Dimensional measurements Nb_3Sn coils after impregnation

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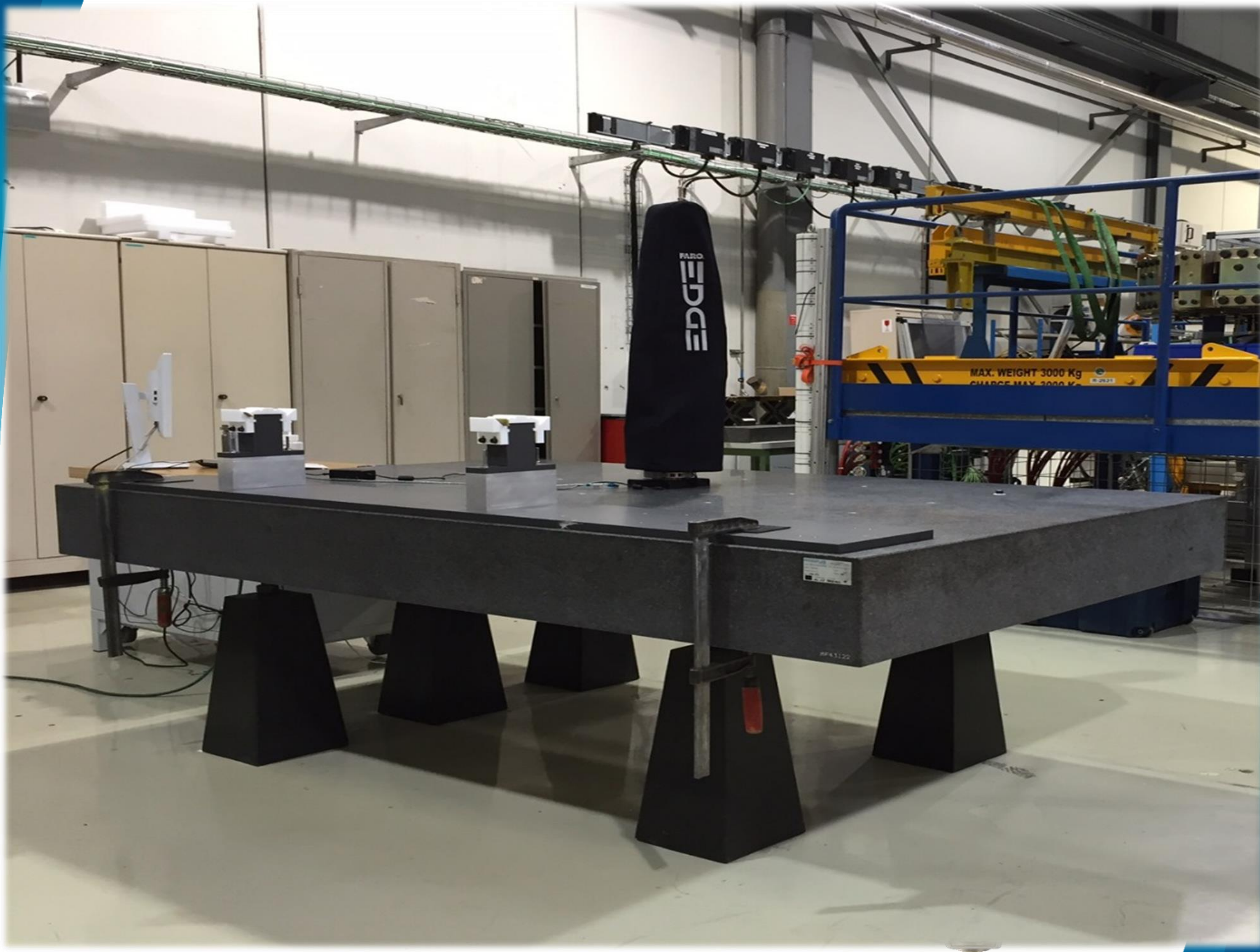
Paris-11 October 2018

Dimensional measurements review
Outline

1. Equipment
2. Methodology
3. Results

- Annex: Backup slides


FARO
EDGE
MAX. WEIGHT 3000 Kg

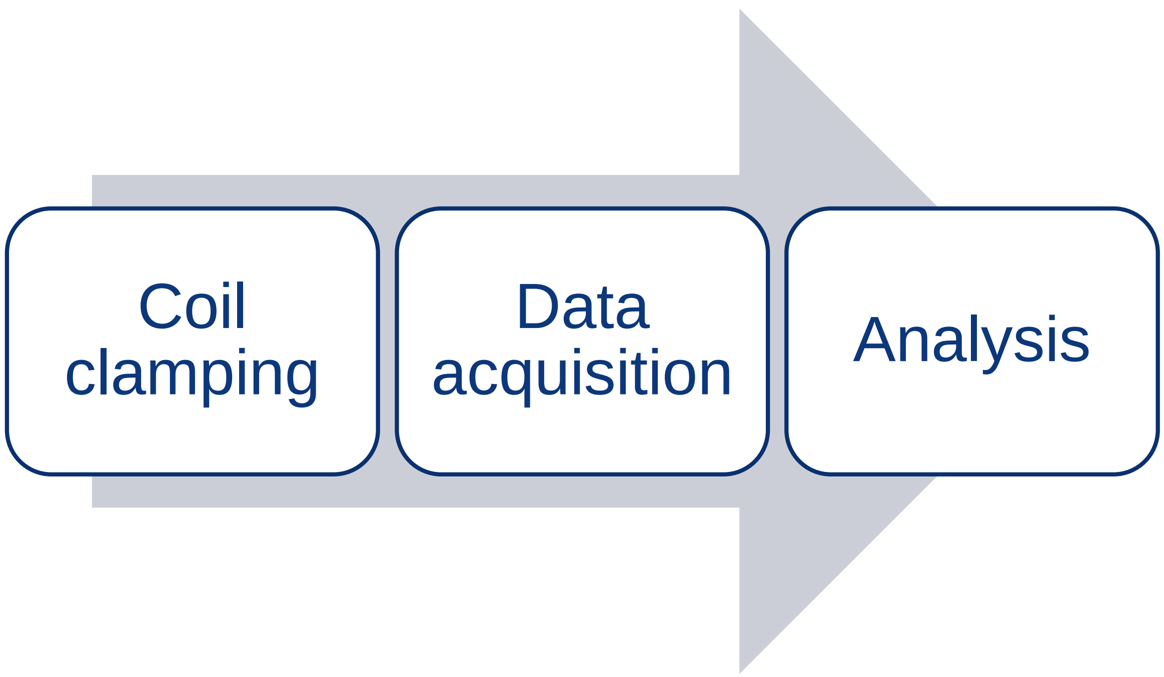
Equipment: Marble & Tooling

Coils clamped using a specially designed support

- Dedicated area for metrology inside the workshop
    - Marble @ short coils (2.5 m x 1.5 m) Class 0
    - Marble @ long coils (10 m x 1.2 m)

- Arm fixed to the table.
- Parts of the support are aligned and screwed to the marble before operations

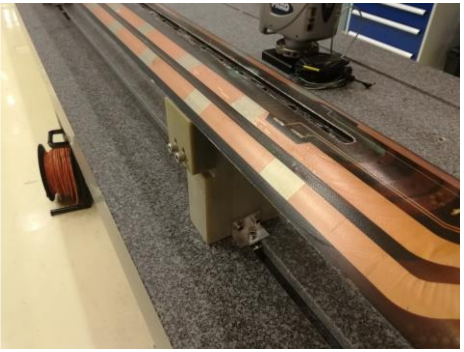
General Procedure

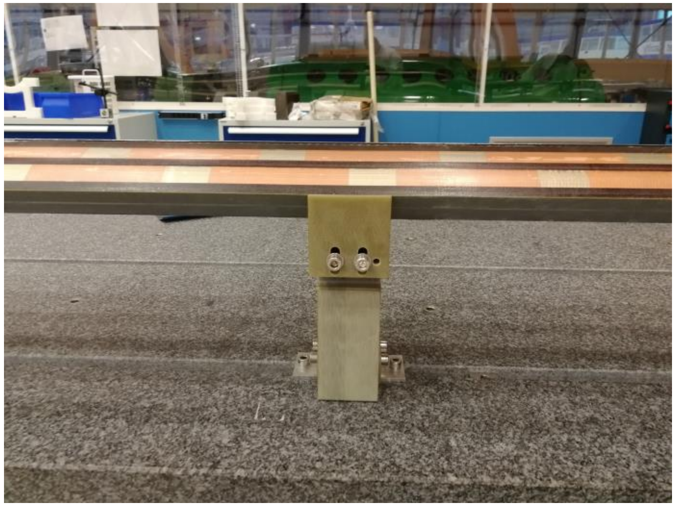


Procedure
Coil clamping (I/IV): MQXFS

Distance between supports : 1200 mm
Distance between lead end and support : 180 mm

