MedAustron quadrupole Magnets Harmonic results, comparison between SIGMAPHI and CERN measurements

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- SIGMAPHI news
- Introduction to MedAustron project
- Measurement bench configuration and rotating coil manufacturing
- Measurement qualification
- Measurement results – harmonics and axis shift
- Comparison with CERN (MedAustron) measurements
- Conclusion

SIGMAPHI NEWS

Sigmaphi has been specialized for 30 years in the design, manufacture and measurement of magnetic systems for particle accelerators

- 2012 sales 11,4 M€, 95% exported to major labs around the world and to hadrontherapy industrial companies
- 70 people

Sigmaphi took over in March 2013 the Power Electronics group of Bruker

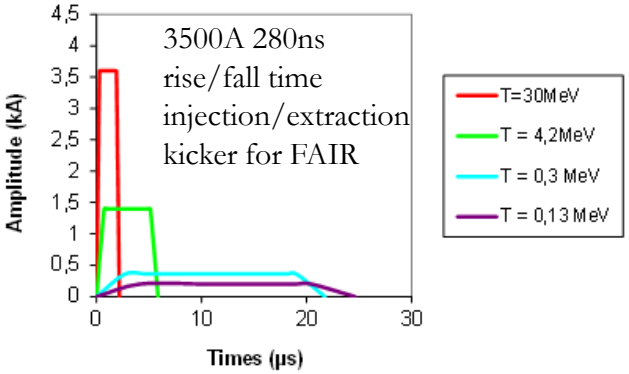
- Ultrastabilized power supplies up to MW
- RF Solid State Power Amplifier
- 43 people, highly skilled, 2012 sales 5 M€

- Magnets facility in Vannes (France)
- Electronics facility in Wissembourg (France)
- 100% Sigmaphi owned facility in Beijing; same quality and management as in our French facilities
- Branch in Japan

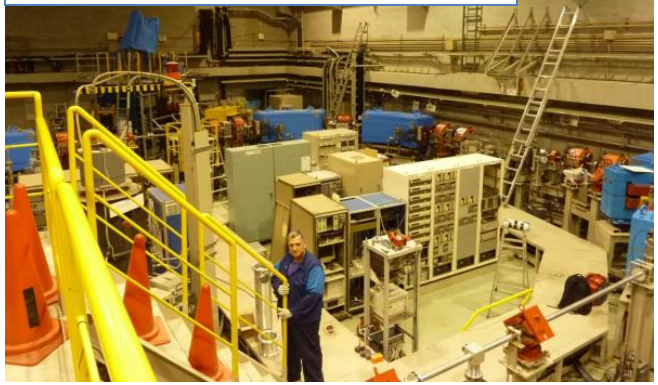
SIGMAPHI NEWS

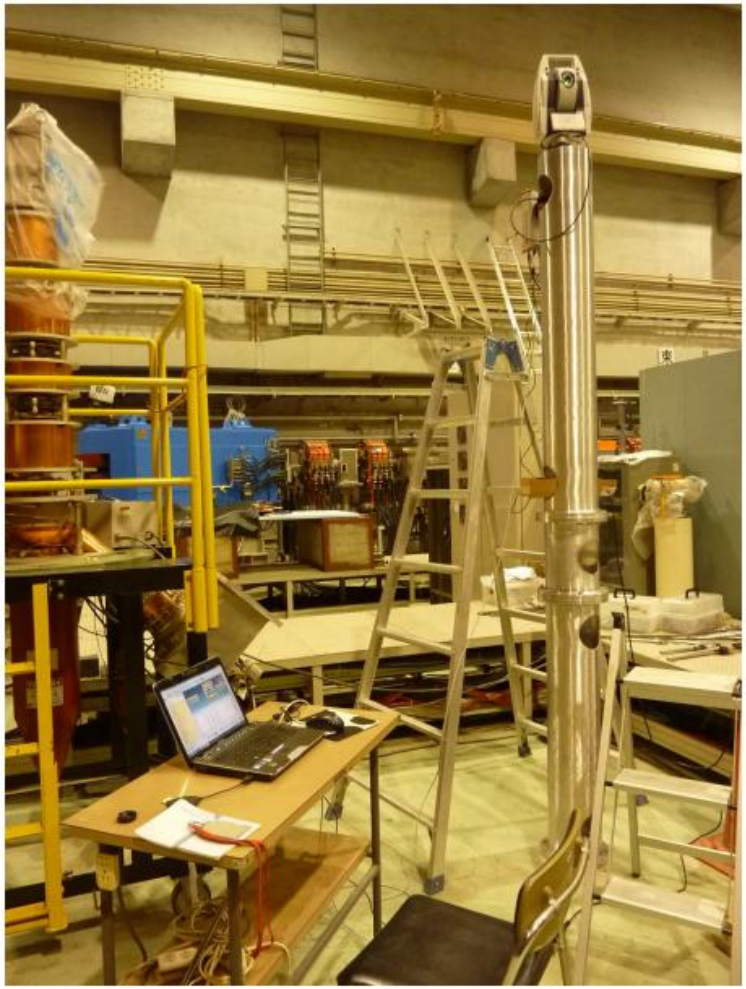
Accelerator technologies

- Injection/extraction pulsed systems
- Complete particle beamline design, installation and alignment
- Accelerator design



Magnets alignment Tohoku - Japan



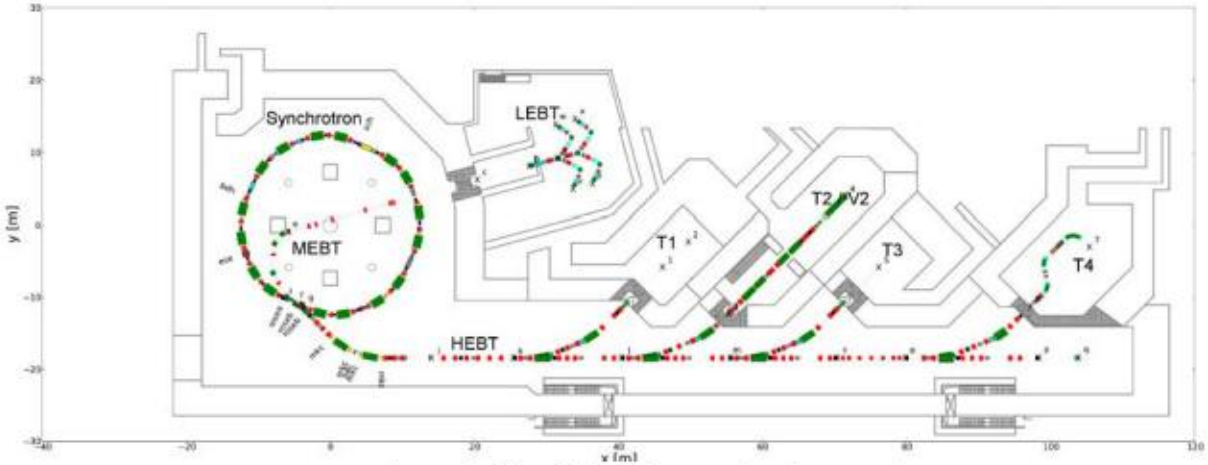


The tracker in location 3 is on a 2.7 m pedestal, thus making sighting level about 2.9 m above ground level

Introduction / MedAustron project

Centre for ion therapy and research in Austria
Quadrupole Magnets for the Synchrotron, MEBT and HEBT lines

