10^{-6}$ m
Z positioning resolution	$10 \cdot 10^{-6}$ m
Pitch angle error	$25 \cdot 10^{-6}$ rad
Yaw angle error	$20 \cdot 10^{-6}$ rad
Roll angle error	$3.5 \cdot 10^{-6}$ rad
Straightness error	$7.8 \cdot 10^{-6}$ m
Flatness error	$6.7 \cdot 10^{-6}$ m
Eigenfrequency in Z direction	90 Hz
Amplitudes in Z direction	$10 \cdot 10^{-9}$ m
Eigenfrequency in Y direction	43.5 Hz
Amplitudes in Y direction	$150 \cdot 10^{-9}$ m
Eigenfrequency for torsion (roll)	23.6 Hz
Amplitudes of torsion	$3 \cdot 10^{-6}$ rad
On-the-fly velocity	$13 \cdot 10^{-3}$ m/s

Uncertainty summary

Parameter	Spec	Measured	Remark
Z-position	50 µm	10 µm	*On-the-fly encoder following error at 2Hz*
X-position	50 µm	7 µm	*Limited by Guidance error*
Y-position	50 µm	5.41 µm	*Limited by Guidance error*
Roll	50 µrad	3.5 µrad	*Guidance error /deformations*
Pitch	50 µrad	25 µrad	*Guidance error /deformations*
Yaw	100 µrad	20 µrad	*Guidance error /deformations*



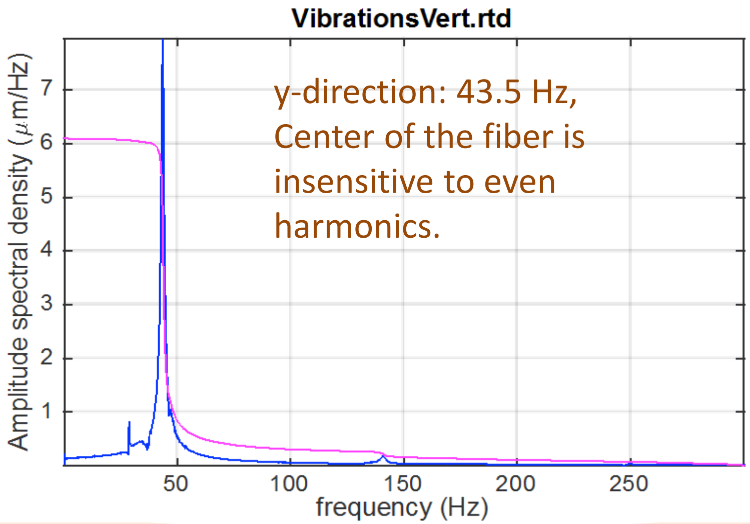
Vibrations: Resonances

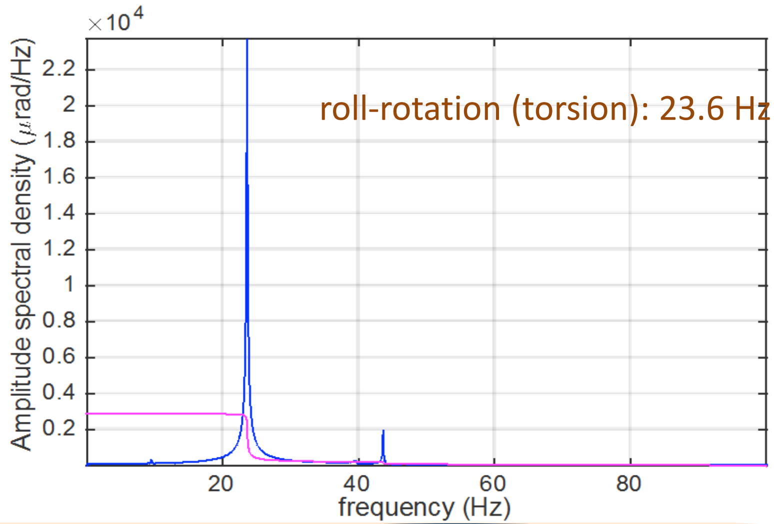


Impulse response function provides a peaks at the resonance frequencies

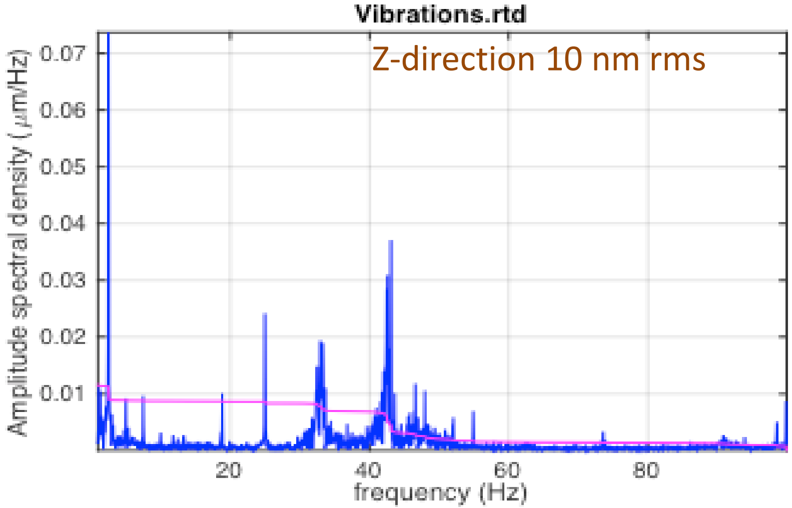
Measured at a string tension of 5000 N

Measured with the 10 g target of the IF to minimize influence of its weight



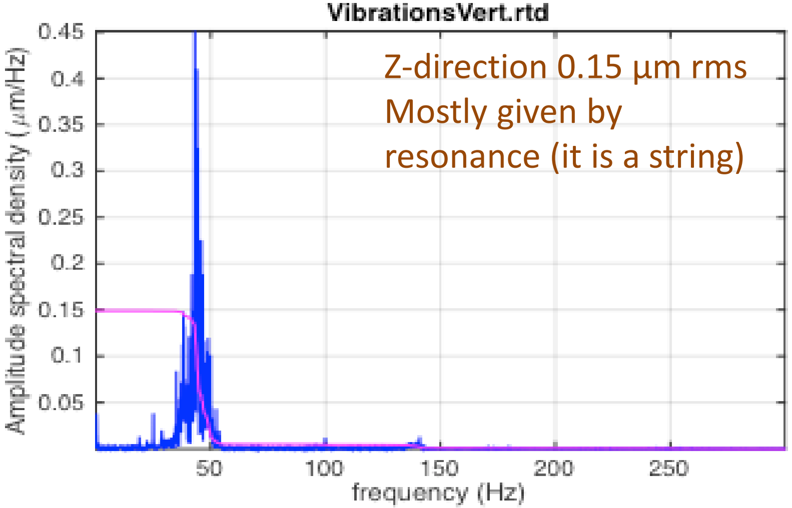


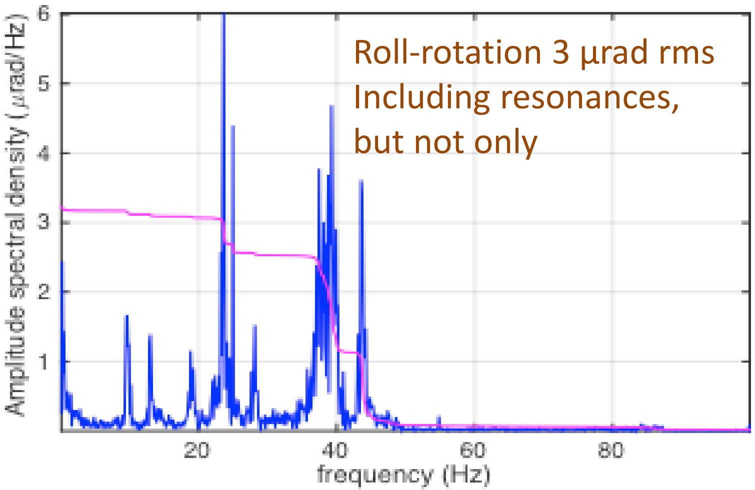
Vibrations: Amplitudes



- *Amplitude depends on the excitation.*
- *Measured at a tension of 5000 N*
- *Measured with the 10g target of the IF to minimize influence of its weight*