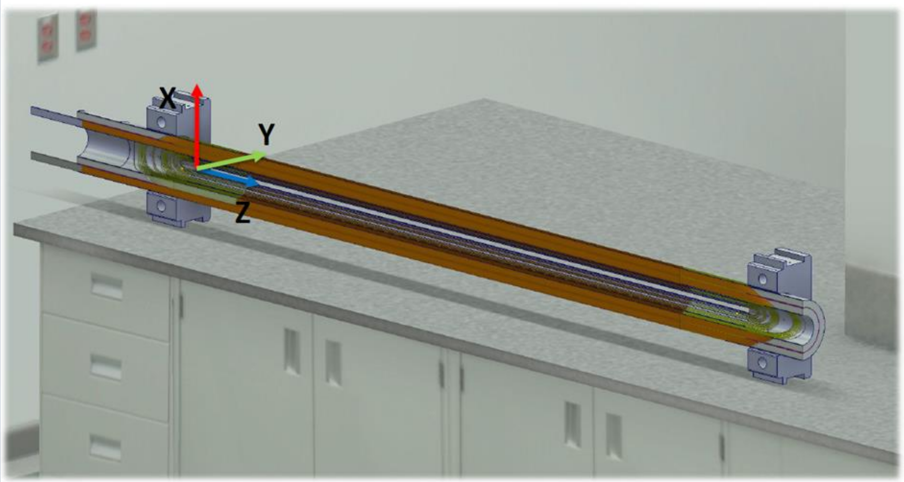
Procedure
Coil clamping (II/IV): MQXFB



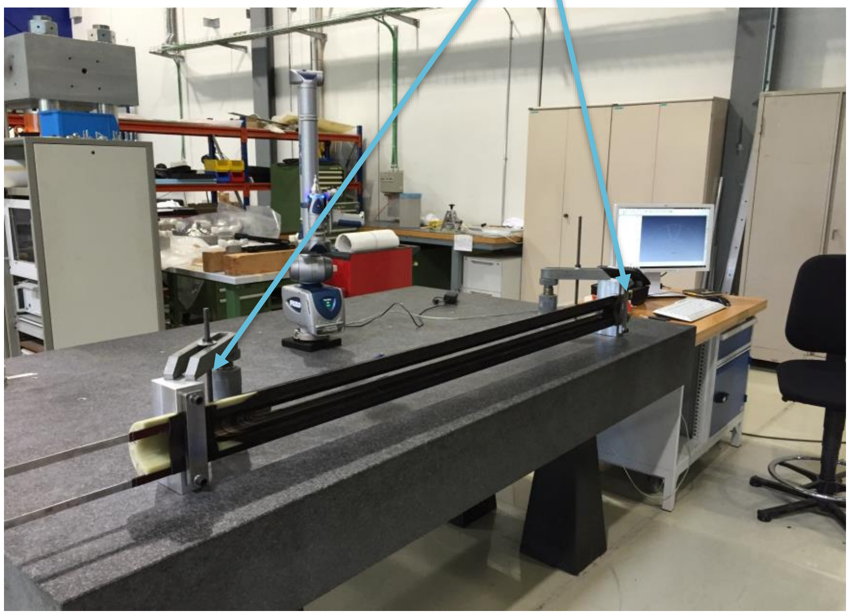


Distance between supports : ~1400 mm
Distance between lead end and support : 250 mm

Procedure
Coil clamping (III/IV): DS 11T

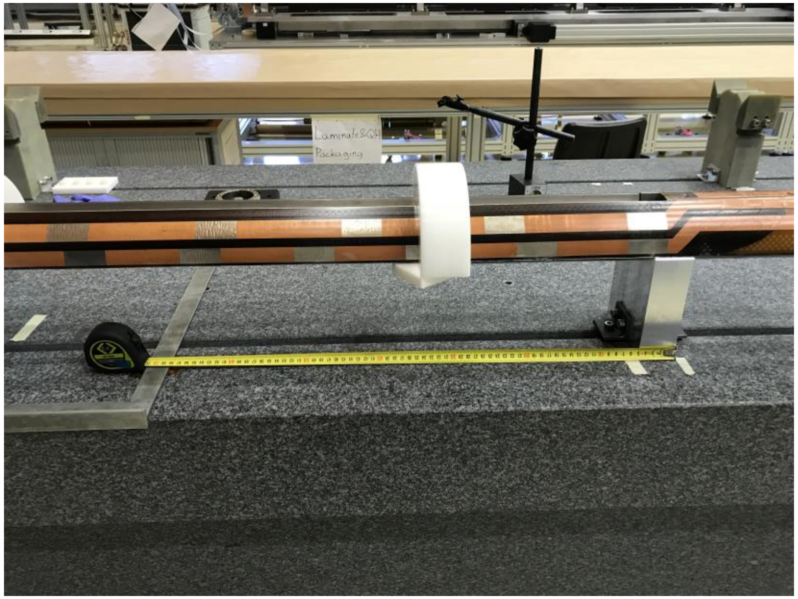


Rubber pads



Distance between supports : 1500 mm
Distance between lead end and support : 120 mm

Procedure
Coil clamping (IV/IV): D 11T



Distance between supports : ~1000 mm

Procedure
Data acquisition (I/II)

Device compensation (already warmed-up)

Usual results:
- Hole compensation 2-sigma: Below 10µm

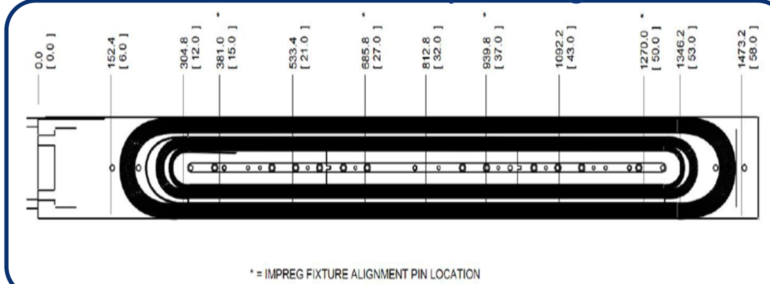
Device validation
- Calibrated pieces:
- Deviation below 8µm

Pre-alignment

General geometry probing

Best fit alignment to precisely determine the position of the cross sections

Cross section probing



[1]Compensation

The process by which a measurement device is optimized to perform accurate measurements. This may be done through mechanical adjustments, as well as software corrections. Although the FaroArm is factory compensated, you have the ability to change probes and individually compensate each probe after mounting to the FaroArm. This process determines the centre of the probe tip relative to the arm coordinate system.

The value reported by 2 sigma is twice the standard deviation of all the points taken while performing the compensation. 2 Sigma is used to determine whether the arm passes or fails.

[1]Calibration

The process by which one proves that a device is performing within factory specification. After calibration, a certificate is issued to authenticate the process, thus the use of the term certification.

[1]https://knowledge.faro.com/Hardware/FaroArm_and_ScanArm/Gage/Compensation_and_Calibration_Standards_for_the_FaroArm_and_Gage

Procedure
Data acquisition (II/II)

MQXFS

11 Cross sections. The straight section is probed each 6 inches.

MQXFB

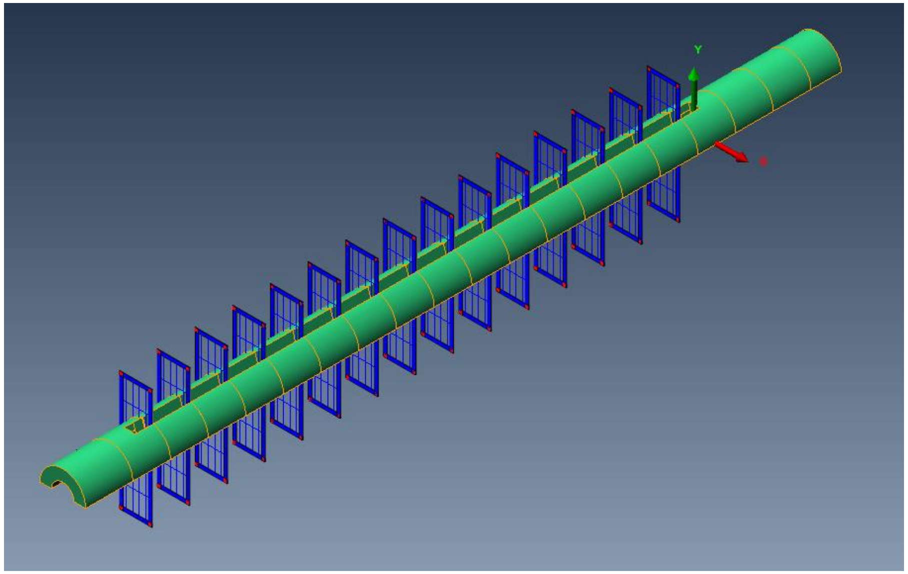
33 Cross sections. The straight section is probed each 200mm

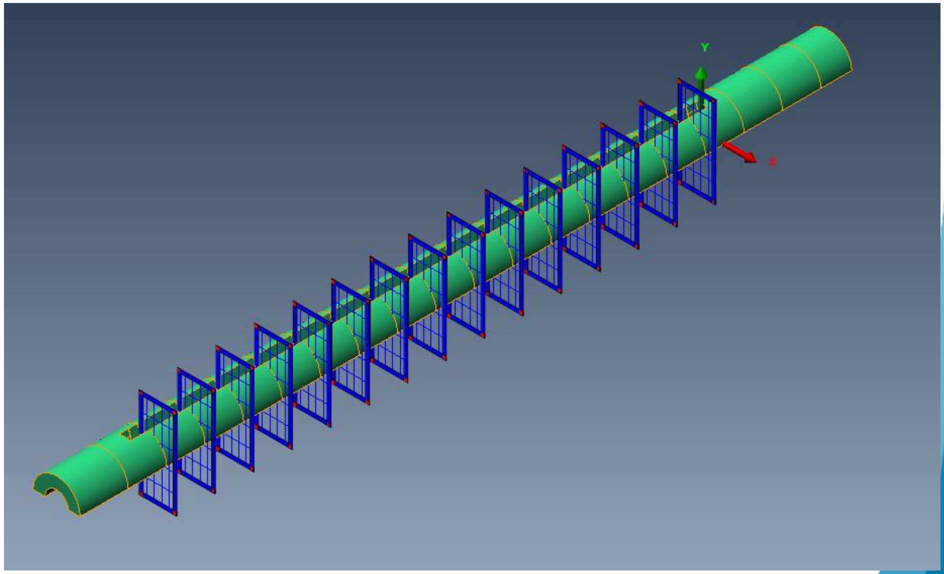
11T 2m

15 Cross sections. Probed each 100mm. The two branches are independent.

11T 5.5m

33 cross sections. Probed each 150mm. The two branches are independent.





Procedure
Post-processing (Polyworks) (I/IV)

1. Normal vectors extraction
2. Point cloud clean-up
3. Each CS is aligned individually
4. Aligned point cloud is exported as .TXT
5. .TXT point cloud is imported as separate data
6. Results

Procedure
Post-processing (II/IV)

Results

- Coil azimuthal size and asymmetry
- Coil length
- Coil width
- Outer diameter of each cross section
- Inner diameter of each cross section

Section TE/MSC/MDT

PROJECT | FICHE DE SUIVI | MQXF

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MQXFS-108: DIMENSIONAL MEASUREMENTS

ABSTRACT:
Geometrical measurements are done using a portable CMM (Coordinate Measurement Machine) at 927 Laboratory.
The geometry of each coil is analysed at the end of its production process. Generally, measurements are repeated for each coil after magnet disassembly. The results rely on the individual alignment of each cross section to the Outer Cylinder surface and both keyway sides, thus deleting the geometrical imperfections of the coils coming from the measurements on their free state (typically coil deflection).
The results presented here are the cross section views (showing the deviation from the nominal geometry), the size and asymmetry chart, the coil length and the outer diameter values.