27 MQZ-C
11 MQZ-B
81 MQZ-E



Layout of the *Med*Austron accelerator complex

Measurement main issues

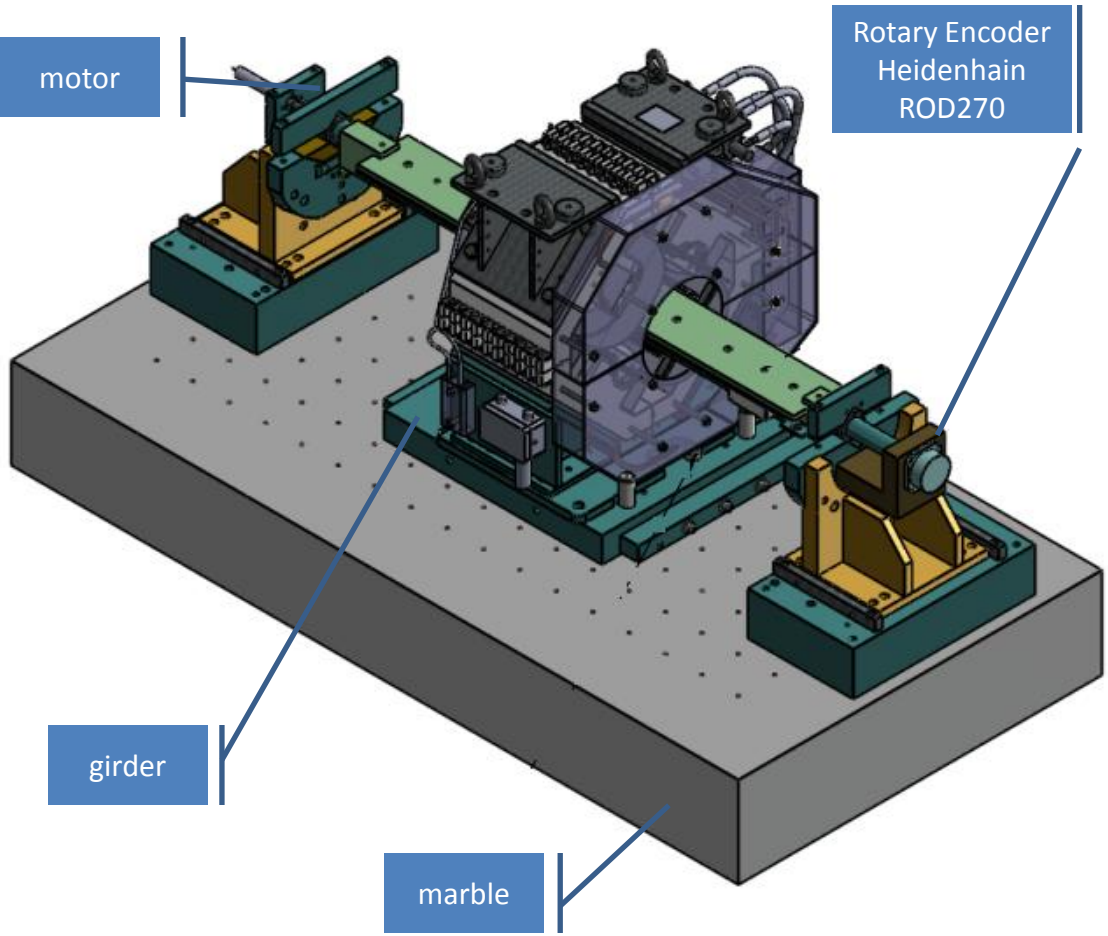
- Upgrade of our rotating coil bench (a new girder)

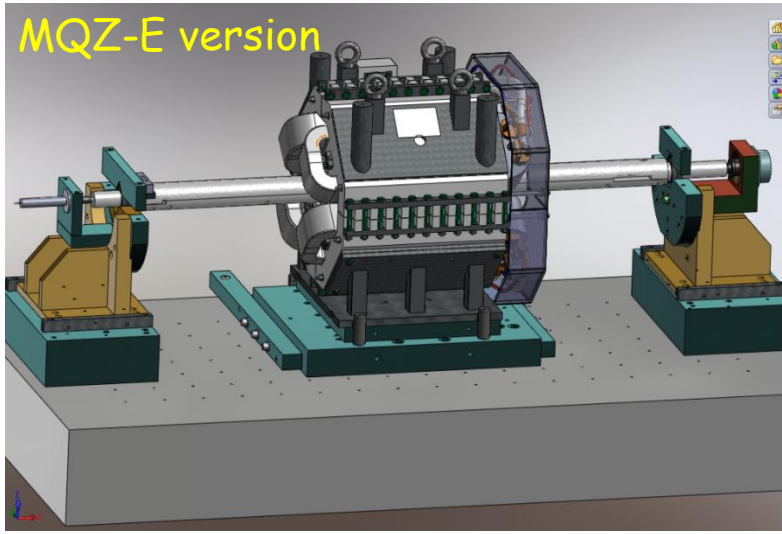
- 2 new rotating coils
  - one FR4 rotating coil, active length 1150mm, Rmeas=67mm (Rmax=70mm)
  - one carbon fiber rotating coil, active length 1150mm, Rmeas=30mm (Rmax=32mm)

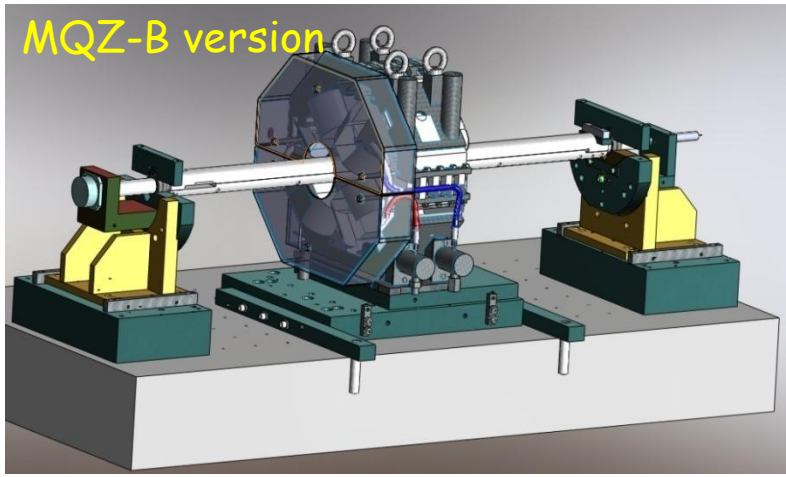
- Minimum current value 1.4A (MQZB/MQZE) and 18A (MQZC)

- Measurement Qualification with a cross-check measurement of 4 prototypes at CERN

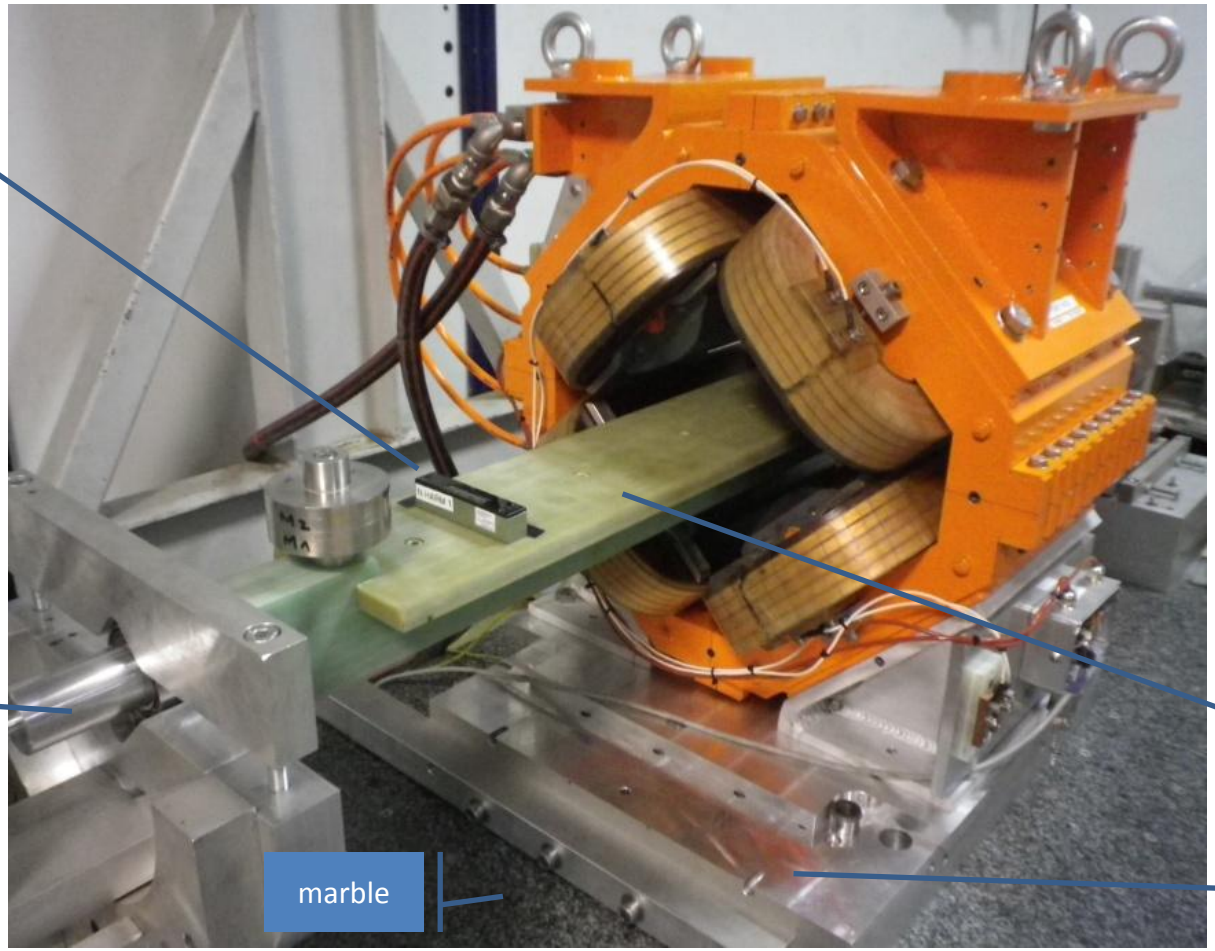
HARMONIC BENCH design (MQZ-C version)