Maximum error: ±0.25 µm ±3 µrad



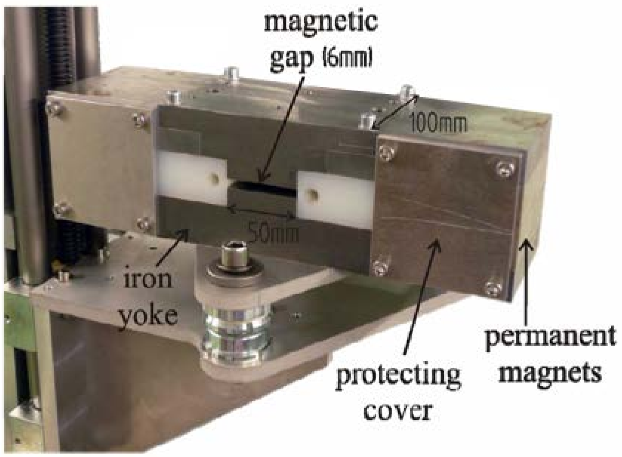


Alignment procedure

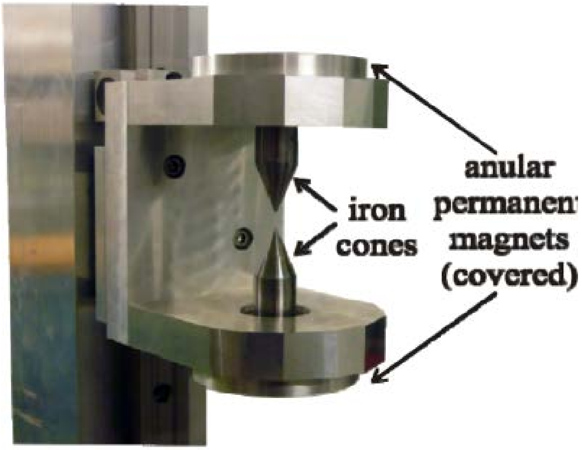
1. Carbon fiber is dettached
2. Carbon fiber is passed through magnetic structure
3. Carbon fiber is reattached and stretched
4. Horizontal reference magnet is placed on Hall probe position and aligned with high precision water level
5. Orientation of Carbon fiber (angles) is set to horizontal using the magnet as reference. Maximization of vertical Hall probe is used as reference.
6. Reference magnet is opened and taken out
7. Cones are placed on Hall probe position
8. Zero field point in cones is found scanning with bench
9. Translation vector between cones and magnetic structure is measured.

Overall mechanical error:
Positioning: ± 30 µm
Angle: ± 25 µrad

Horizontal magnet accuracy: **±0.75 µrad**



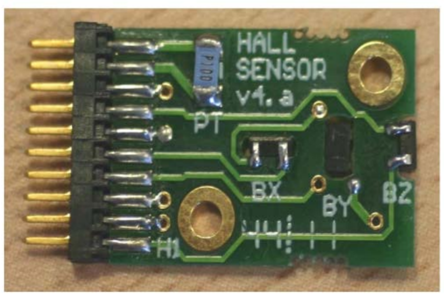
Positioning cone system accuracy: **±10 µm**



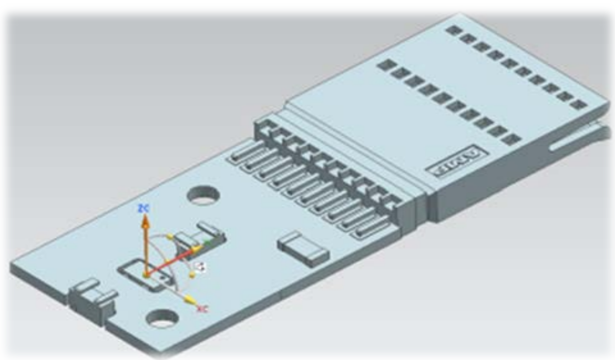
Data acquisition

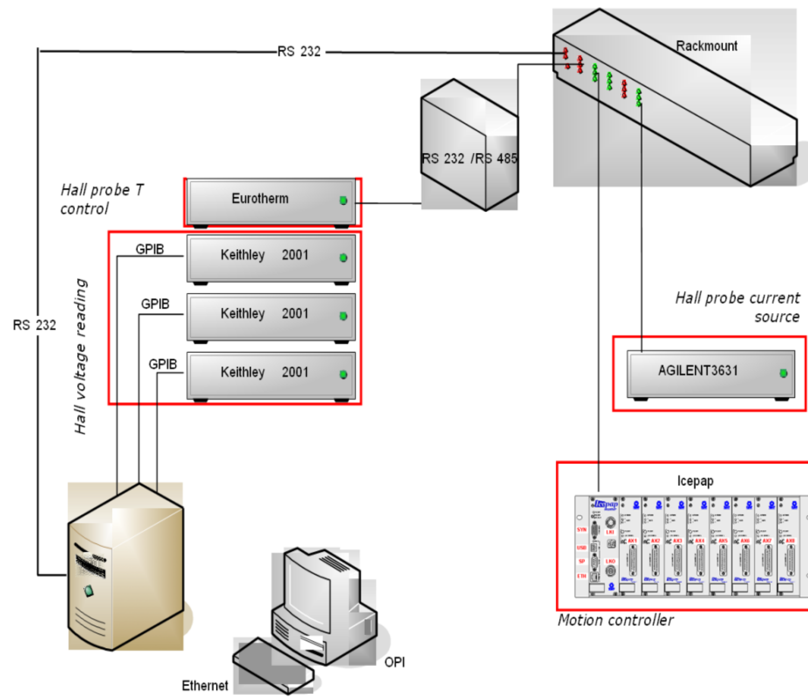
- Design of new 3D Hall probe thin holder
    - 2 mm height, 10 mm wide, 14 mm long
- Temperature reading with 0.01º accuracy
- Acquisition system triggered by ICEPAP in real time