Date of the measurement: July, 7th 2017
Operator: S. Ferradas

Author: S. Ferradas
Checked by: J. Ferradas

Procedure
Post-processing (III/IV)
MQXF Coil azimuthal size and asymmetry

$$dev\ right = avg(signed\_abs(deviation\ left\ wo\ outliers))$$
$$dev\ left = avg(signed\_abs(deviation\ right\ wo\ outliers))$$

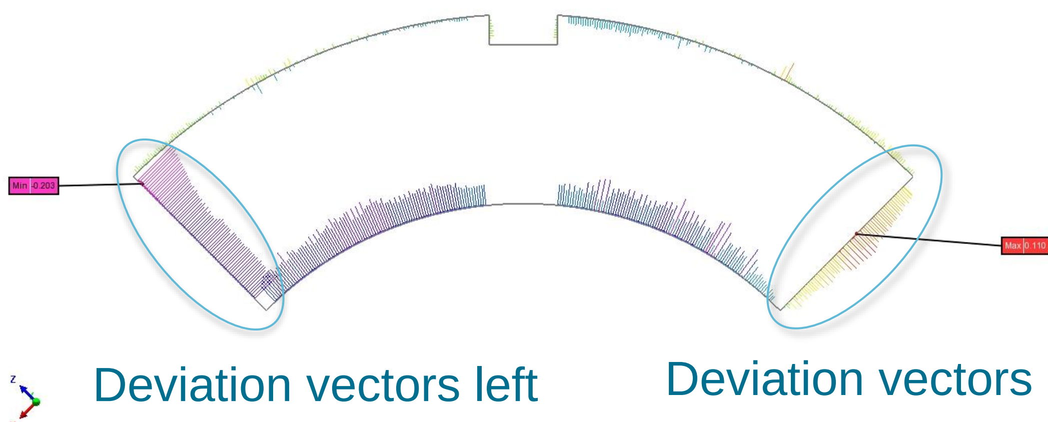
- $coil\ azimuthal\ size = dev\ left + dev\ right$
- $coil\ asymmetry = dev\ left - dev\ right$

Only results from cross sections along the keyway are used because these values depend on the alignment

Sample results:

	MP R	*MP L*
381	0.008	-0.196
533.4	0.001	-0.044
685.8	-0.042	-0.039
812.8	0.036	-0.014
939.8	0.009	-0.083
1092.2	0.061	-0.140
1270	-0.072	-0.063
	0.000	**-0.083**

	108	
	L-R	*L+R*
381	-0.204	-0.188
533.4	-0.045	-0.043
685.8	0.003	-0.081
812.8	-0.050	0.022
939.8	-0.092	-0.074
1092.2	-0.201	-0.079
1270	0.009	-0.135
	-0.083	**-0.083**
	-0.083	-0.083



Deviation vectors left

Deviation vectors right

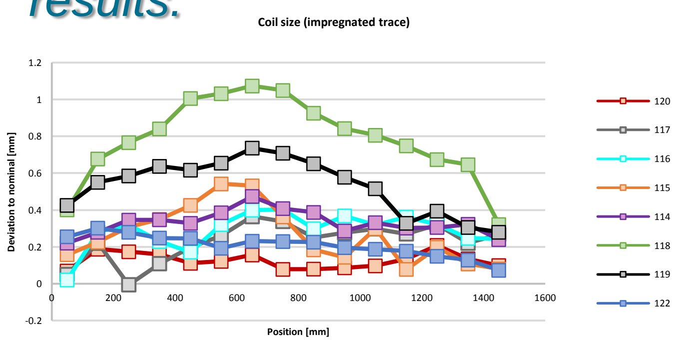
Procedure
Post-processing (IV/IV)
11T Coil azimuthal size and asymmetry

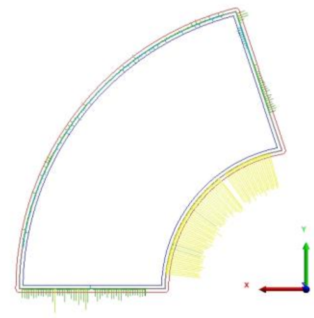
$$dev\ right = avg(signed\_abs(deviation\ left\ wo\ outliers))$$
$$dev\ left = avg(signed\_abs(deviation\ right\ wo\ outliers))$$

- $coil\ azimuthal\ size = dev\ left + dev\ right$
- $coil\ asymmetry = dev\ left - dev\ right$

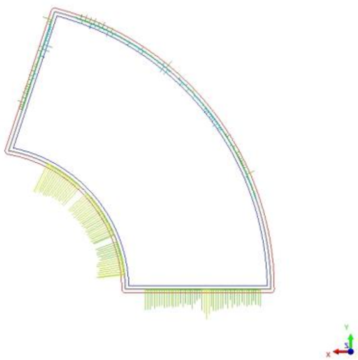
Only results from cross sections along the loading plate are used

Sample results:





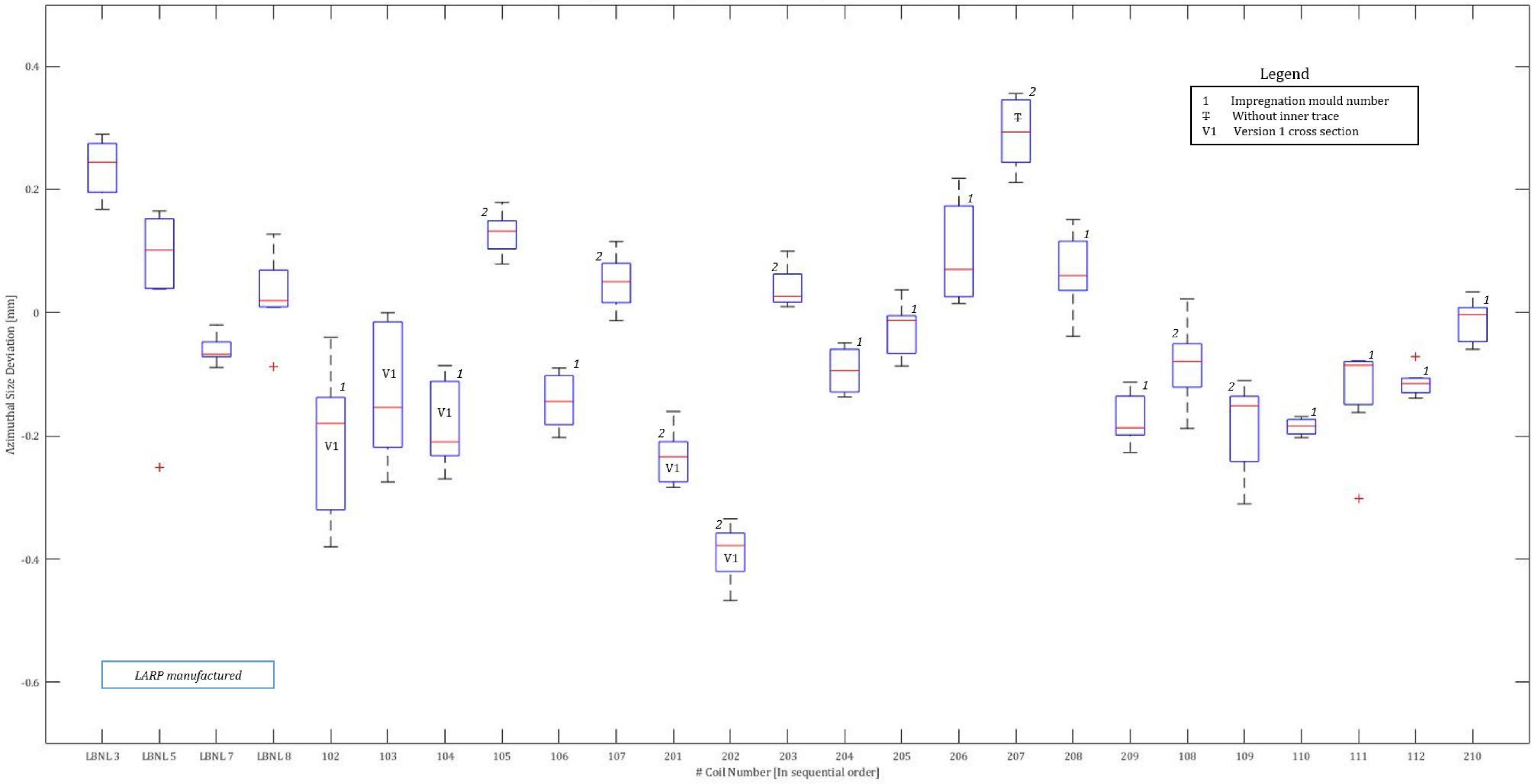
Deviation vectors left



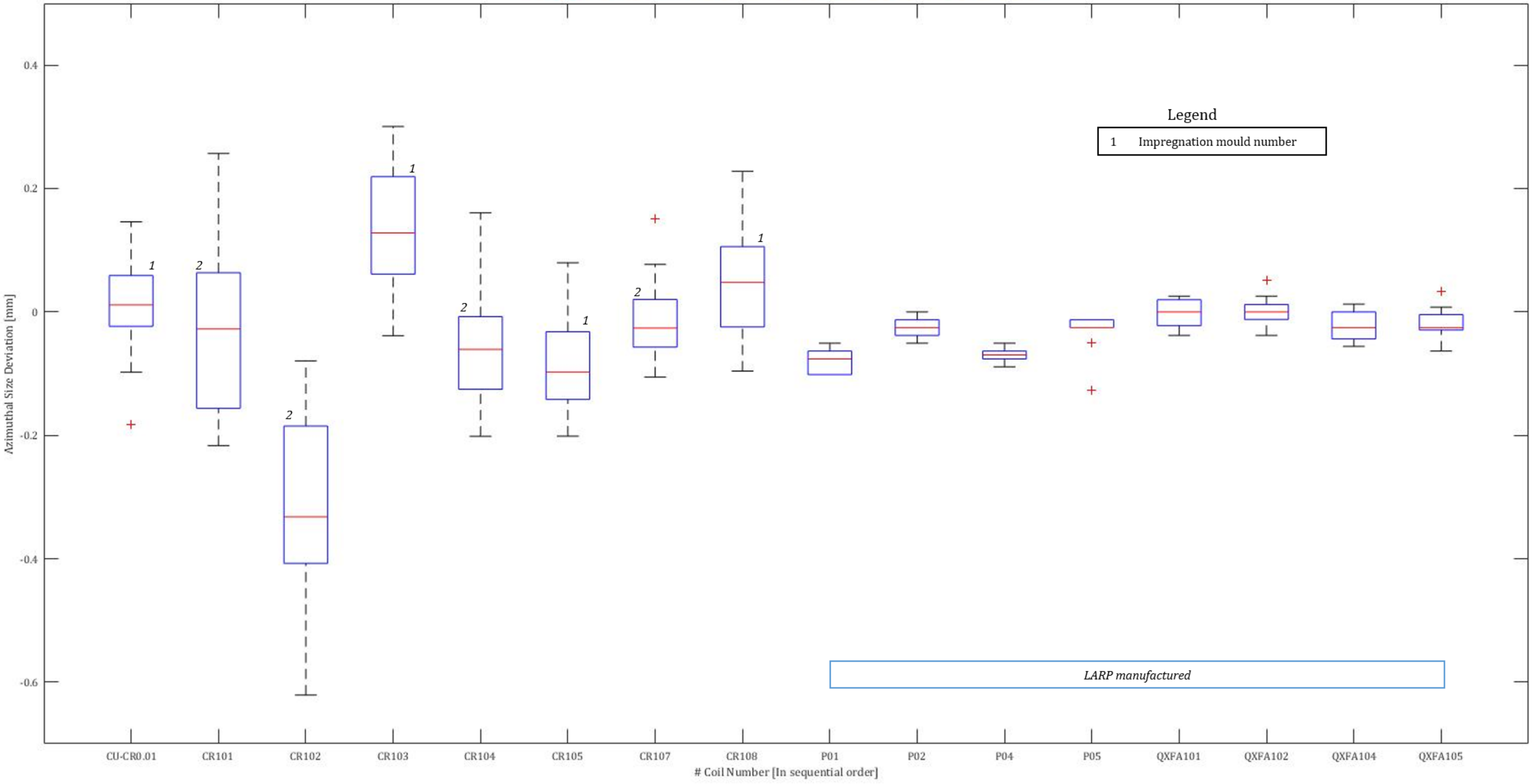
Deviation vectors right

Results:
Production plots

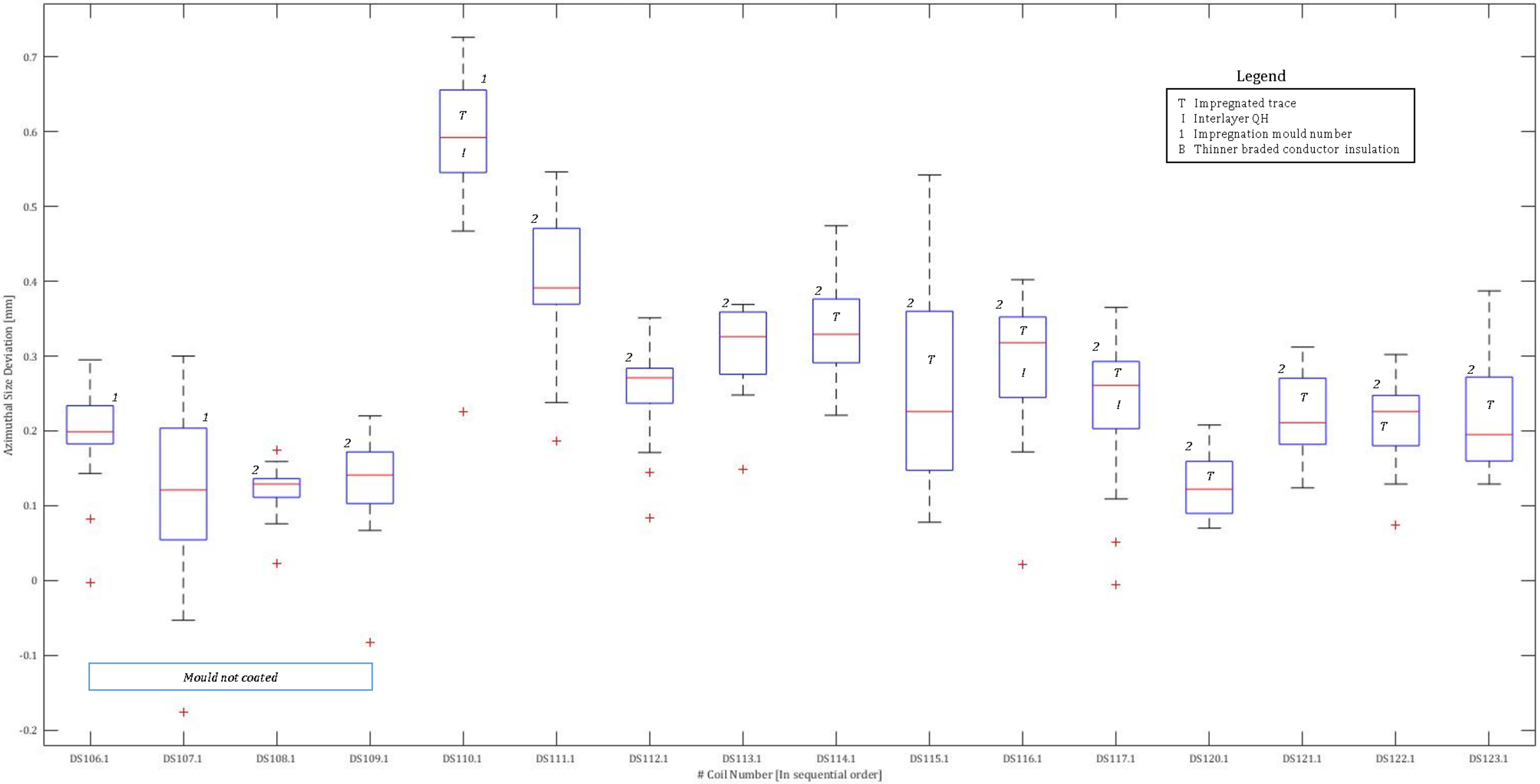
MQXFS Azimuthal Coil Size



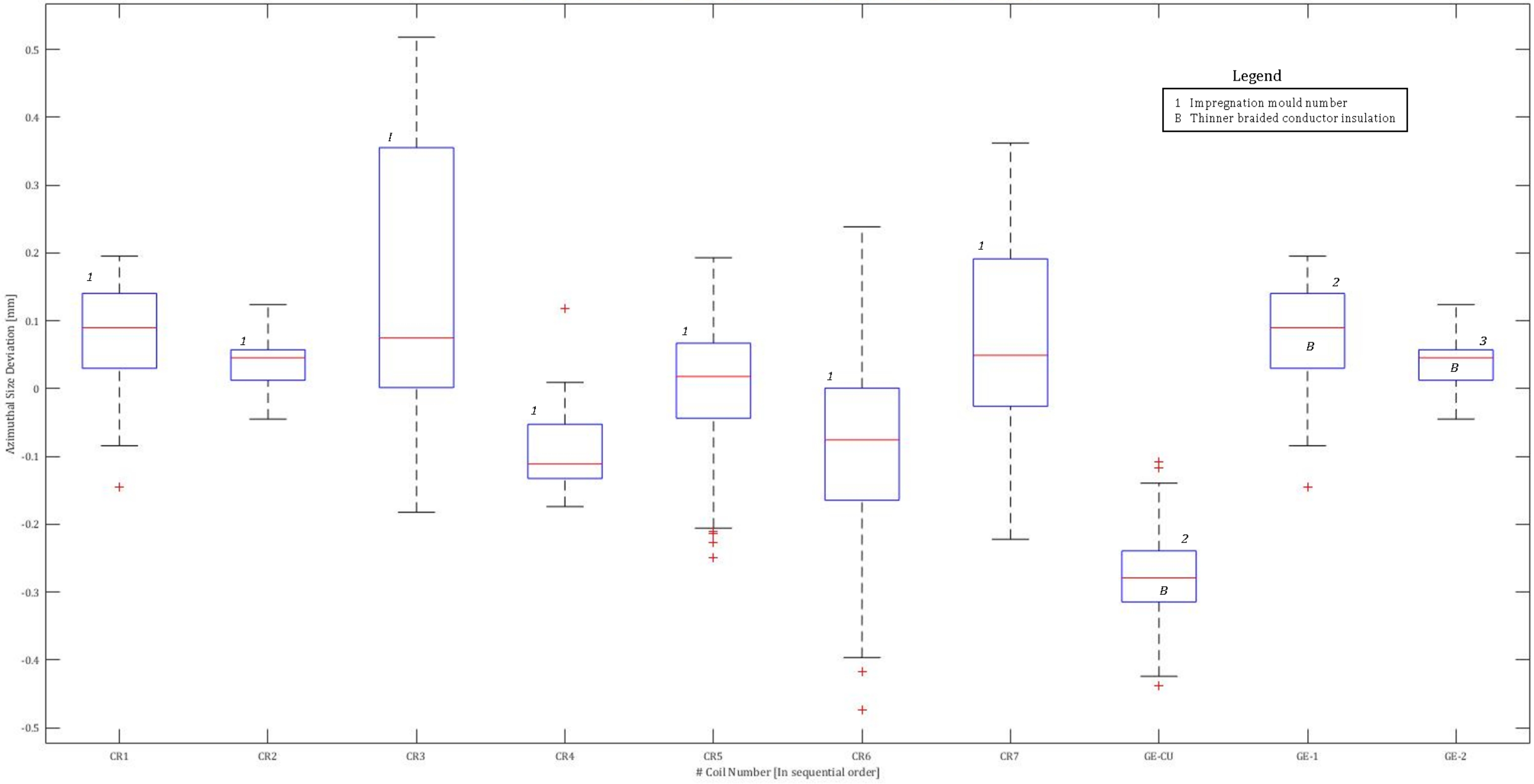
MQXFB&A Azimuthal Coil Size



DS11T Azimuthal Coil Size