HARMONIC BENCH design (MQZ-C version)



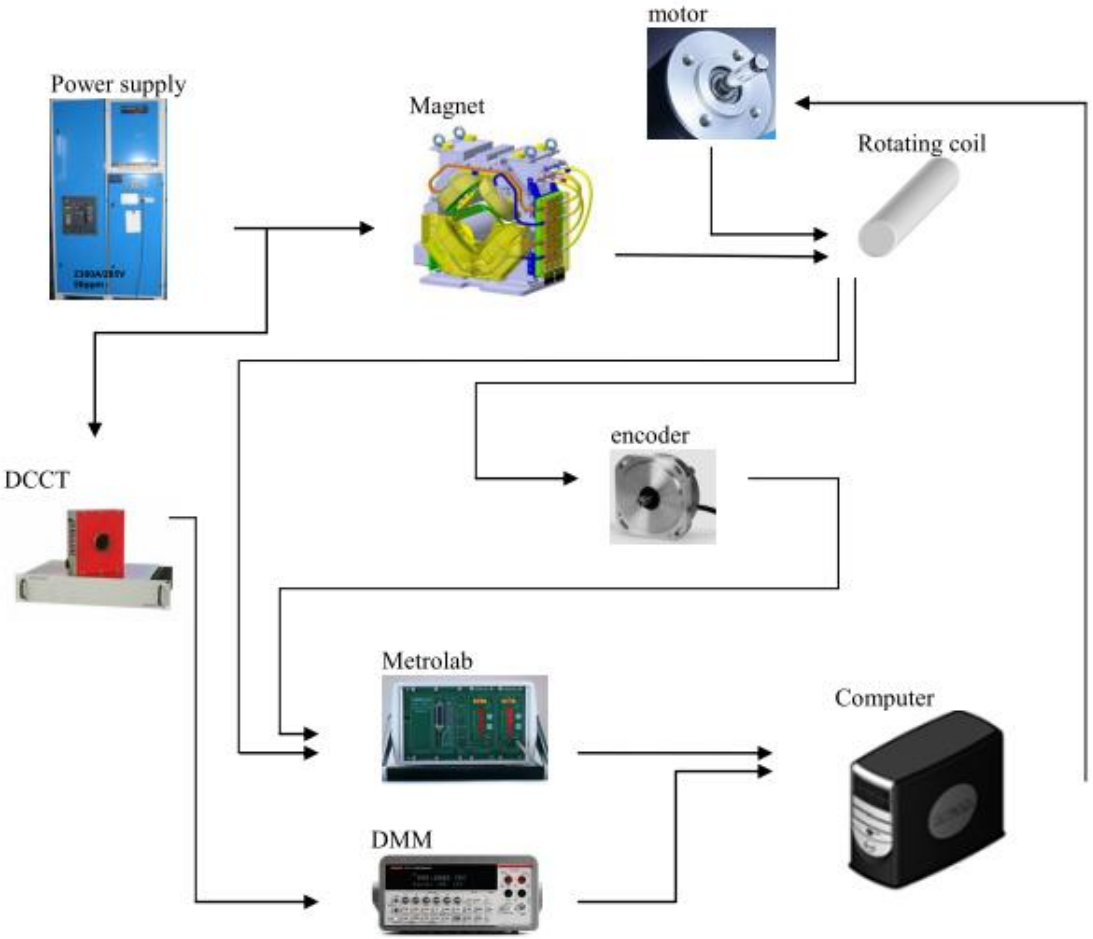
HARMONIC BENCH – description of the measurement chain (MQZ-C version)

Power converter
• Hazemeyer 0/2285A

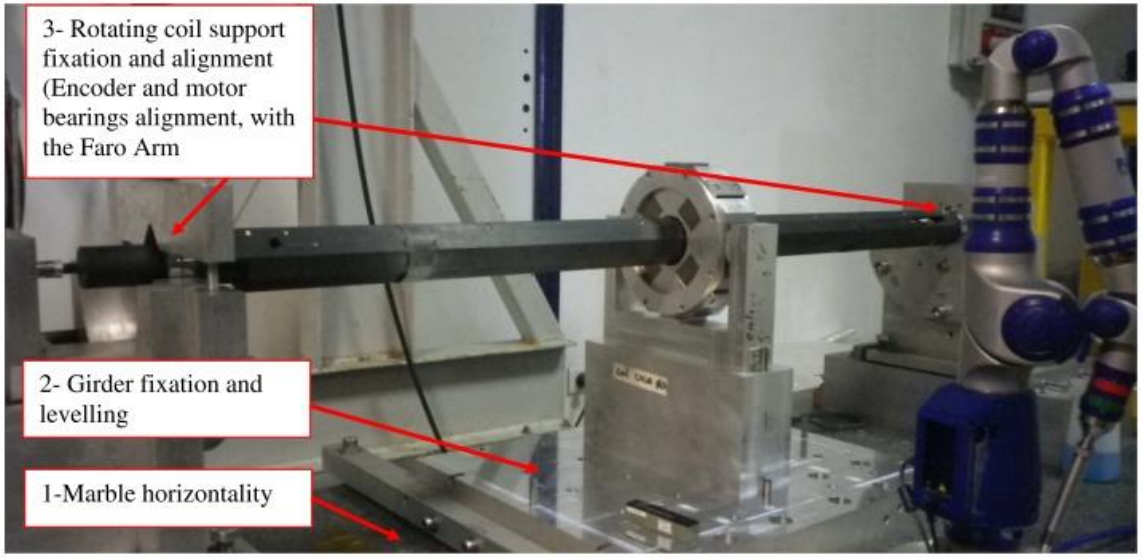
DC current transducer
• DCCT Danfysik 0/2000A
linearity < 1.5ppm, offset < 15ppm
Noise < 0.3ppm

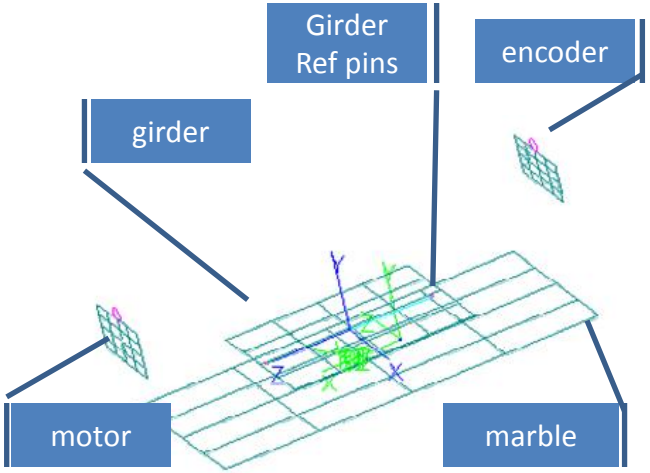
Rotating coil system
• Quadrupole mole diameter 147mm, with maximum 70mm reference radius (Rref = 67mm), and an effective coil length of 1150mm
• rotary encoder 720000 points
• bubble level 0.02mm/m