Control system



3D new Hall probe holder





Data acquisition

Industrial PC with Devian 8

Hall probes current supply

3 Keithley multimeters

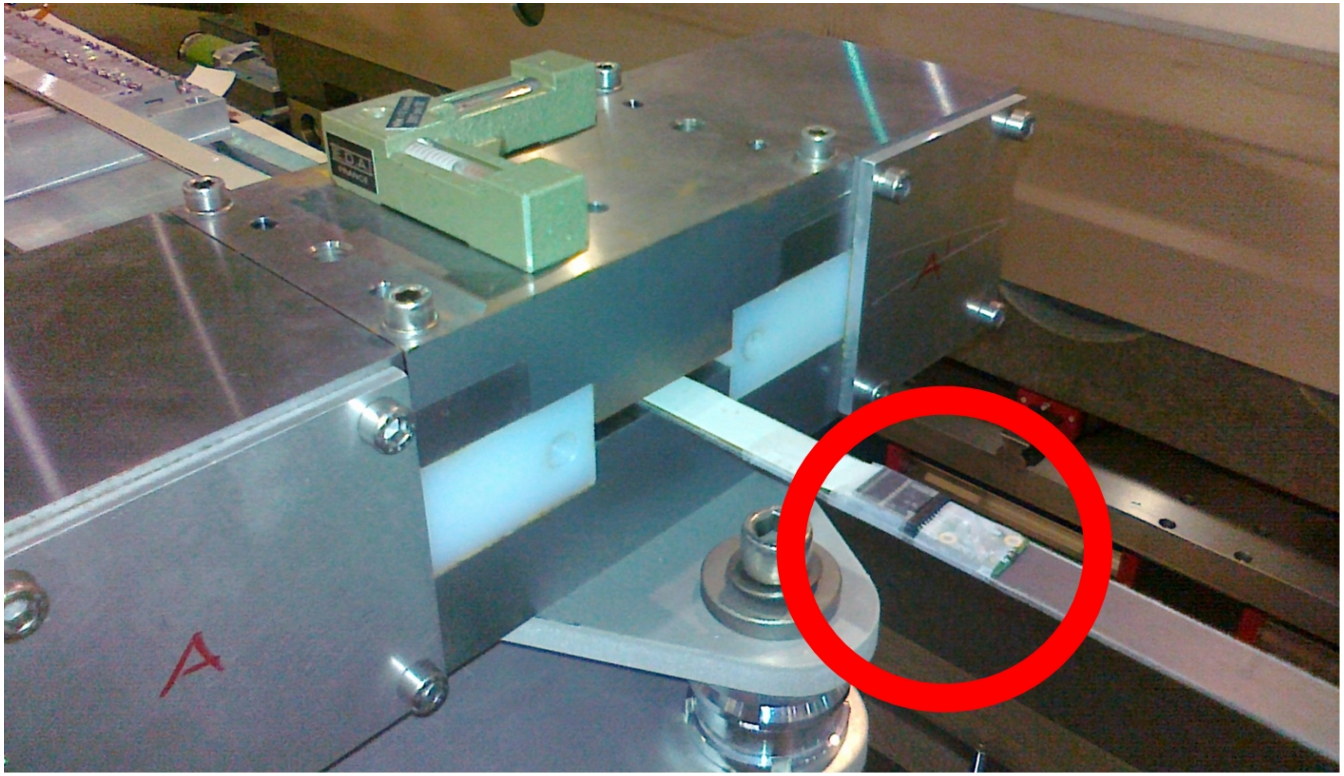
1 Eurotherm controller

EPS system

ICEPAP motion controller for 5 motors

MAGNETIC PERFORMANCE

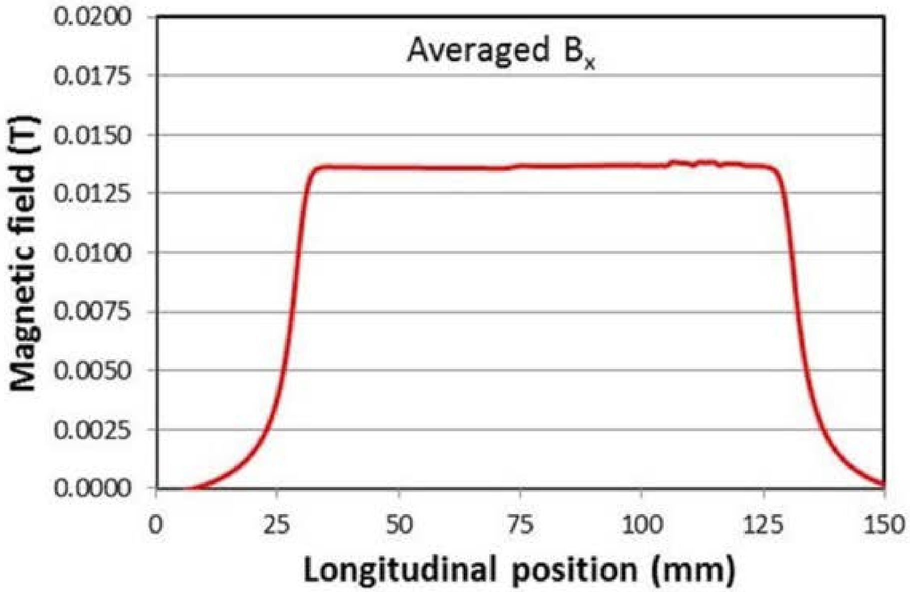
Homogeneous fields: experimental setup

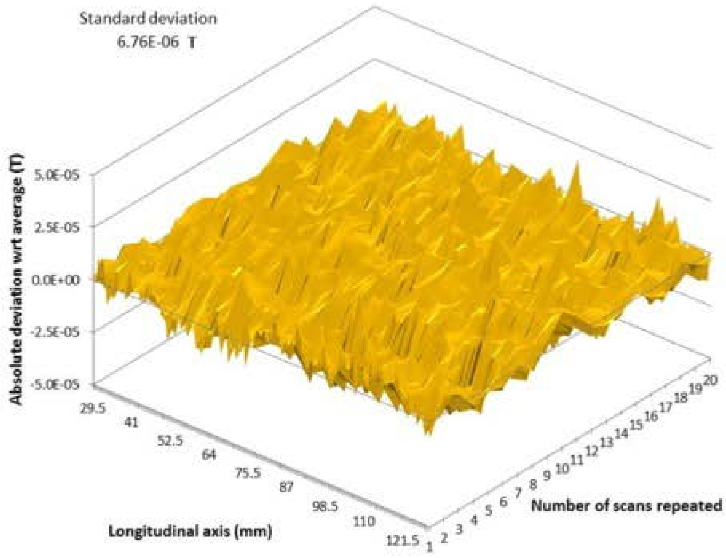


Magnetic field $B_x \sim 0.0130$ T

Repetitivity: $6.7 \cdot 10^{-6}$ T

Relative accuracy: $\sim 5 \cdot 10^{-4}$

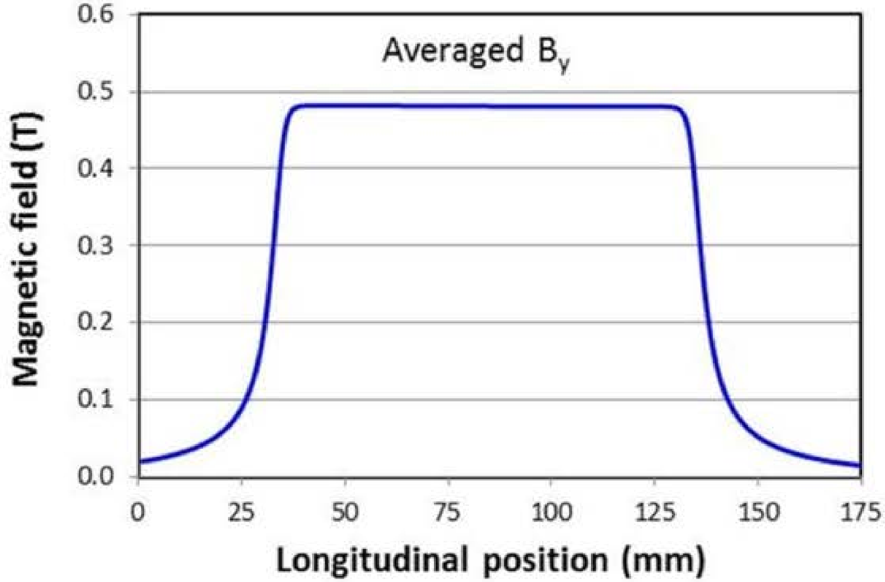


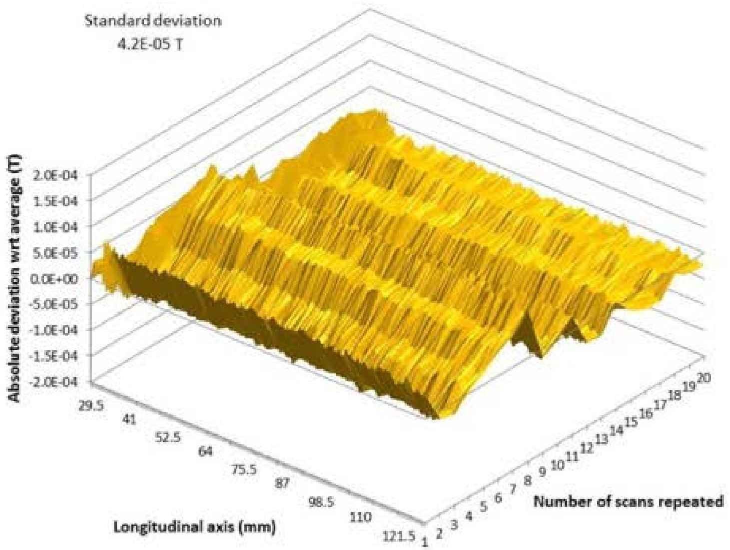


Magnetic field B_y ~ 0.49 T

Repetitivity: $4.2 \cdot 10^{-5}$ T

Relative accuracy: $\sim 8 \cdot 10^{-5}$