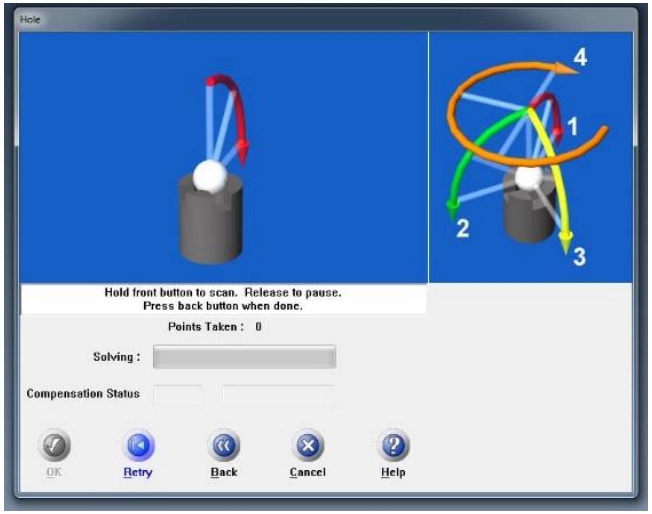
5.5 m 11T Coils Azimuthal Coil Size

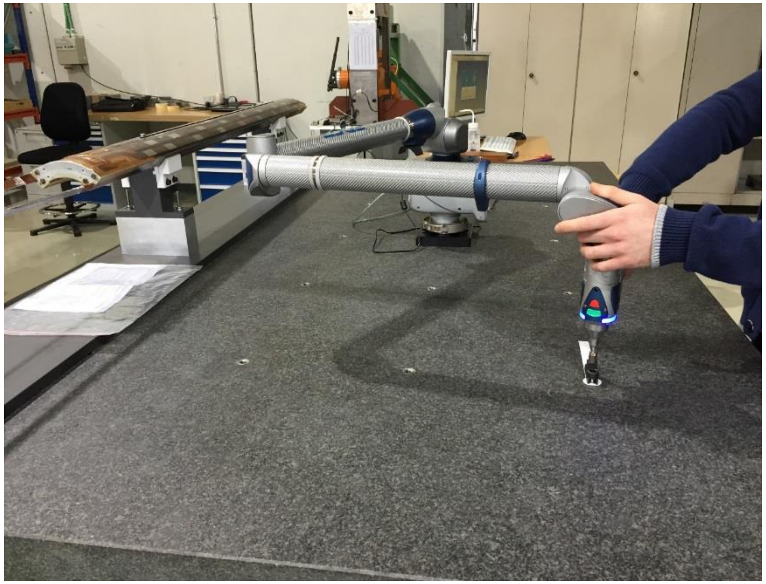


Annex:
Backup slides

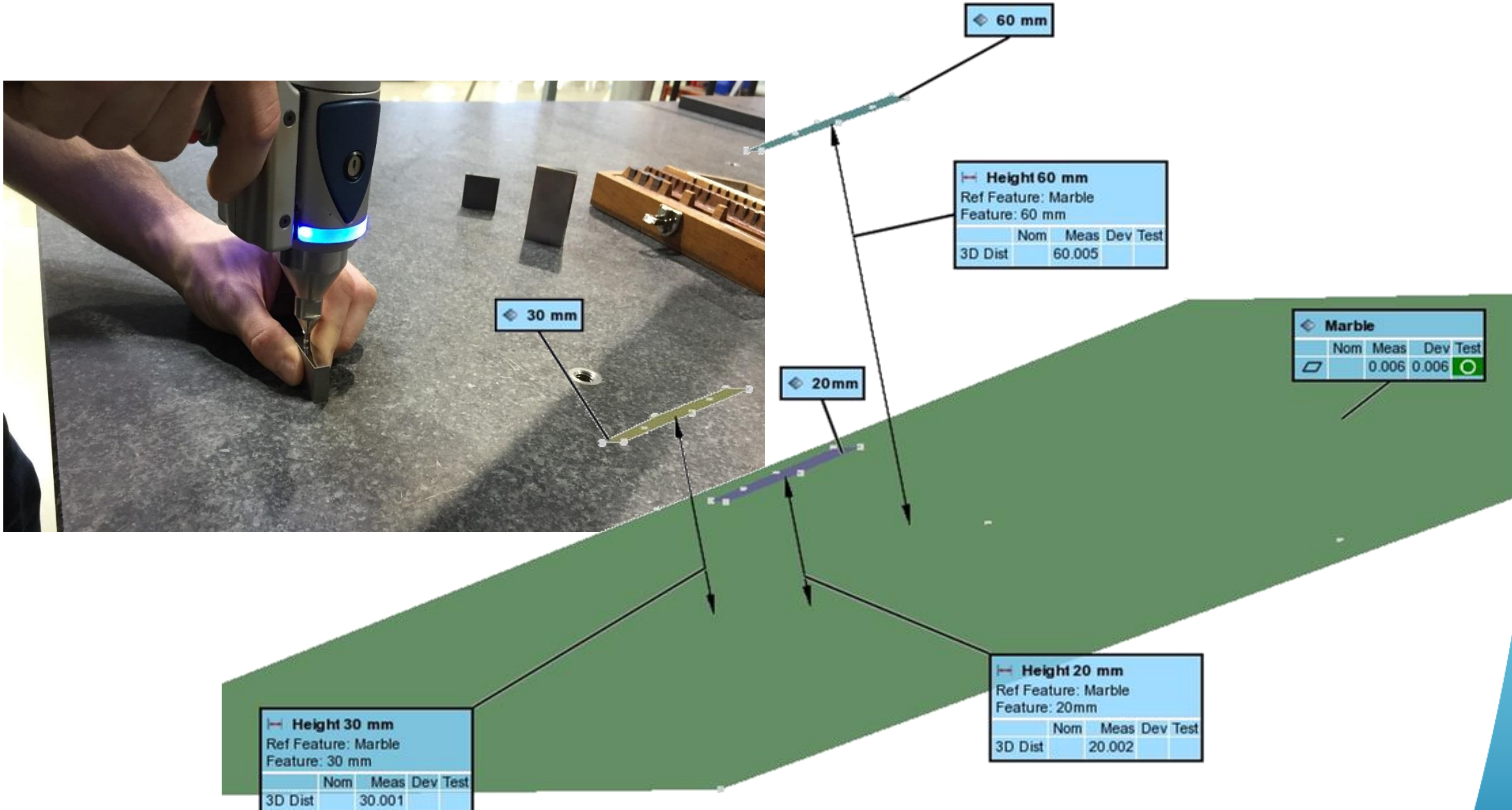
Procedure: Measurements Device compensation

- Performed following FARO hardware calibration procedures:
    - Hole compensation method (600 points)