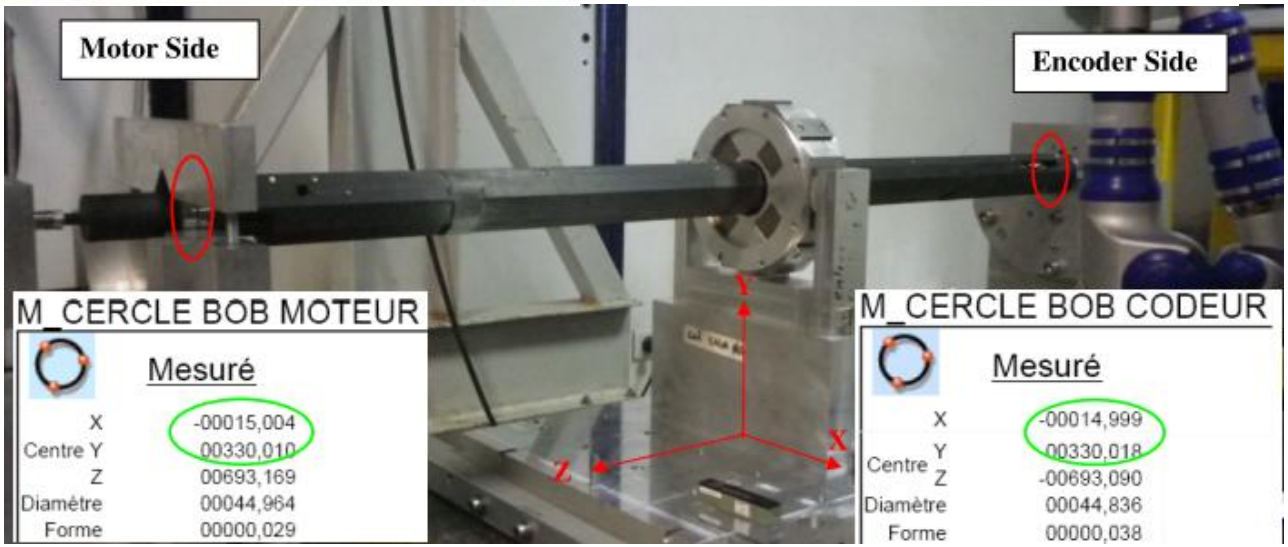
Metrolab PDI5025



HARMONIC BENCH alignment results





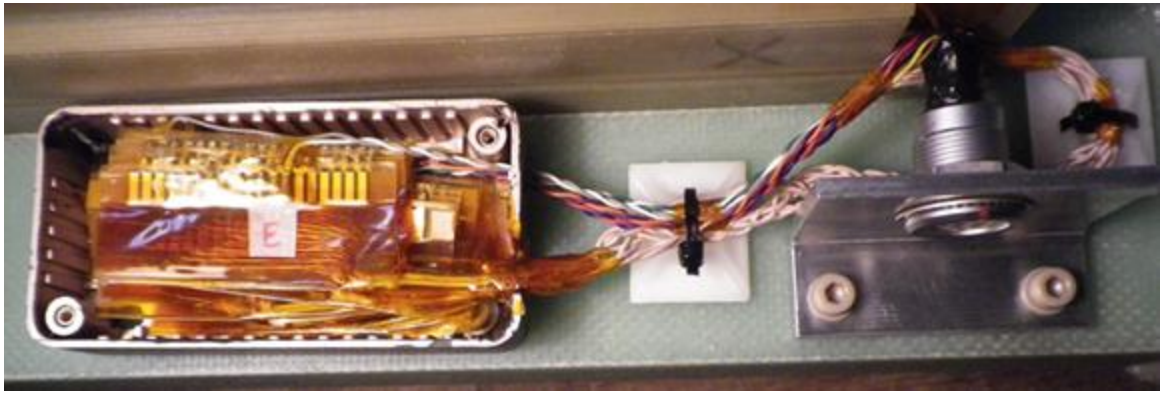


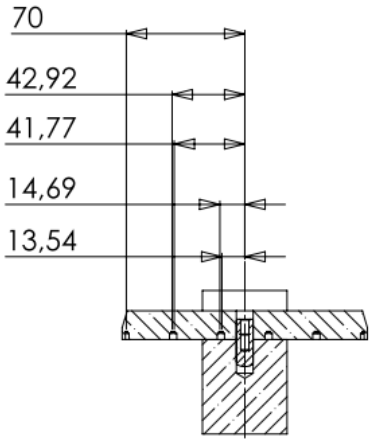
Theoretical values

X = -15.000 mm

Y = 330.000 mm

Rotating coil, Design and manufacture





Dimensions

- External ∅ = 147mm

Max Reference radius = 70mm

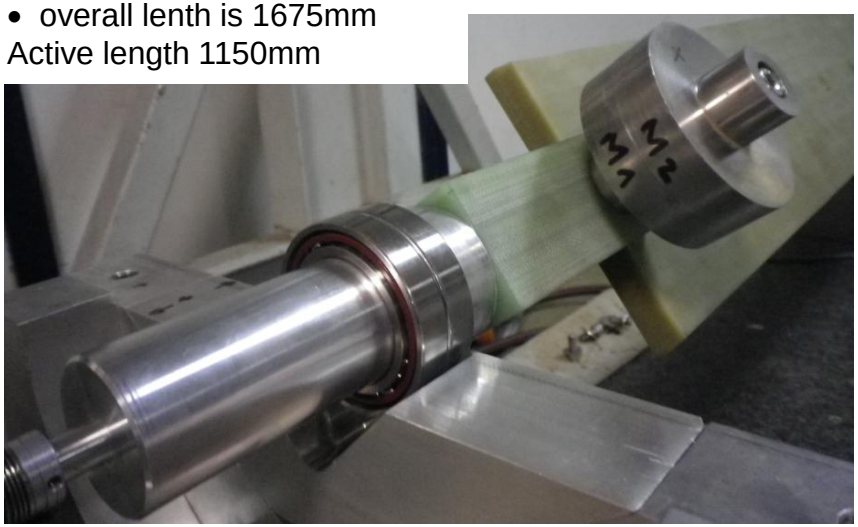
- overall lenth is 1675mm

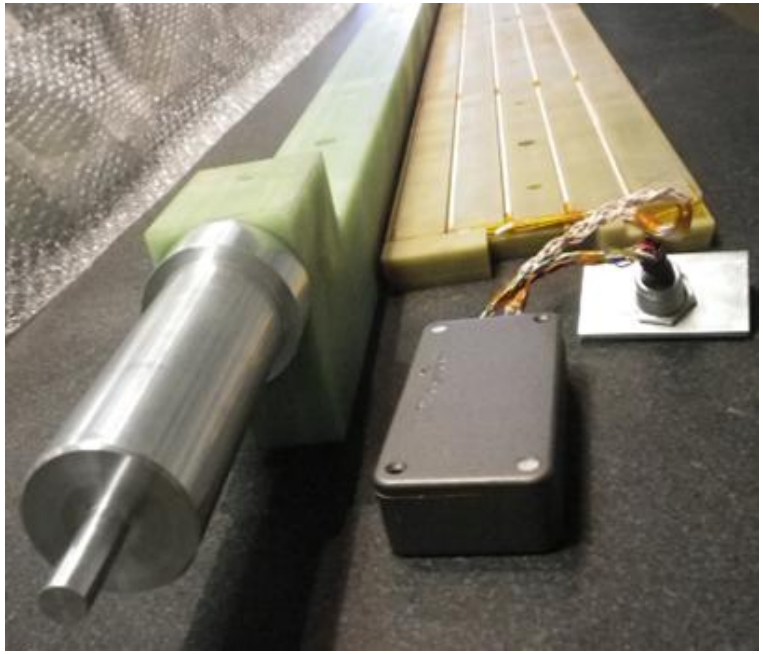