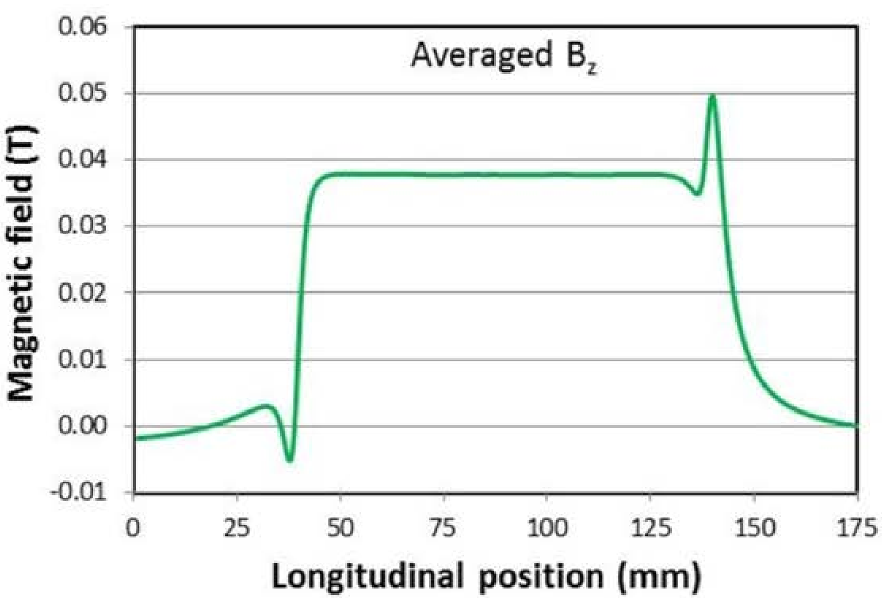


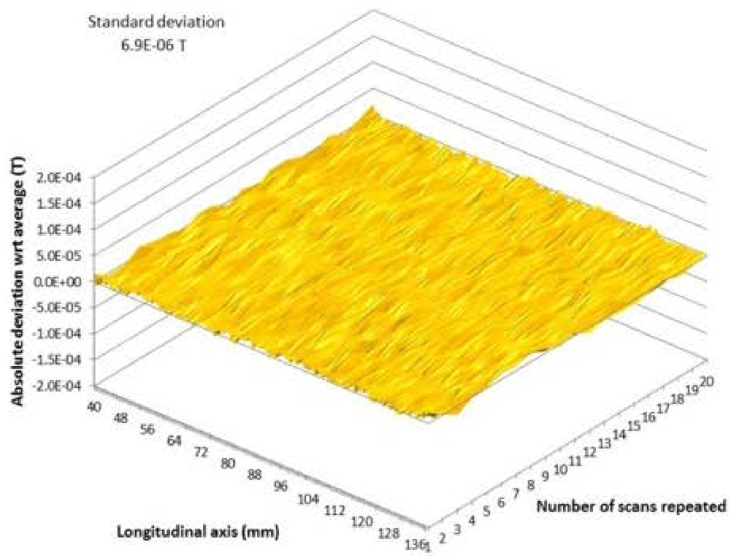


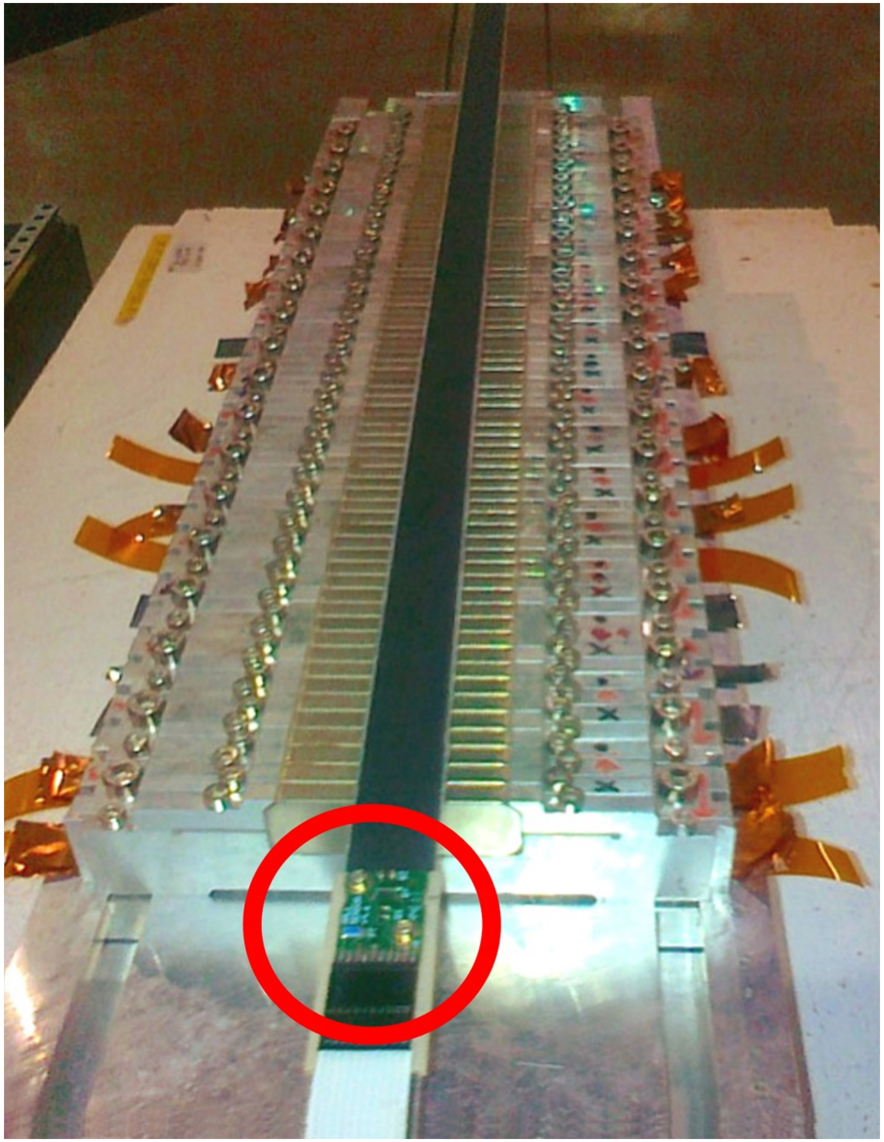
Magnetic field B_z ~ 0.039 T

Repetitivity: $6.9 \cdot 10^{-6}$ T

Relative accuracy: $\sim 1.7 \cdot 10^{-4}$







MAGNETIC PERFORMANCE

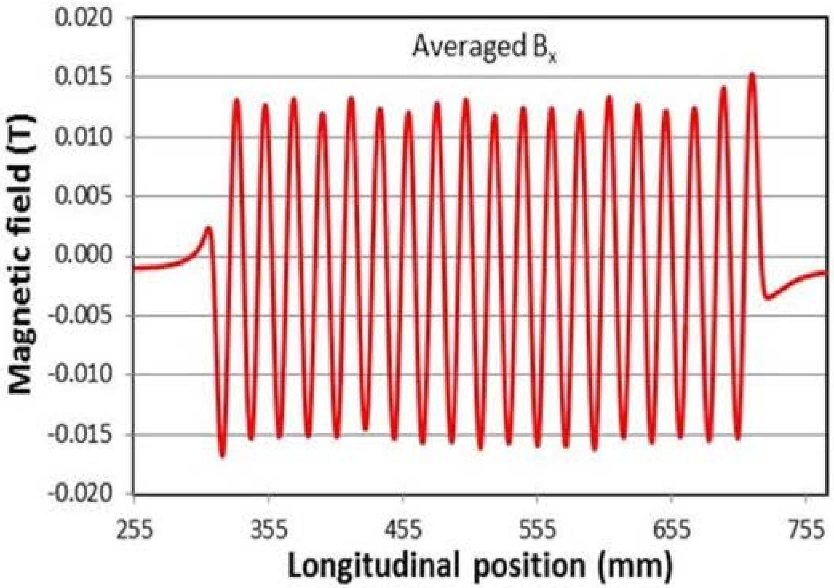
Variable fields: experimental setup

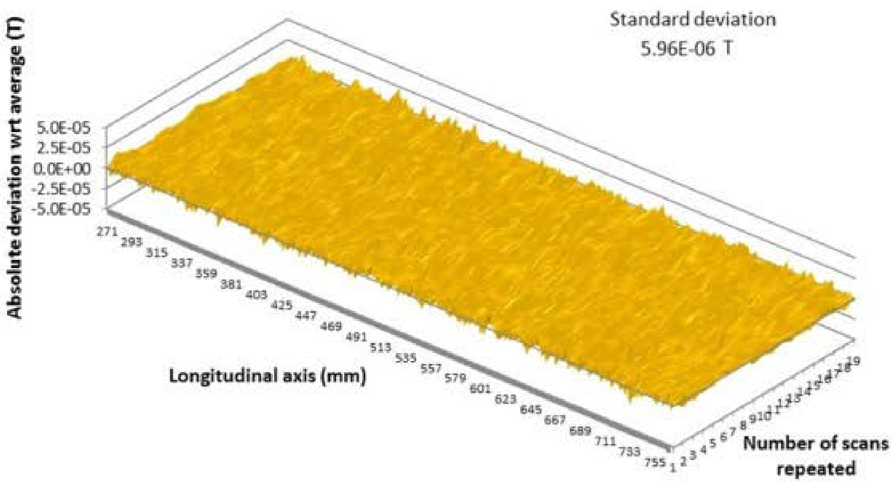
FIRST MEASUREMENTS

Magnetic field B_{0x} ~ 0.012 T

Repetitivity: $5.9 \cdot 10^{-6}$ T

Relative accuracy: ~$4.9 \cdot 10^{-4}$

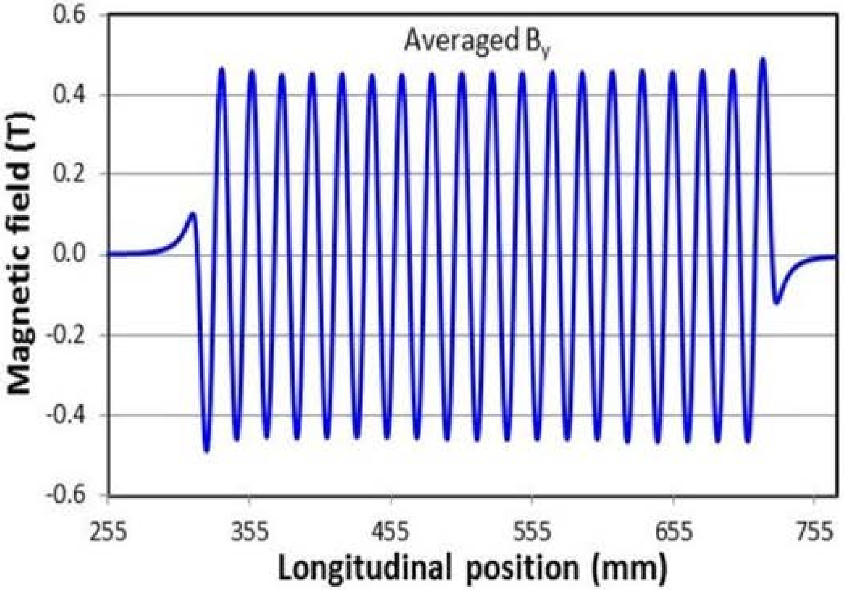


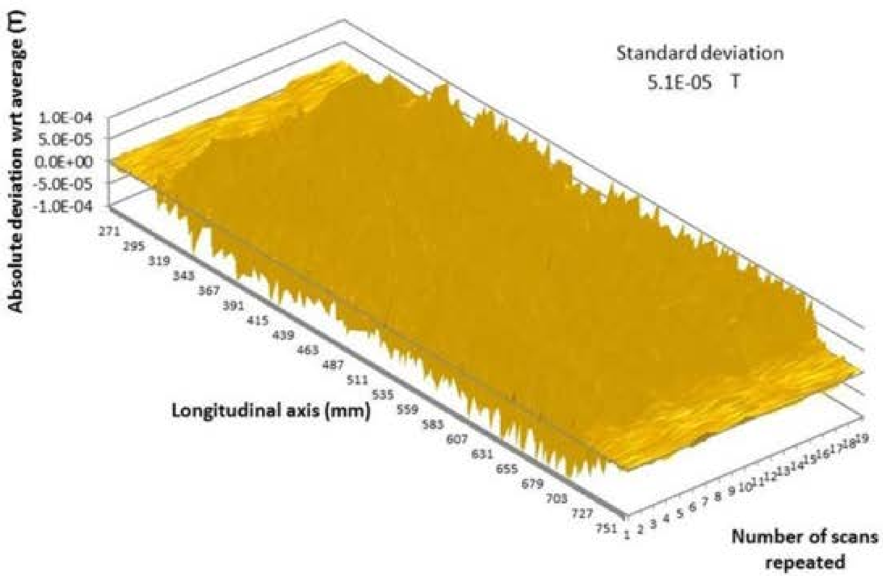


Magnetic field B_{0y} ~ 0.45 T

Repetitivity: $5.1 \cdot 10^{-5}$ T

Relative accuracy: ~$1.1 \cdot 10^{-4}$

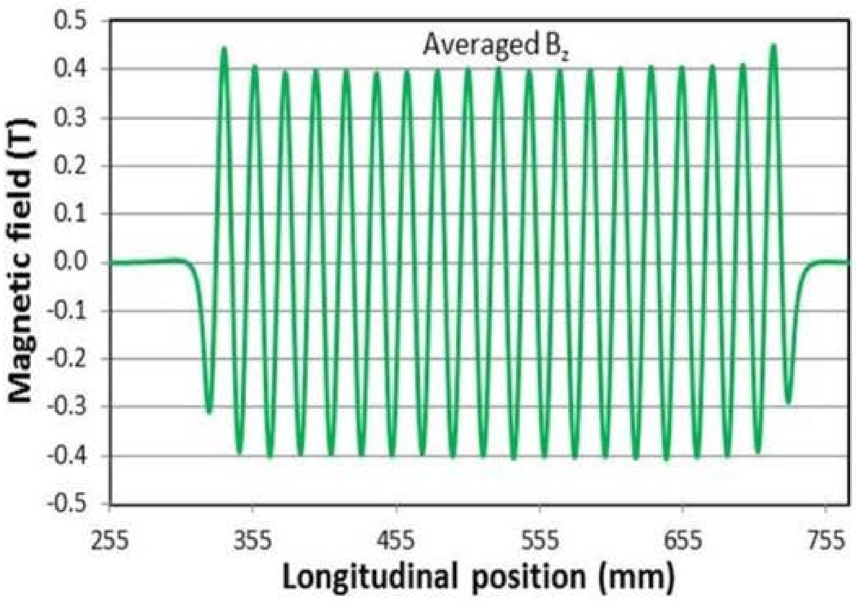