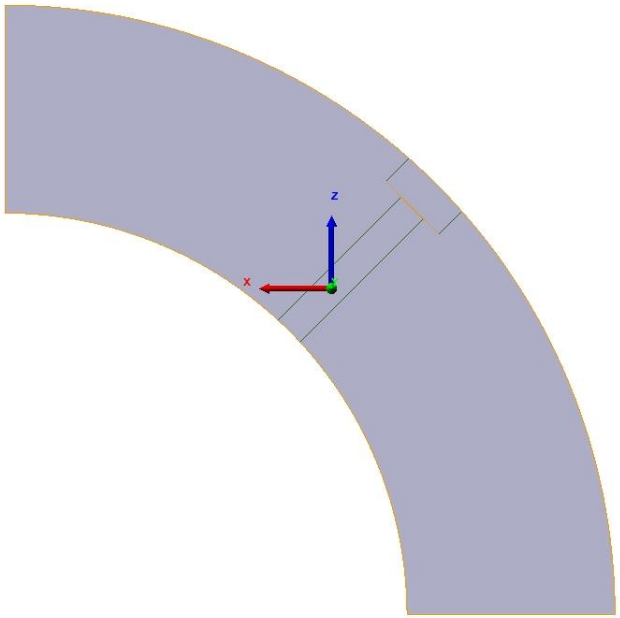


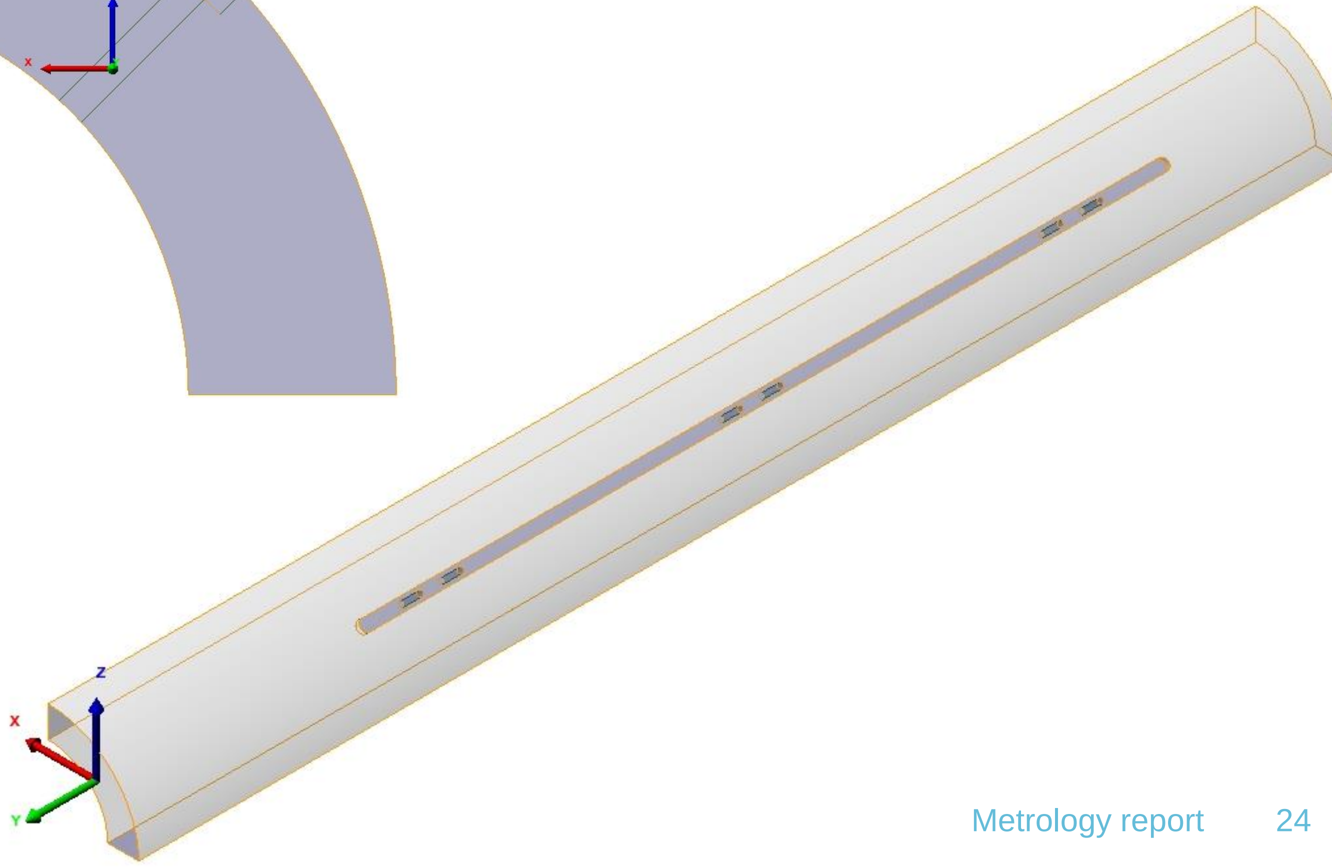


Procedure: Measurements
Device validation

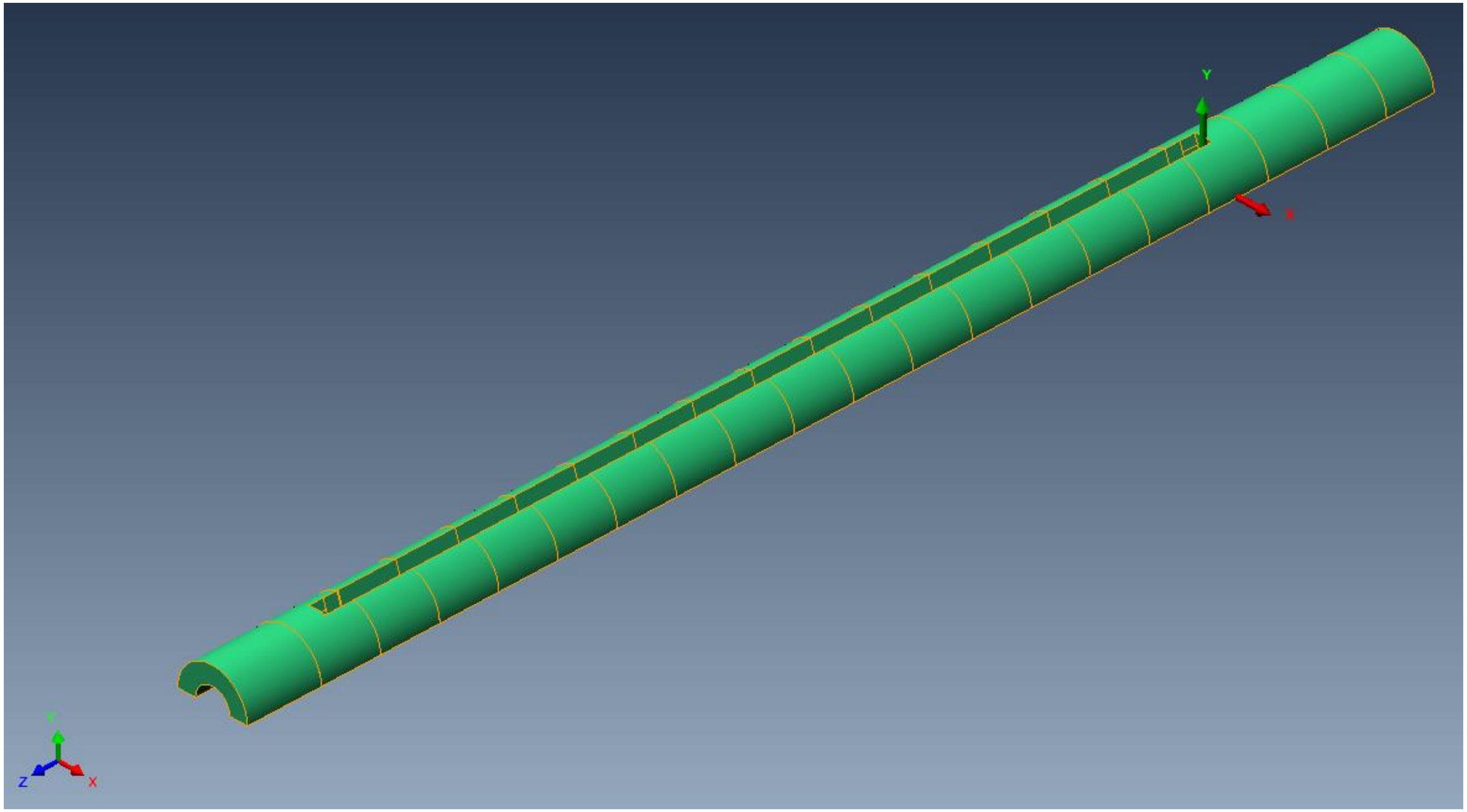


Procedure: Measurements
Reference system (MQXF Quadrupole)



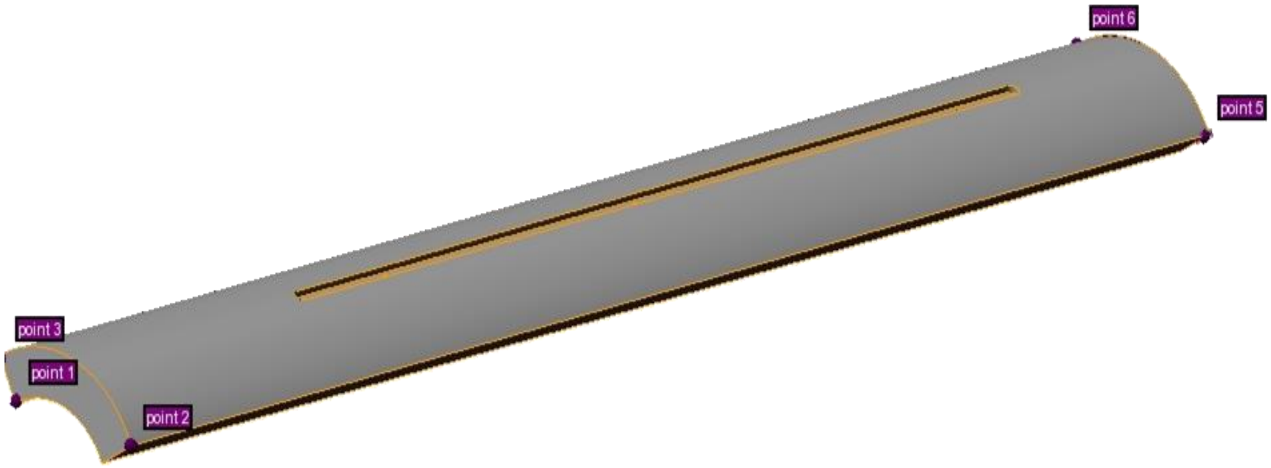


Procedure: Measurements
Reference system (11T dipole)



Procedure: Measurements
Pre-alignment

- Starting point: Pre-alignment of real coil to CAD model
  - Using 6 “Surface point alignment”
  - 6 points are defined in the CAD model, operator must probe the same 6 points in real coil
  - For improving reproducibility, singular points are chosen (Corners, edges…)



Procedure: Measurements
Best fit alignment (MQXF) (1/3)

- After the general geometry is probed, we perform a better alignment to precisely locate the cross sections

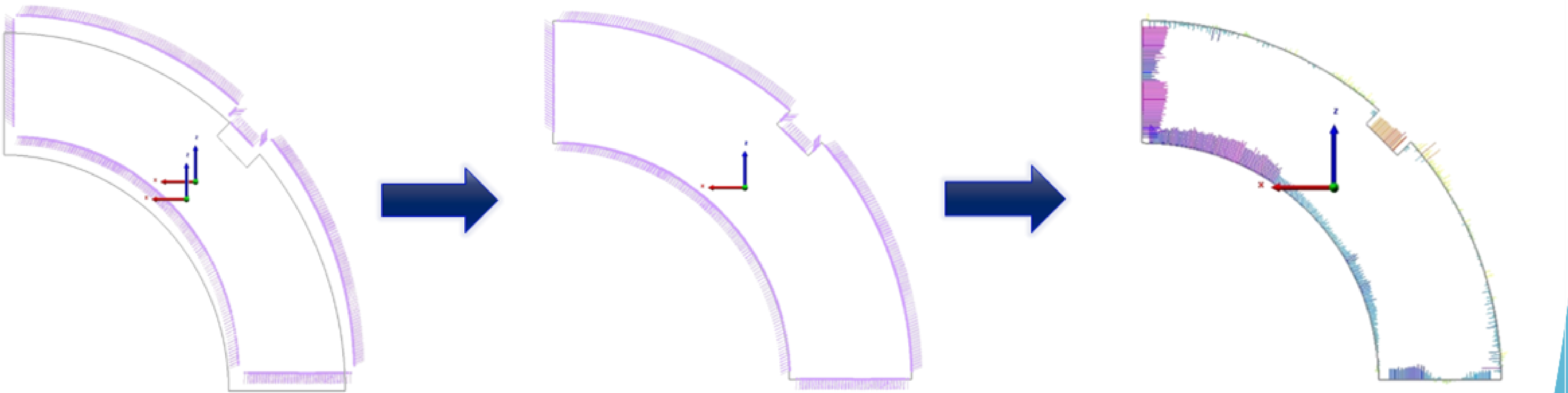
- Best-fit alignment of real point cloud to CAD model is performed using:
    - Lead end plane
    - Outer cylinder
    - Left key plane
    - Right key plane