Active length 1150mm

Litz wire

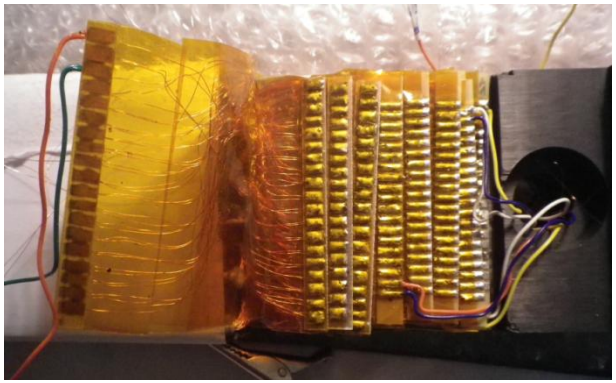
Multi-filament wire = 66 filaments

External ∅ 1.15mm, 1 turn

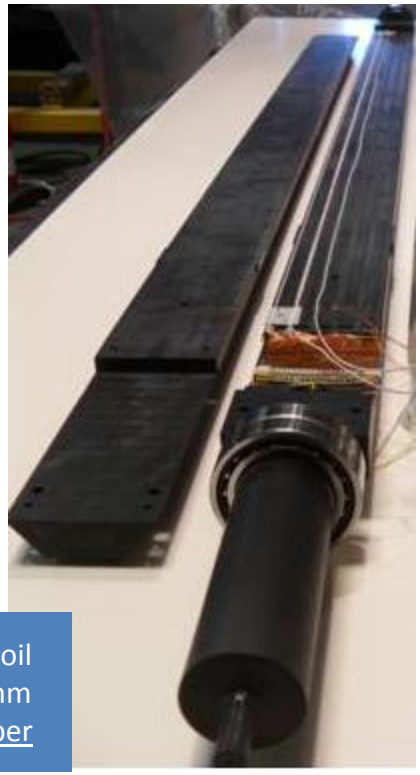


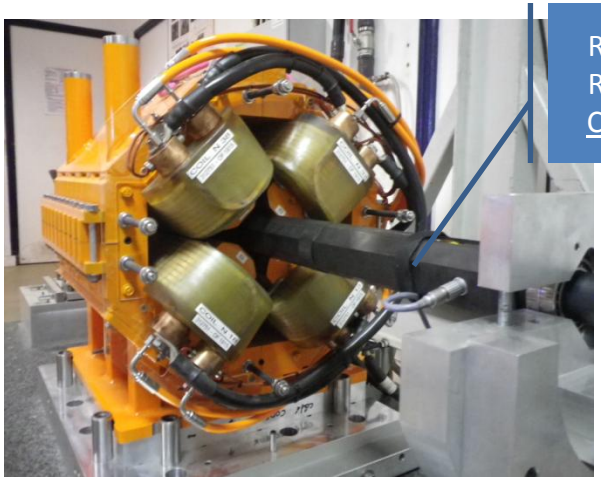


Rotating coil, Design and manufacture

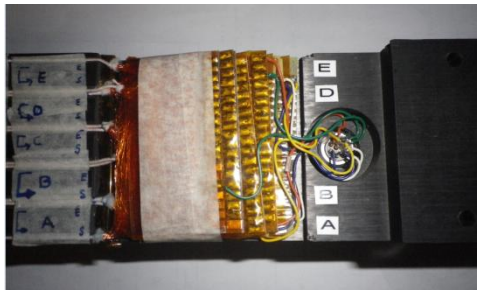


Litz wire connections

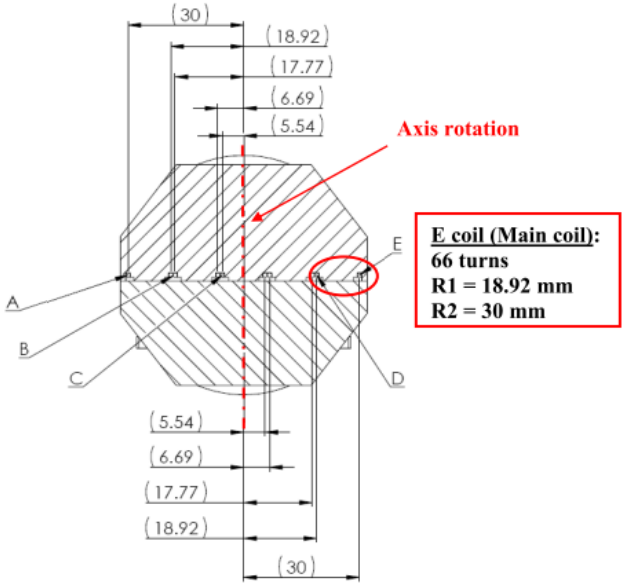




Rotating coil
Rref =30mm
Carbon fiber



Mechanical data (radius position)