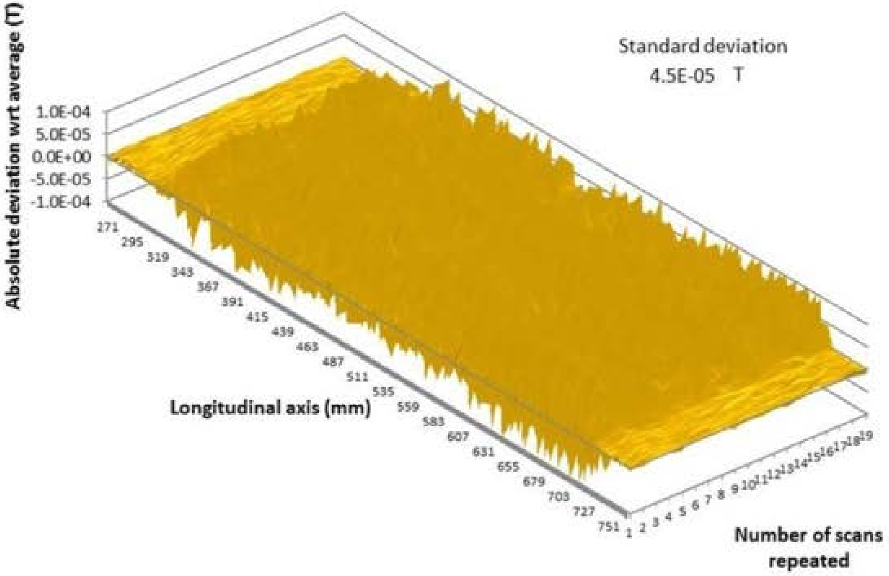


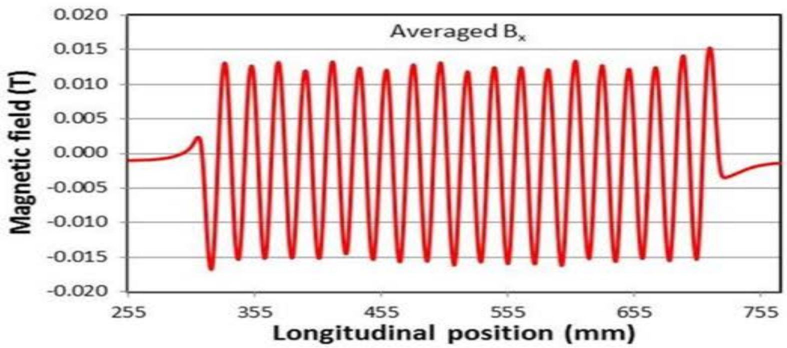
Magnetic field B_{0z} ~ 0.4 T

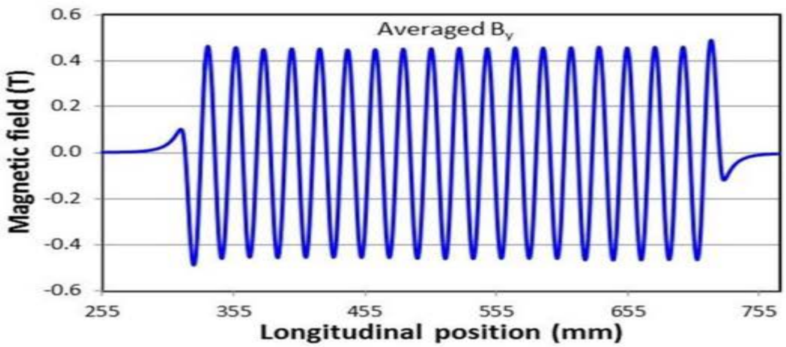
Repetitivity: $4.5 \cdot 10^{-5}$ T

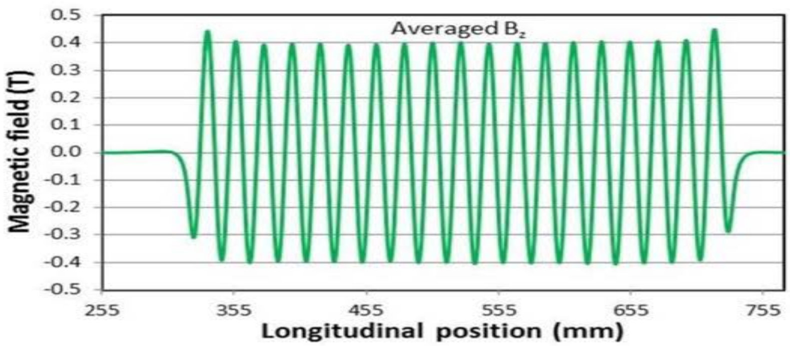
Relative accuracy: ~$1.1 \cdot 10^{-4}$





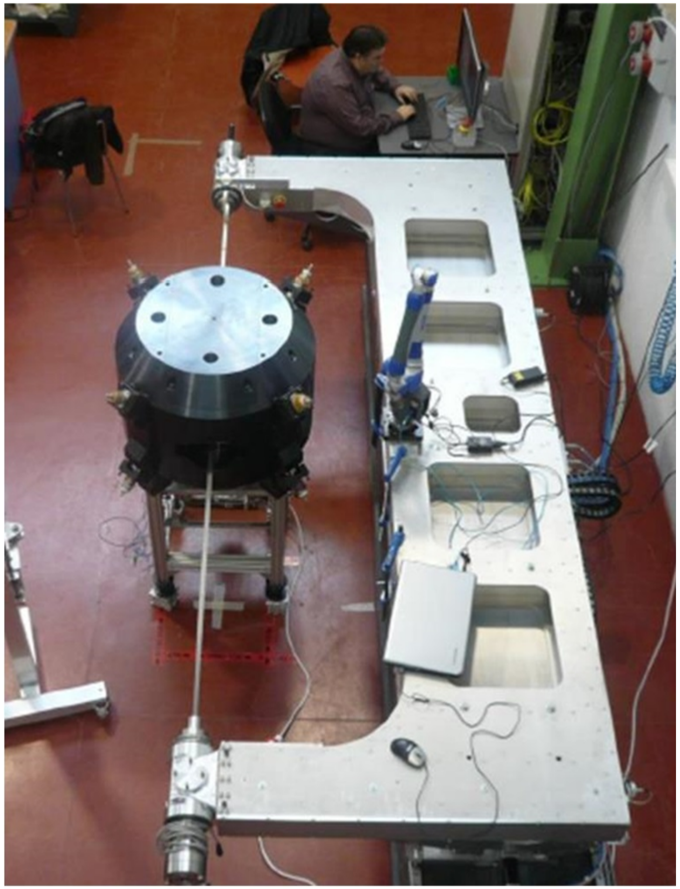






Period determination using zero-crossing

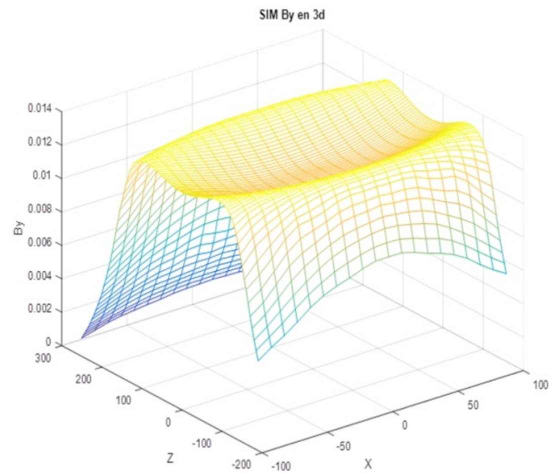
Statistic error: < 1 µm



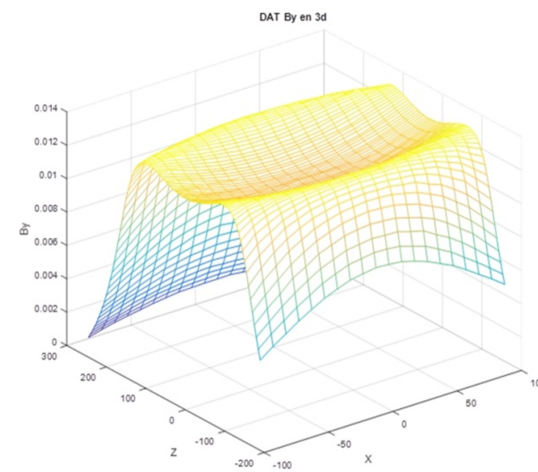
1^{st} real case

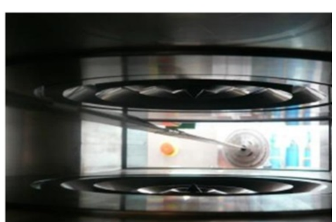
Currently, the bench is at CIEMAT in Madrid to characterize the main SC magnet of a compact cyclotron

OPERA 3D simulation



Measurement