- All degrees of freedom are fixed

- Coil is aligned to Lead end in order to define the cross section distances

Procedure: Measurements
Best fit alignment (MQXF) Cross section alignment (2/3)

- Example of cross section alignment



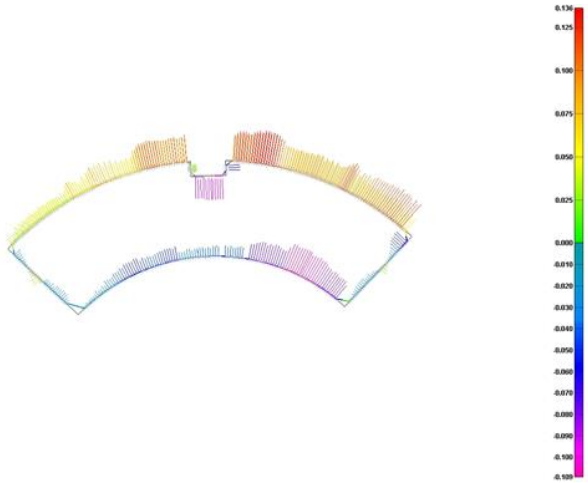
Probed points are far from nominal position because of banana shape

Each Cross Section is aligned individually to OD and key

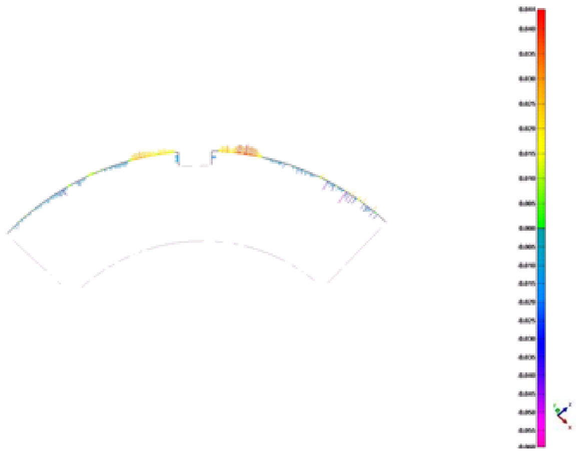
Deviations are obtained between nominal curve and real curve

Procedure: Measurements
Best fit alignment (MQXF) Cross section alignment (3/3)

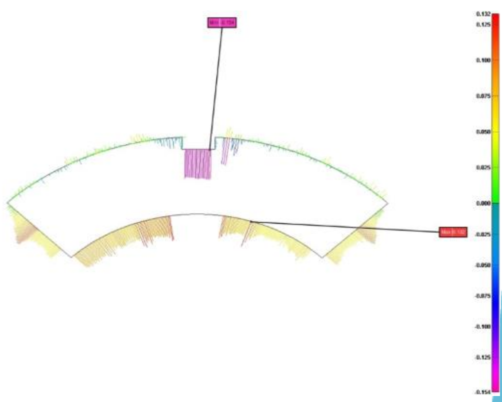
- Example of cross section alignment



Original CS
Banana shape present



CS aligned using special CAD

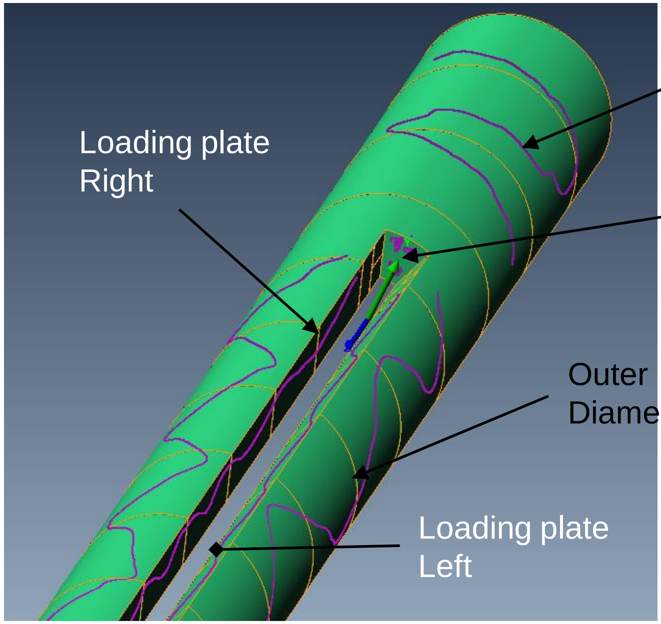


Resulting CS
Aligned points compared with full CAD

Procedure: Measurements
Best fit alignment (11T Dipole) (1/3)

- After the general geometry is probed, we perform a better alignment to precisely locate the cross sections

- Best-fit alignment of real point cloud to CAD model is performed using:
  - Pole end Lead end
  - Outer cylinder
  - Left loading plate plane
  - Right loading plate plane

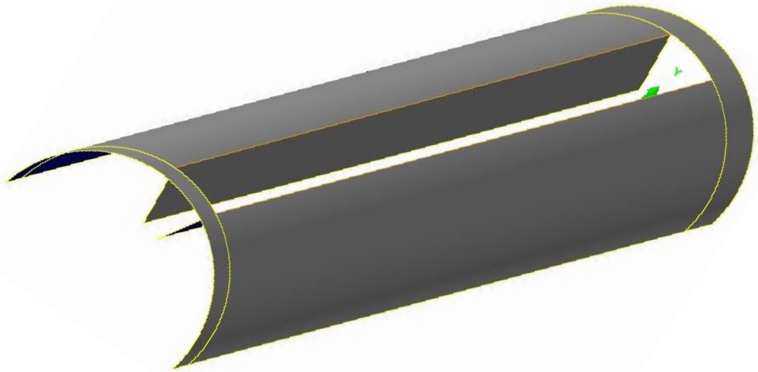


Procedure: Measurements
Best fit alignment (11T Dipole) (2/3)

- After first part of the probing process, information is enough to perform a better alignment

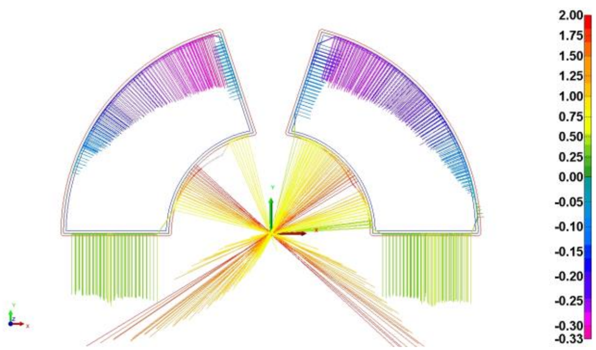
- Best-fit alignment of real point cloud to CAD model is performed using:
  - Pole end Lead end
  - Outer cylinder
  - Left loading plate plane
  - Right loading plate plane

- Coil is aligned to Lead end in order to define the cross section distances

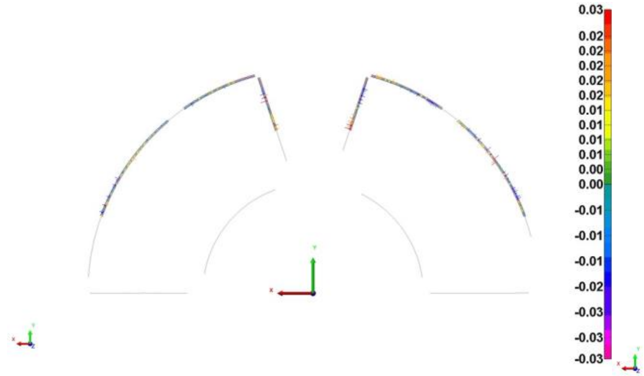


Procedure: Measurements
Best fit alignment (D11T Cross section alignment (1/3)