Dimension

- External ∅ = 67 mm

Max reference radius = 30mm

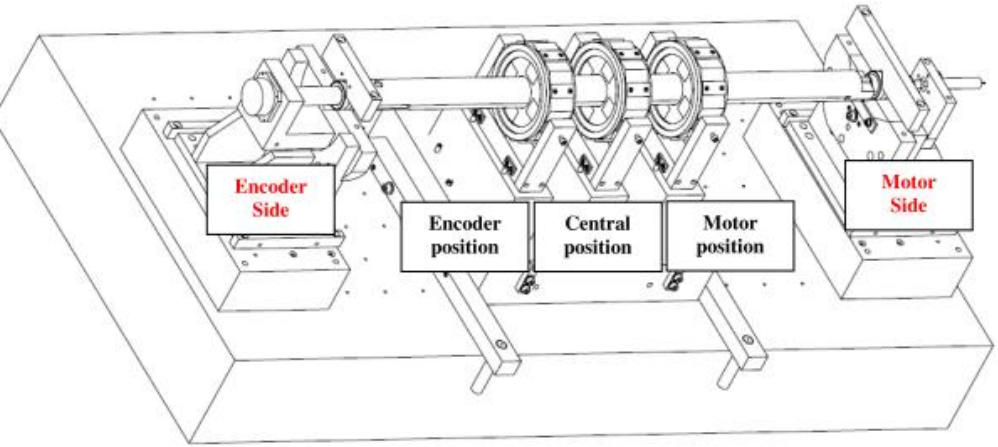
- Overall length is 1675 mm,

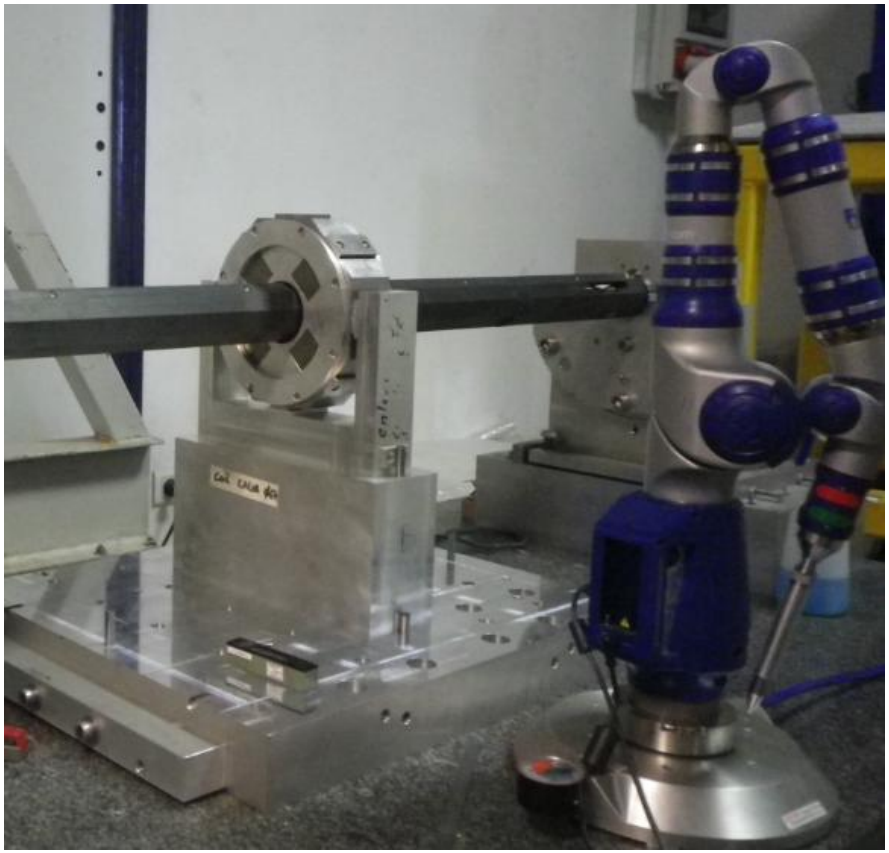
Active length = 1150 mm

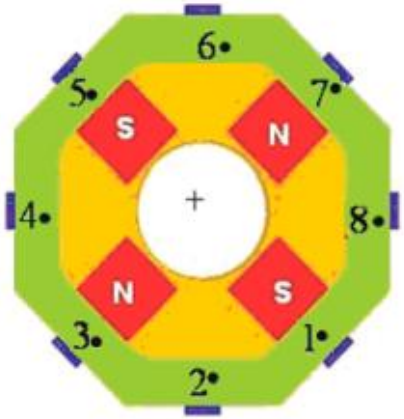
Litz wire

Multi-filament wire = 66 filaments
External ∅ = 1.15 mm
1 turn

Rotating coil calibration with our quadrupole permanent magnet

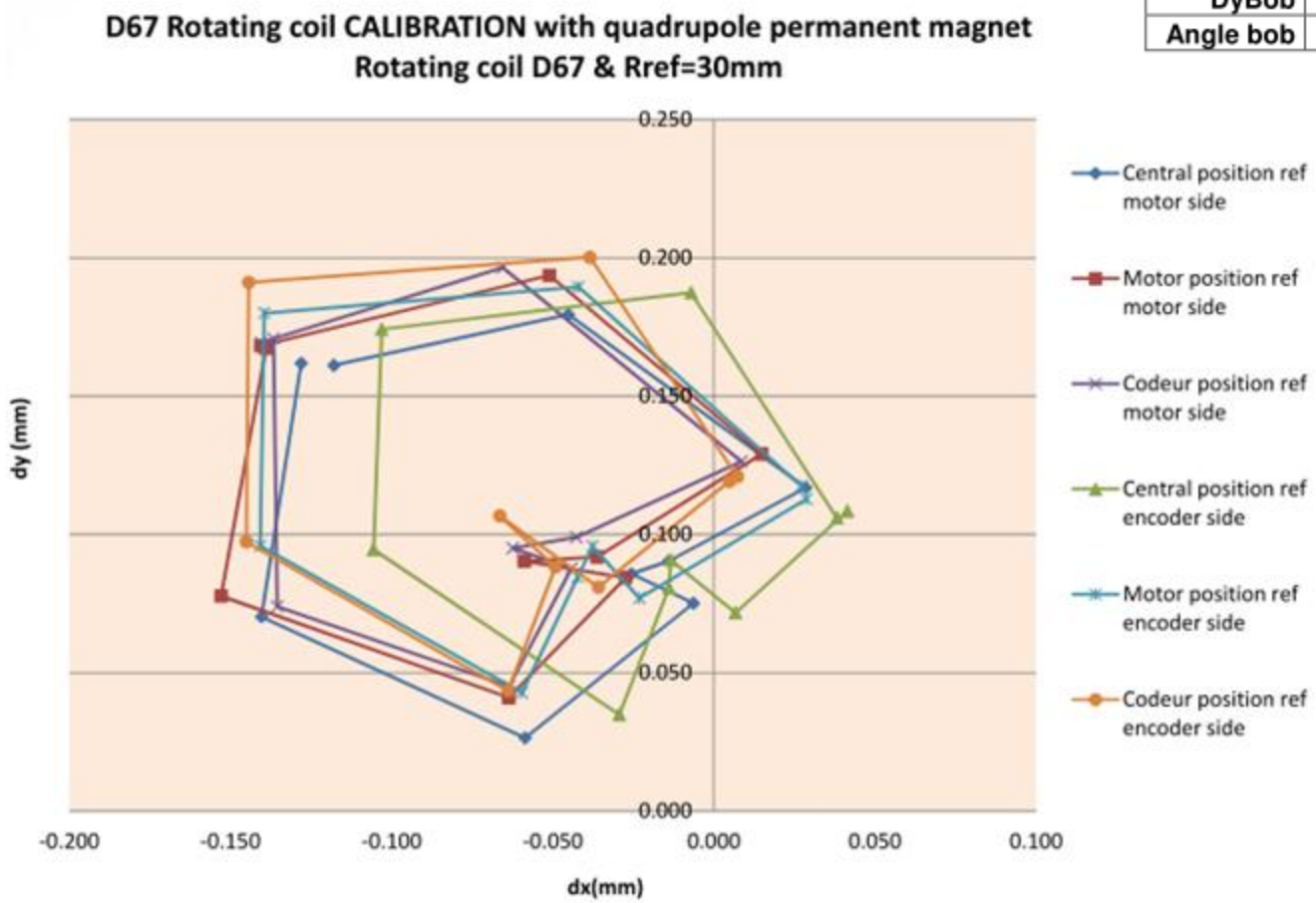




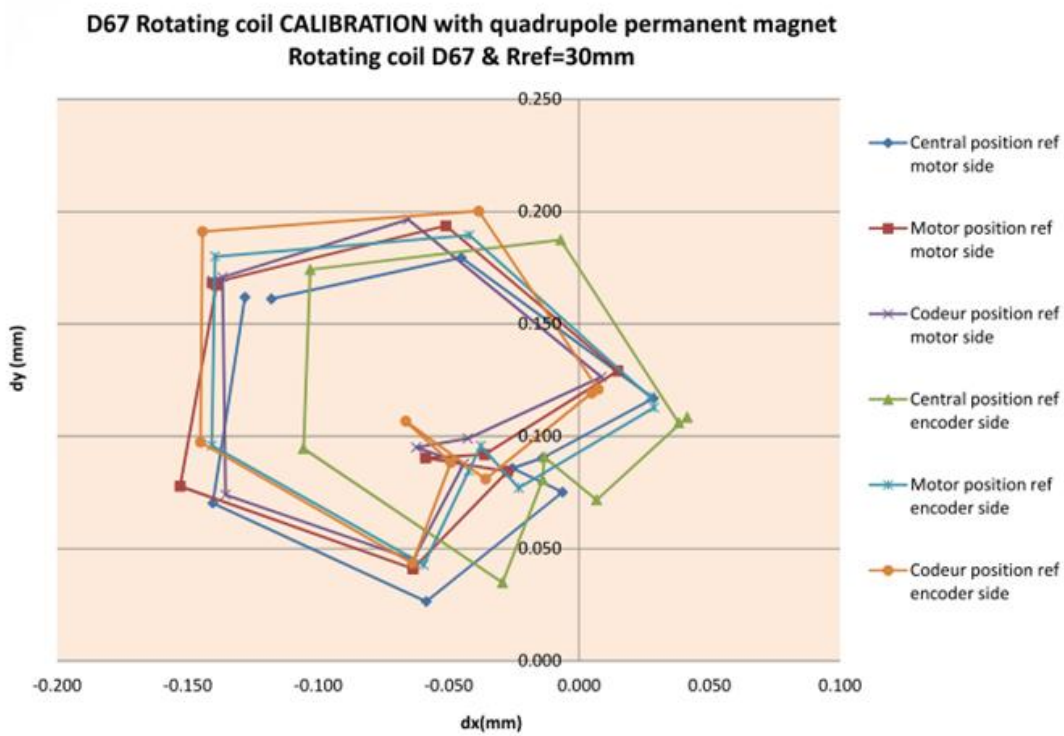


Rotating coil calibration RESULTS

DxBob	-39	µm
DyBob	103	µm
Angle bob	2.28	mrad



Rotating coil calibration
Comparison between both rotating coils



DxBob	-39	µm
DyBob	103	µm
Angle bob	2.28	mrad

D147R67 offset values

Dx Coil (mm) :	-0.048
Dy Coil (mm) :	0.165
Theta Coil (rad) :	-0.0022

Comparison results MQZC2	D147R70	D67R30
ref radius meas (mm)	30	30
dx (mm)	0.062	0.077
dy (mm)	0.201	0.204
θ (rad)	0.0014	0.0010
Main field module (T.m)	0.04313	0.04310
Gdl (T)	1.4378	1.4365
c3 (units)	0.87	0.87
c4 (units)	0.09	0.08
c6 (units)	0.09	0.15
c10 (units)	0.01	0.07
c14 (units)	0.00	0.19
Sum c3 to c15 (units)	1.07	2.28
Field reconstruction max (units)	0.92	1.30
Field reconstruction min (units)	-0.96	-1.28