Deviations from theoretical model are smaller than 1 mT for the whole volume, and most of the points in the interest area deviate much less than 0.5 mT

SUMMARY

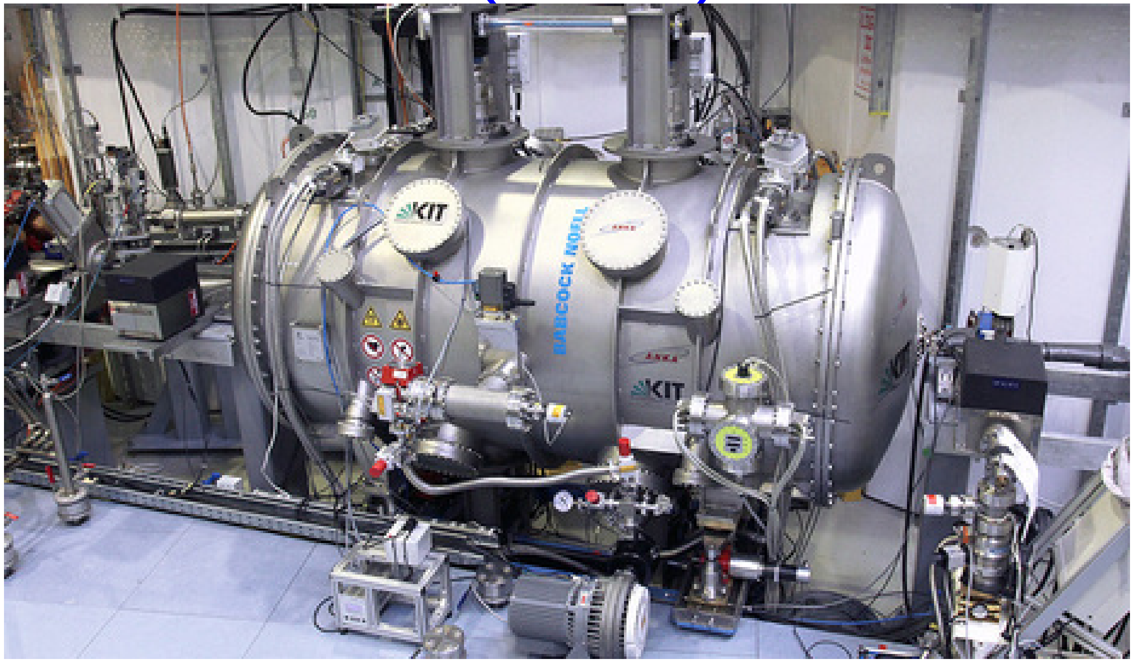
- Magnetic measurements repetitivities in the range of 100 ppm
- For low intensity fields, repetitivity ~ $5 \cdot 10^{-4}$
- For high intensity fields, repetitivity ~ $1 \cdot 10^{-4}$
- Period determination accuracy: < 1 µm

LESSONS LEARNED

- Vibrations are not a problem (submicron)
- Attachement and dettachement are repetitive (accuracy ±30 µm / ±25 µrad)
- No major problems with acquisition (cable length, temperature, noise)

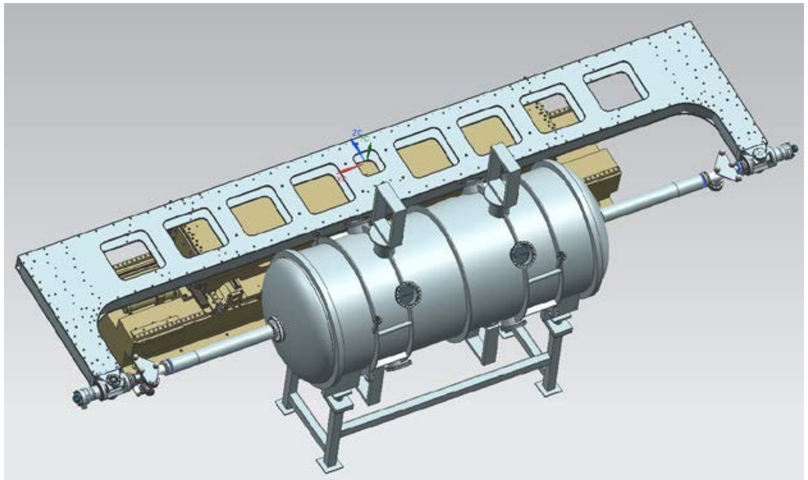
NEXT STEP: UPGRADES

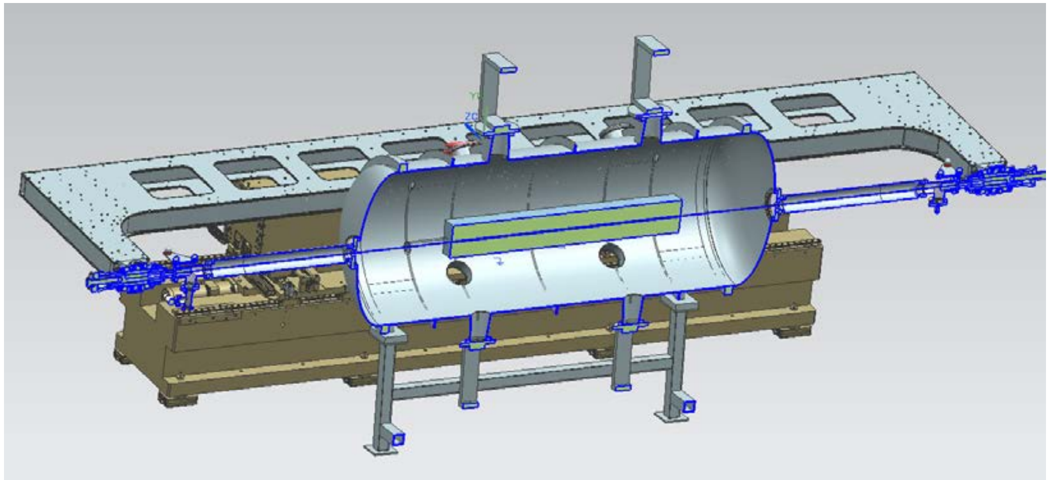
- **in-vacuum** (~10^{-2} Pa) 10^{-4} mbar
- **in-cold** (~10 K)