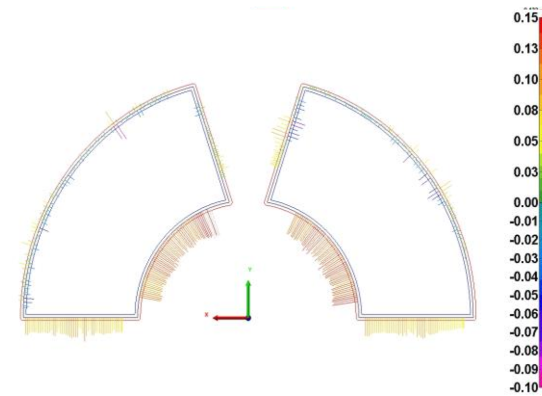
- Example of cross section alignment



Original CS
Banana shape present



CS aligned using special CAD



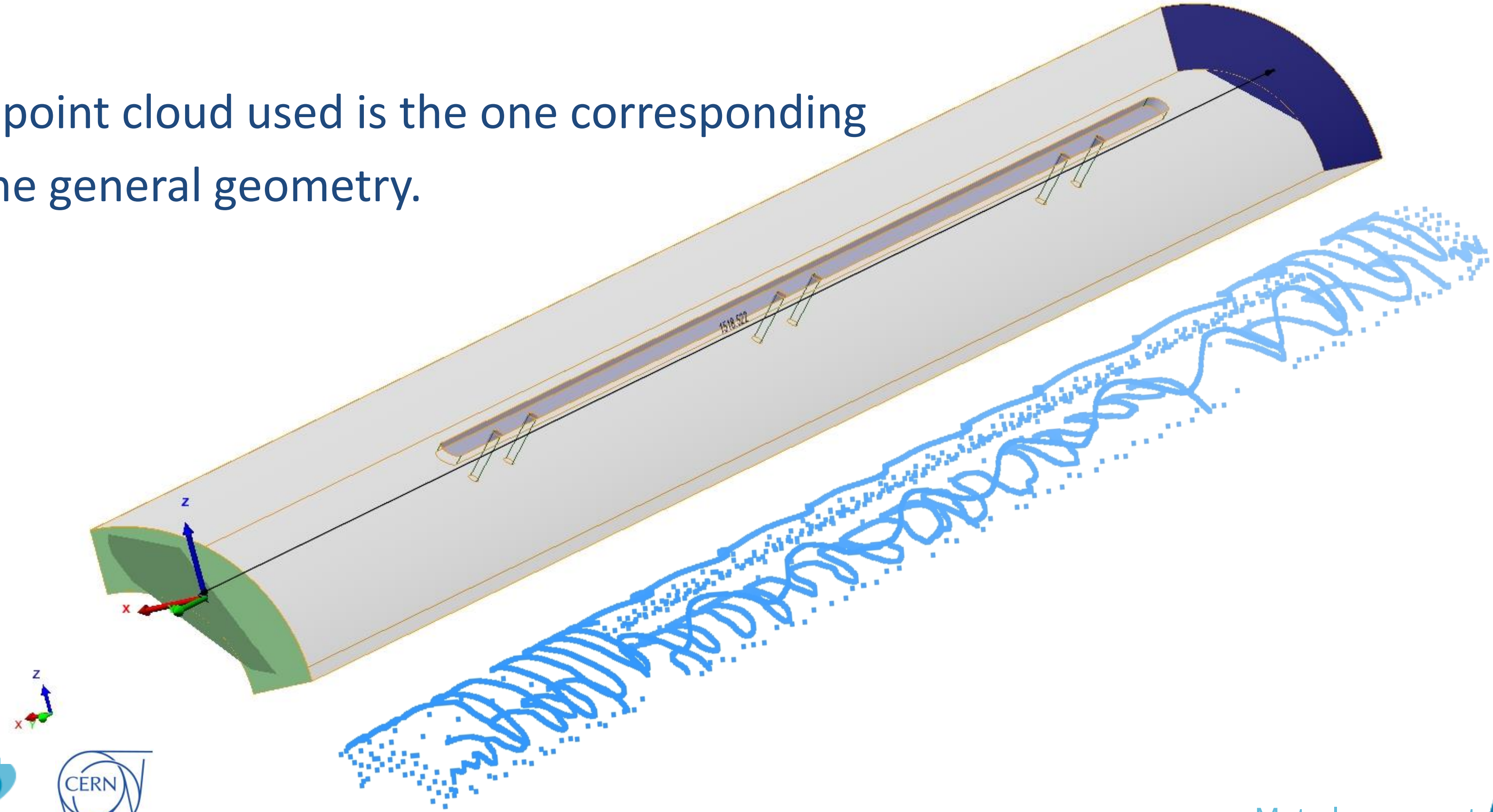
Final “CS Aligned” points and deviation vectors to nominal

Procedure: Measurements
Extra: Post-processing (V/IV)
Coil length

Ref.

- $coil\ length = y\_component[distance(lead\ end\ plane, return\ end\ plane)]$

- The point cloud used is the one corresponding to the general geometry.



Procedure: Measurements Extra: Post-processing (VI/IV)

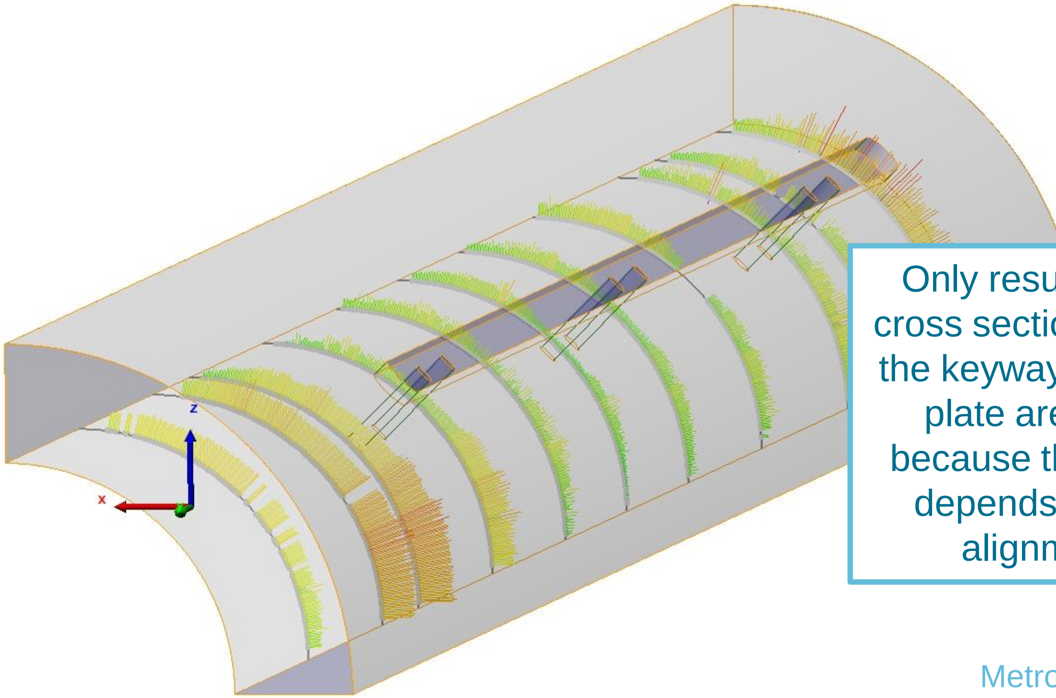
Coil width

- $coil\ width = avg[signed\_abs(deviation\ vectos\ wo\ outliers)]$

- The individually aligned cross sections are duplicated and then trimmed. Only the points belonging to the ID remain.

Sample results:

Name	***Dev***
Δ T3	-0.177
Δ T4	-0.100
Δ T5	-0.120
Δ T6	-0.058
Δ T7	-0.097
Δ T8	-0.101
Δ T9	-0.135

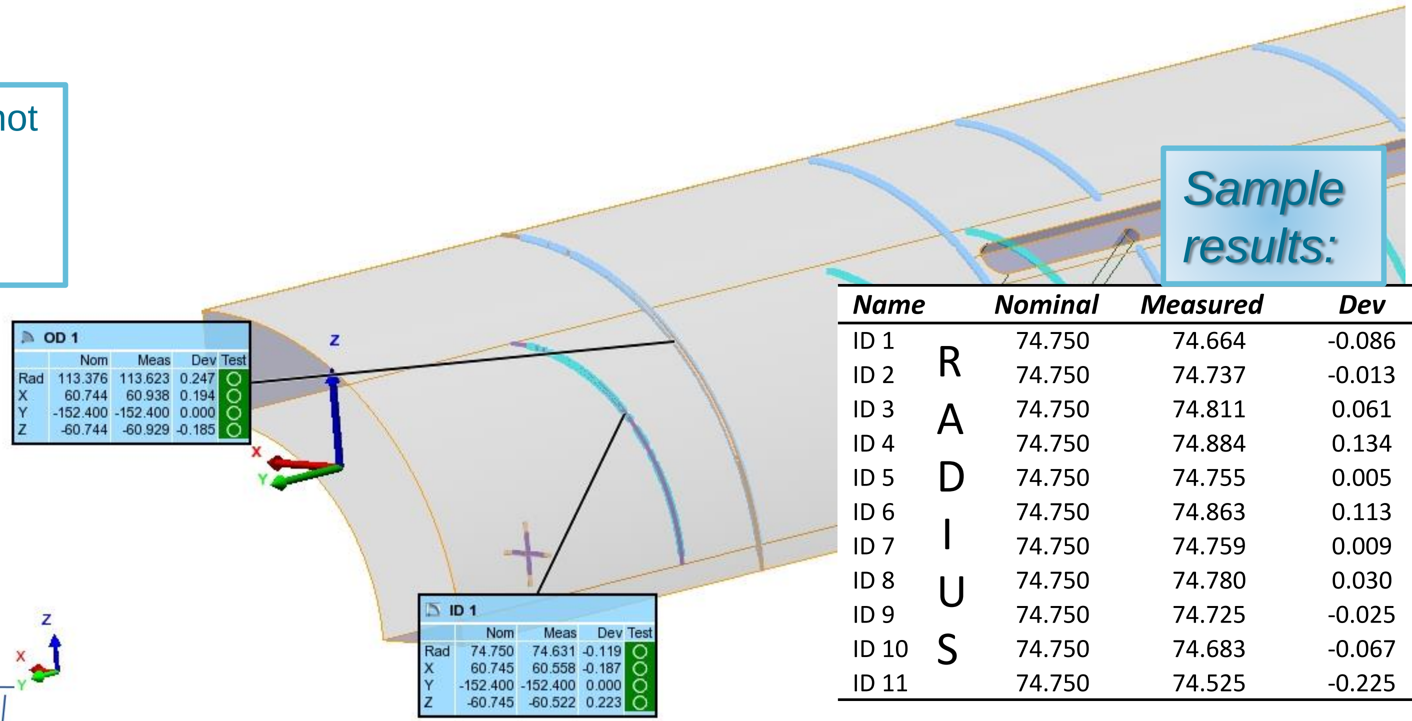


Only results from cross sections along the keyway//loading plate are used because the result depends on the alignment

Procedure: Measurements
Extra: Post-processing (VII/IV)
Outer diameter and Inner diameter

- Circumferences are best-fitted to the points belonging to the inner and outer diameter (wo outliers). The algorithm makes minimum the square of the deviation of the points belonging to the arc. Then the center and the radius are computed.

The radius does not depend on the alignment. The center does.



Sample results:

Name		Nominal	Measured	Dev
ID 1	R	74.750	74.664	-0.086
ID 2		74.750	74.737	-0.013
ID 3	A	74.750	74.811	0.061
ID 4		74.750	74.884	0.134
ID 5	D	74.750	74.755	0.005
ID 6		74.750	74.863	0.113
ID 7	I	74.750	74.759	0.009
ID 8		74.750	74.780	0.030
ID 9	U	74.750	74.725	-0.025
ID 10	S	74.750	74.683	-0.067
ID 11		74.750	74.525	-0.225

Thanks for your attention,