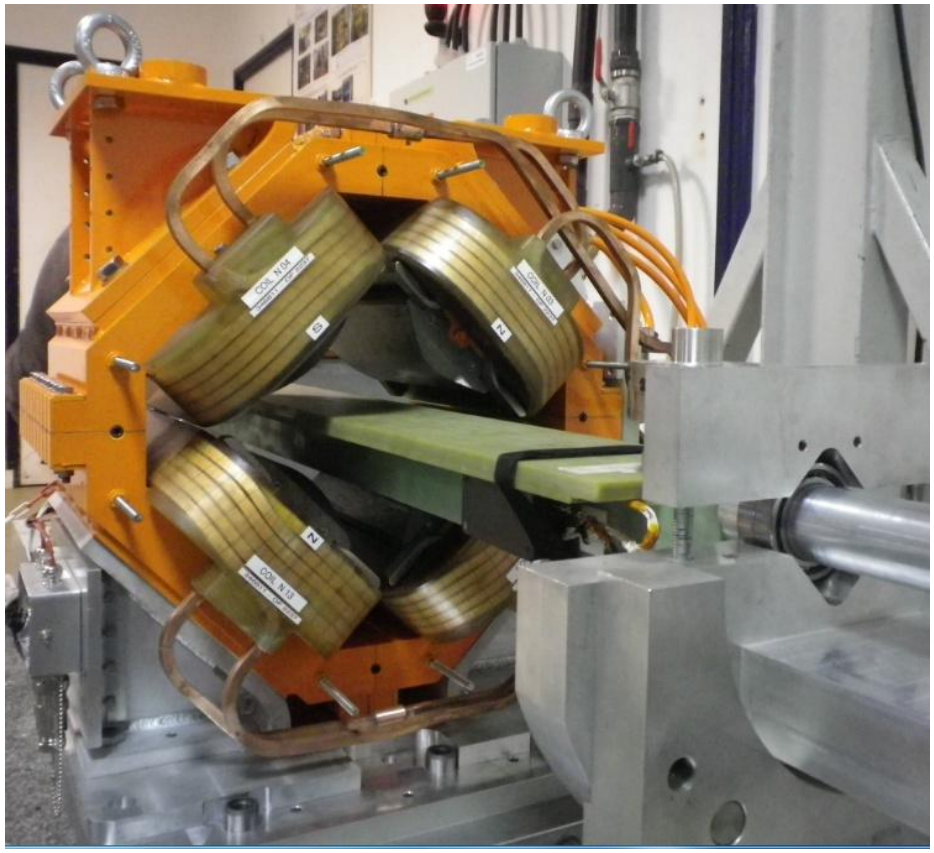
D67R30 Rotating coil measurement qualification : harmonic

Current / process	Harmonic components	Repeatability
@ Inom	b6	< 0.03 unit
3 meas	b10	< 0.02 unit
	∑ c3 to c15	< 0.12 unit
@ Imin (1% Inom)	b6	< 1 unit
	b10	< 0.3 unit
3 meas	∑ c3 to c15	< 4 unit < 1.5 unit with Drusch power supply
3% Inom	b6	< 0.3 unit
	b10	< 0.15 unit
3 meas	∑c3 to c15	< 0.8 unit

MEDAUSTRON specification

- Harmonic accuracy :1.10^{-3} (for 1% to 100% Gnom)
- Harmonic repeatability : 3.10^{-4} (for 1% to 100% Gnom)

D147R67 Rotating coil measurement qualification : harmonic

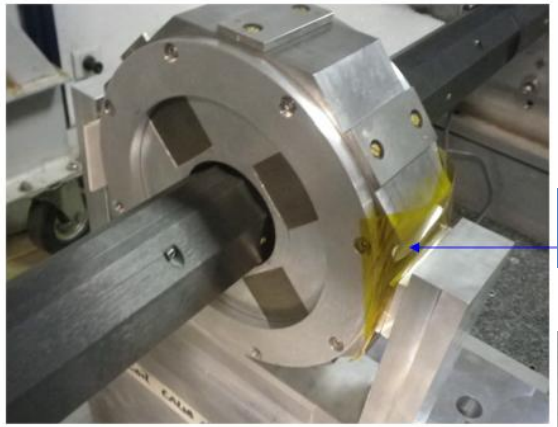


Current / process	Harmonic components	Repeatability
@ Inom	b6	< 0.03 unit
3 meas	b10	< 0.03 unit
	∑ c3 to c15	< 0.06 unit
@ Imin (3% Inom)	b6	< 0.1 unit
	b10	< 0.1 unit
3 meas	∑ c3 to c15	< 0.1 unit

MEDAUSTRON specification

- Harmonic accuracy :2.10^{-4} (for 3% to 100% Gnom)
- Harmonic repeatability : 1.10^{-4} (for 3% to 100% Gnom)

D67R30 Rotating coil measurement **qualification** : axis shift



50 µm Kapton
(coil sensitivity test)

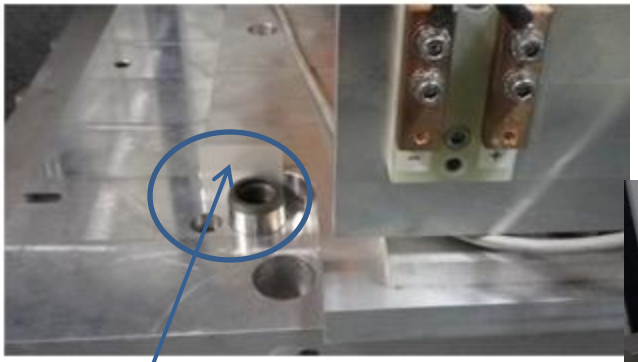
Parameters	Repeatability
Coil sensitivity Dx	7 µm (on 50 µm)
Coil sensitivity Dy	1 µm (on 50 µm)
Horizontality 10 level measurements	0.035 mrad
10 successives measurements @ Inom	Δdx < 1 µm Δdy < 2 µm ΔdΘ < 0.02 mrad
With rotating coil removal (*3 @ Inom)	Δdx = 5 µm Δdy = 2 µm ΔdΘ = 0.07 mrad
With rotating coil and magnet removal (*4 @ Inom)	Δdx = 20 µm Δdy = 4 µm ΔdΘ = 0.11 mrad
3 successives measurements @ Imin	Δdx = 20 µm Δdy = 20 µm ΔdΘ < 0.2 mrad

MEDAUSTRON specification

- Positionning accuracy +/-0.1mm and +/-0.2mrad

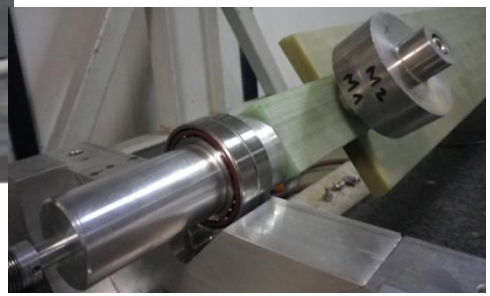
D147R67 Rotating coil measurement qualification : axis shift

X direction

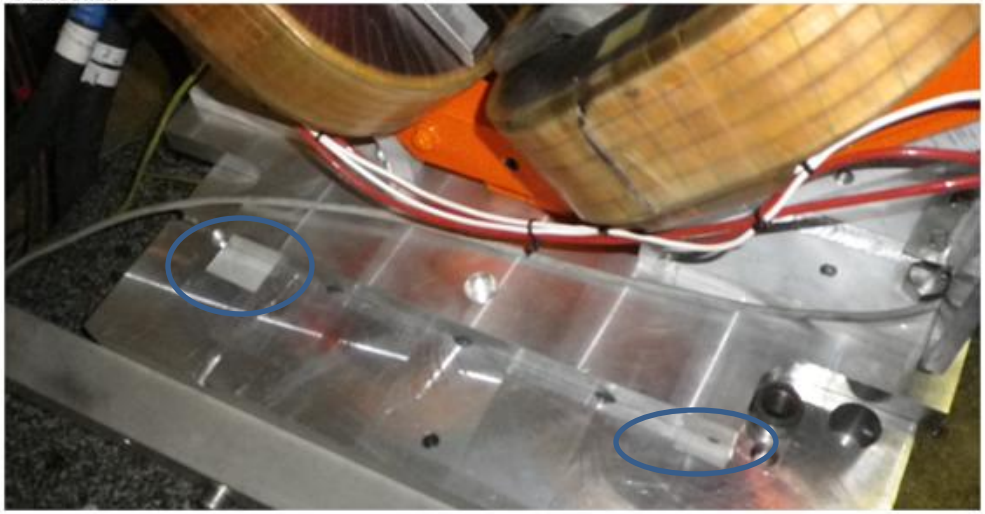


0.5mm FR4 sheet
(coil sensitivity test)