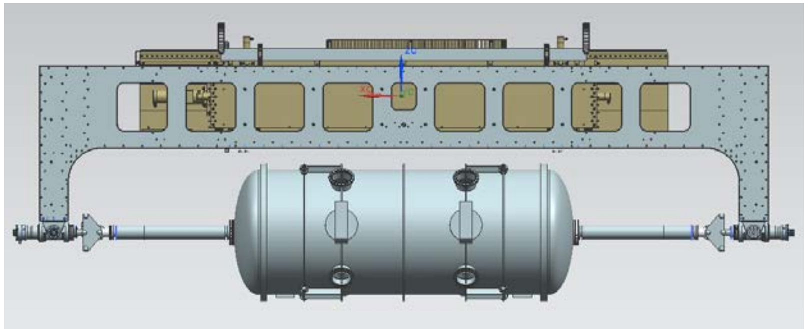


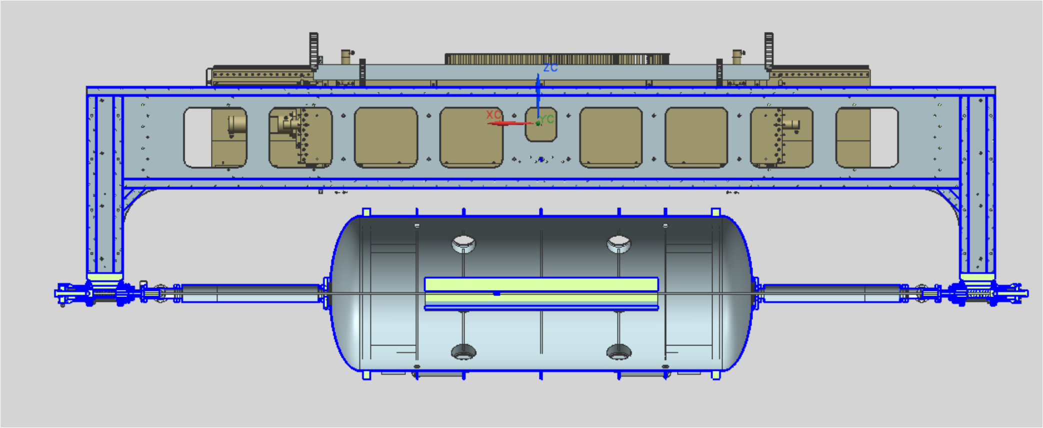
ANKA-KIT Babcock-Noël SCU15

BENCH UPGRADES



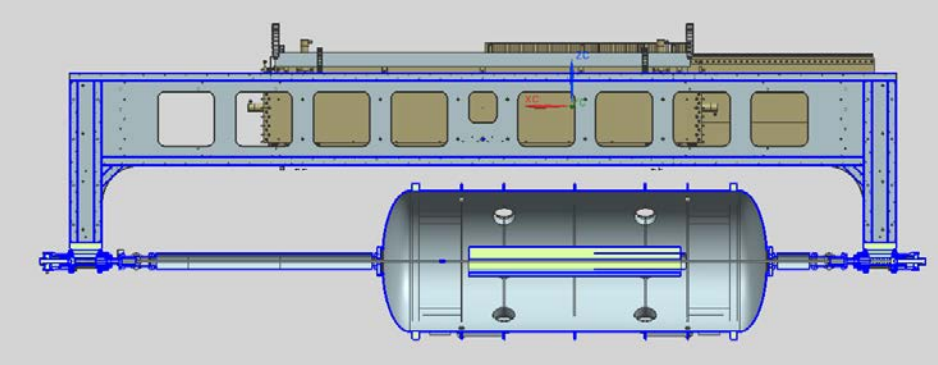


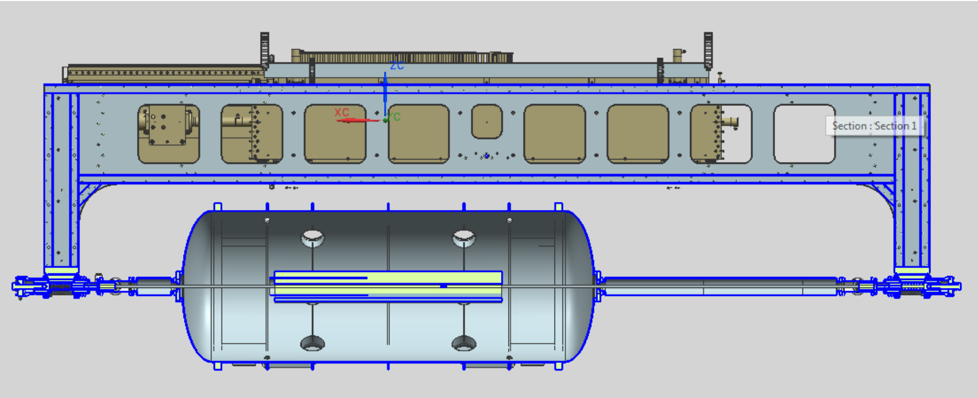




Vacuum and thermal isolation will be assured through long bellows

BENCH UPGRADES



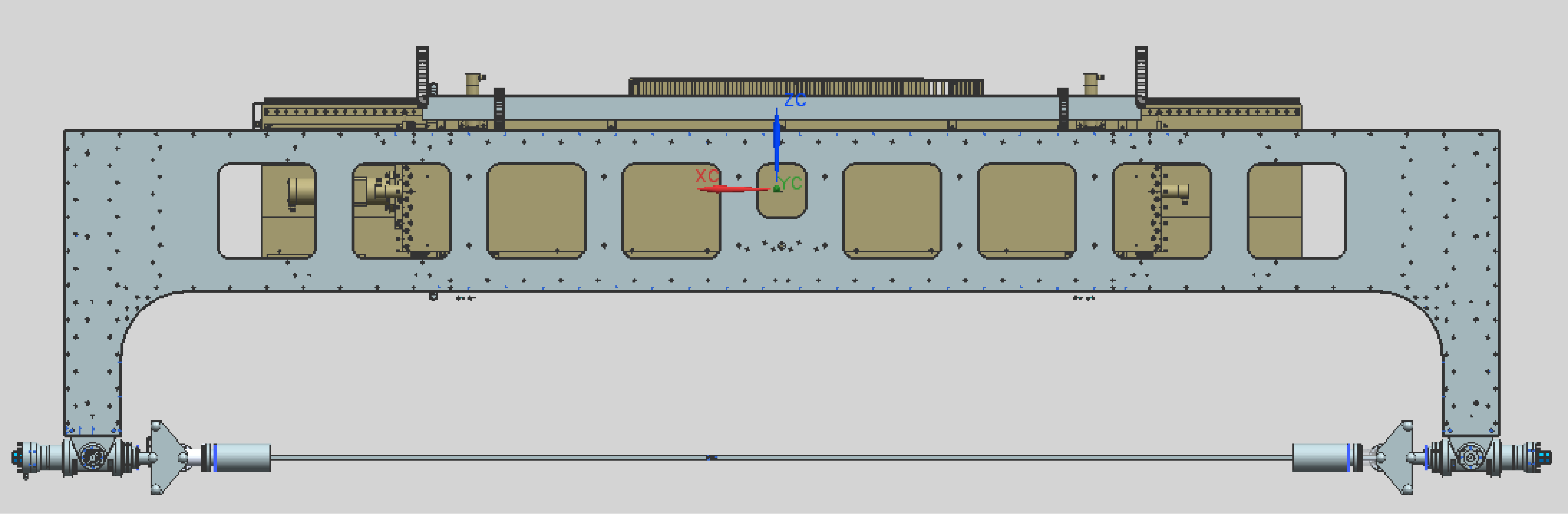


Measurement procedure:

1) Assemble and align the device with respect to the bench
2) Measure 1.3 m (half the array + 0.2 m external + 0.1 m internal)
3) Dissassemble the device, turn it 180º and realing it with respect to the bench
4) Measure 1.3 (the other half + 0.2 m external + 0.1 internal)
5) Data treatment: merge both measurements. Merging zone 0.1 m

BENCH UPGRADES

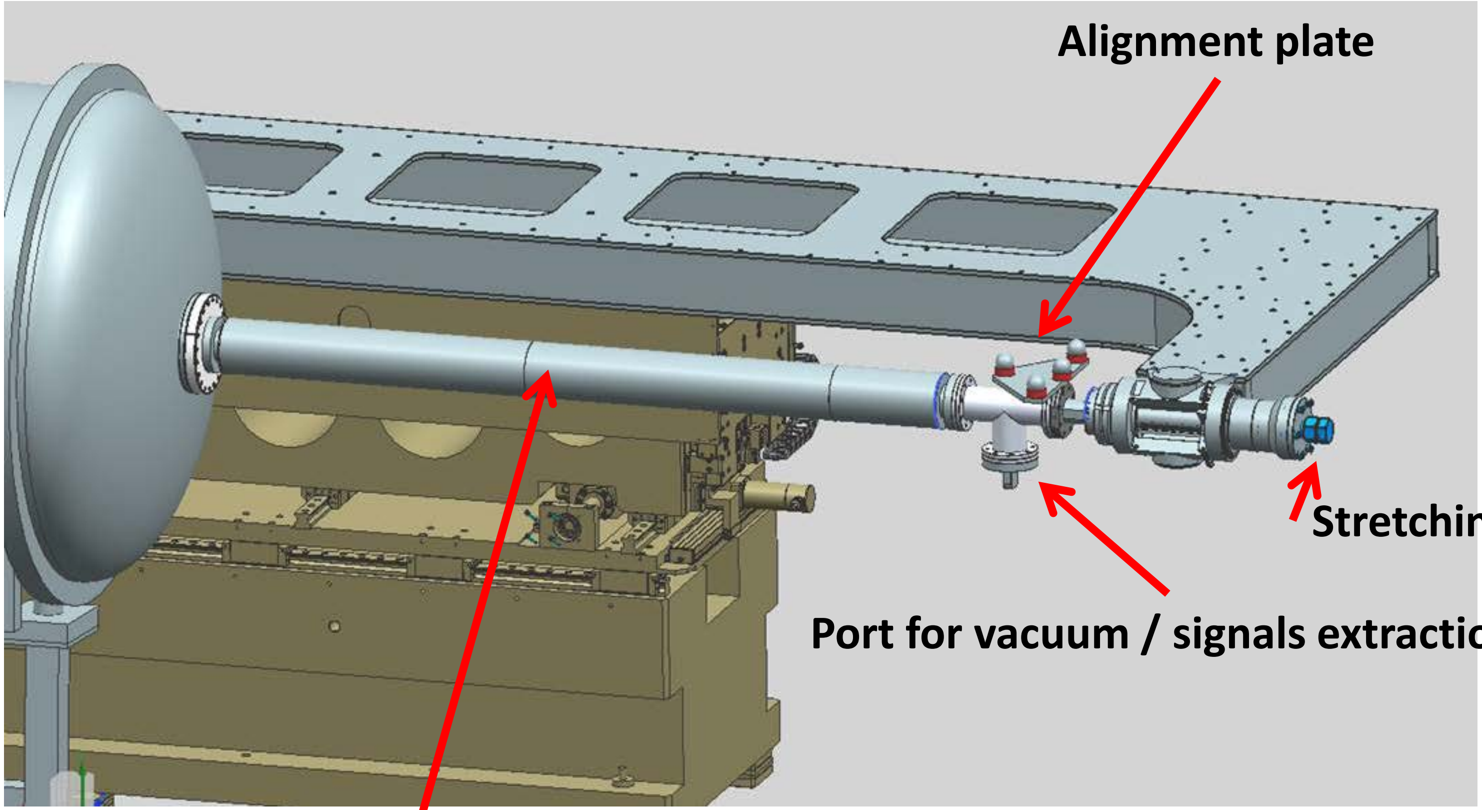
TASKS TO DO



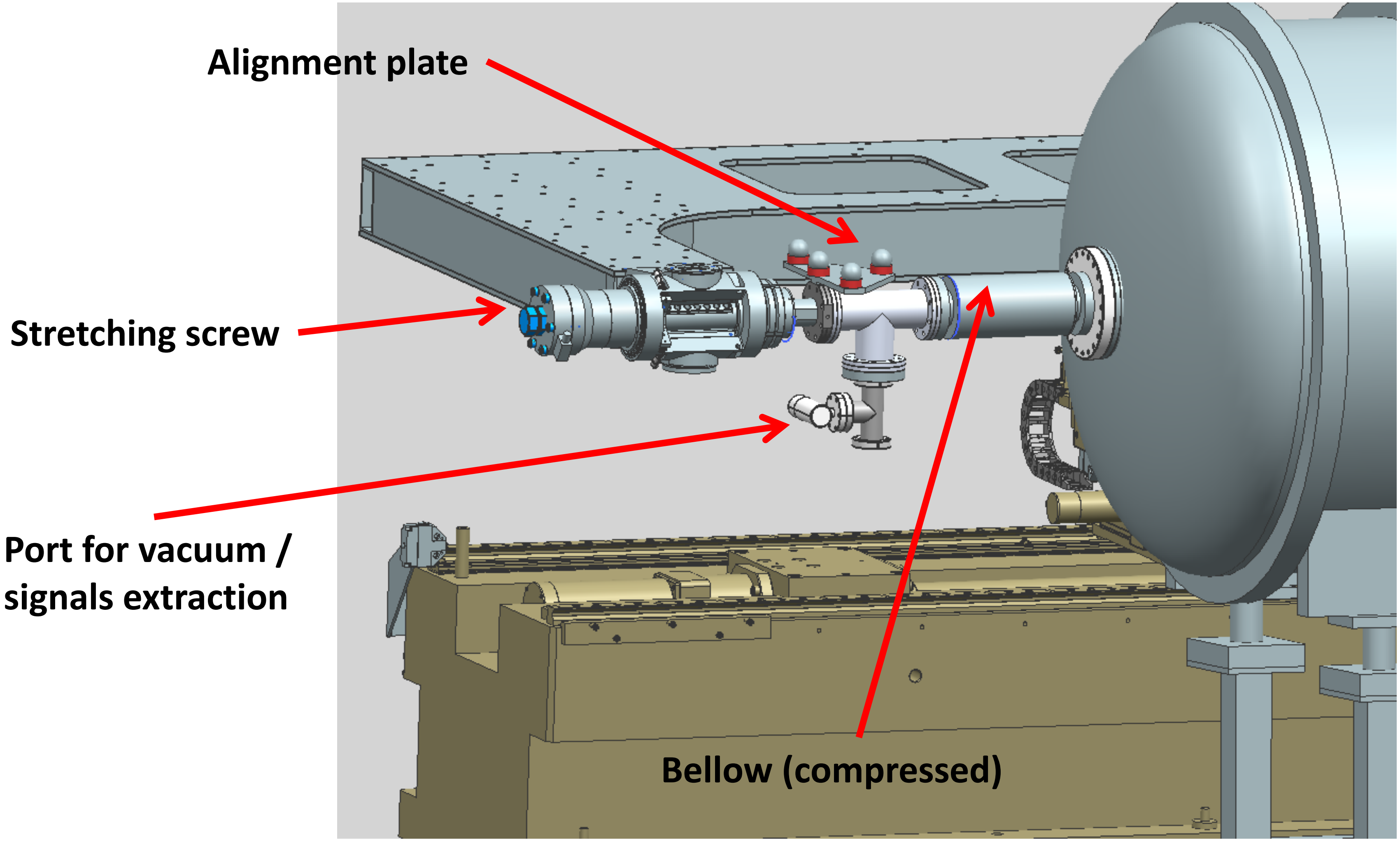
Enlarge the “C” frame

BENCH UPGRADES

VACUUM SPECIFIC ITEMS



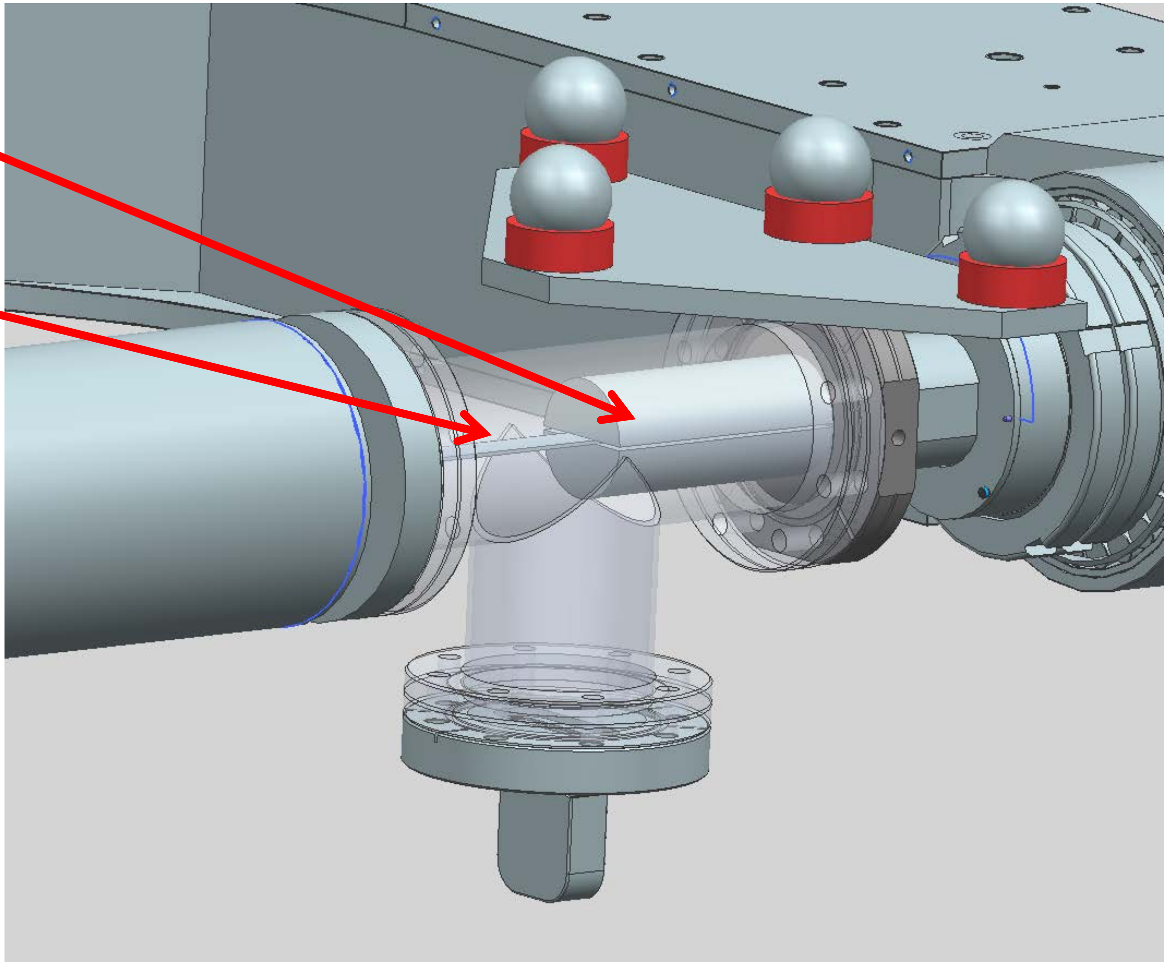
BENCH UPGRADES



BENCH UPGRADES

in-vacuum jaws

Belt supporting Hall probes



In this approach, Hall probes will be rigidly fixed to belt, and overall accuracy will rely on the repetitivity of dettachment / reattachment operation

BENCH UPGRADES

OPEN ISSUES & TASKS TO DO

1. Define theoretical model of the new string (adjust linear density and tension to have the first frequency mode at a safe range)

2. Check the carbon fiber behavior at ~10º K / if needed, look for an alternative

3. Calibrate Hall probes at ~10º K / if needed, look for an alternative

4. Structural design of the new wide C structure for a stable performance

5. Validation of alignment procedure

6. Detail and production of the new vacuum components and new arc structure

Thanks for your attention