MEDAUSTRON specification
- Positionning accuracy +/-0.1mm and +/-0.2mrad
- Measurement 3 times better

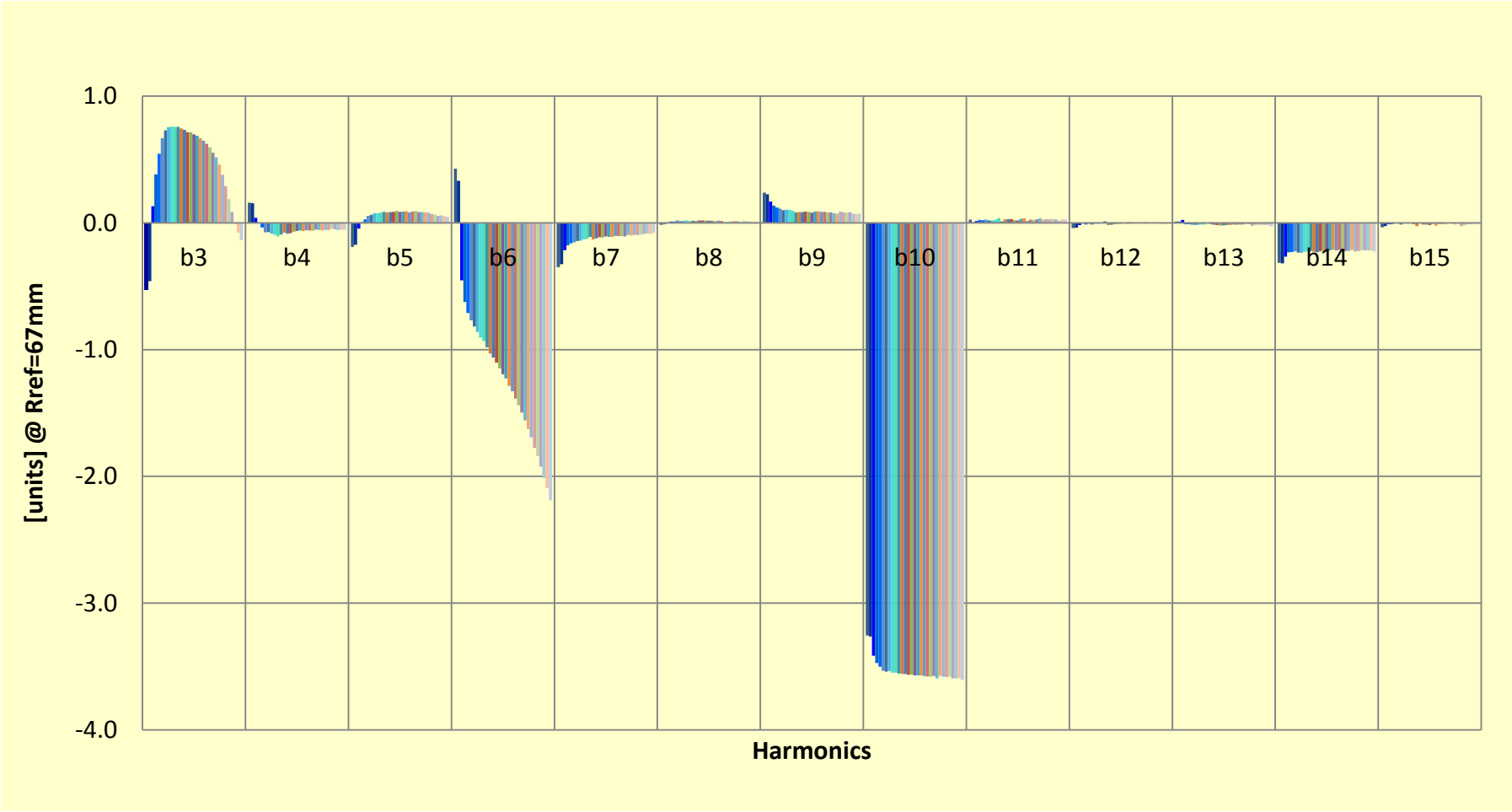


Y Direction



Parameters	Repeatability
Coil sensitivity Dx	8 µm (on 0.541mm)
Coil sensitivity Dy	17µm (on 0.2 mm)
Horizontality 10 level measurements	0.07 mrad
10 successives measurements @ Inom	Δdx < 1µm Δdy < 3µm ΔdΘ < 0.06mrad
3 successives measurements @ Imin	Δdx < 10 µm Δdy < 10µm ΔdΘ < 0.1mrad
With rotating coil removal (*3 @ Inom)	Δdx < 50 µm Δdy < 30 µm ΔdΘ < 0.4 mrad
With rotating coil and magnet removal (*4 @ Inom)	Δdx < 50 µm Δdy < 30 µm ΔdΘ < 0.4 mrad

MQZ-C 002 Harmonics bn from Imin to Inom

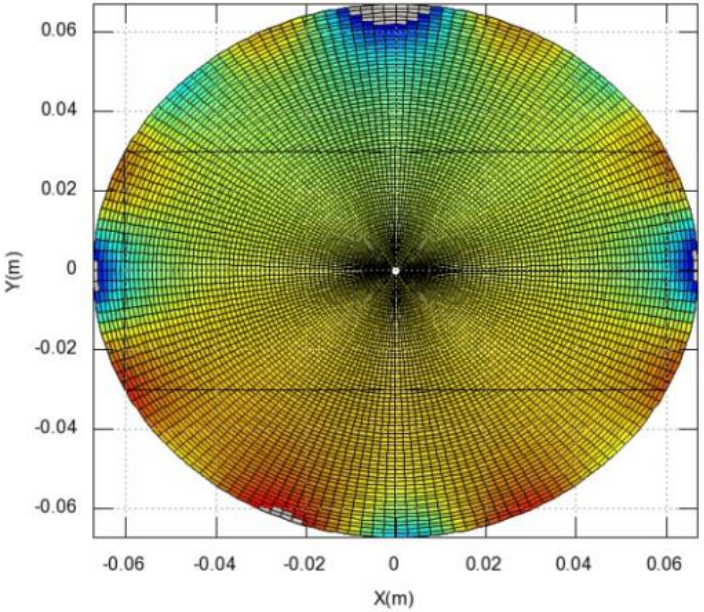


$$\varepsilon(I,x,y)=\frac{\sqrt{B_x(I,x,y)^2+B_y(I,x,y)^2}-B_2(I)\cdot\frac{\rho}{r_0}}{B_2(I)\cdot\frac{\rho}{r_0}}$$

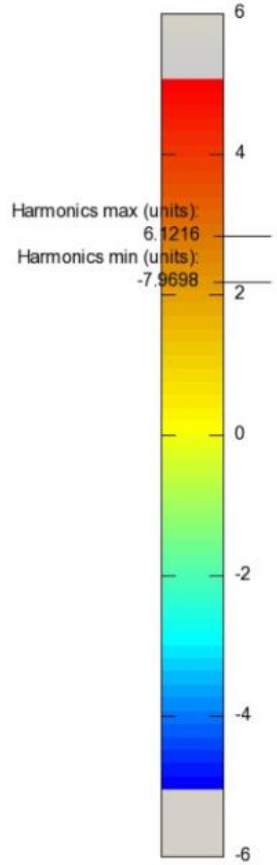
Field reconstruction @ Inom (spec +/-5 unit)

GFR +/-60mm X and +/- 30mm Y

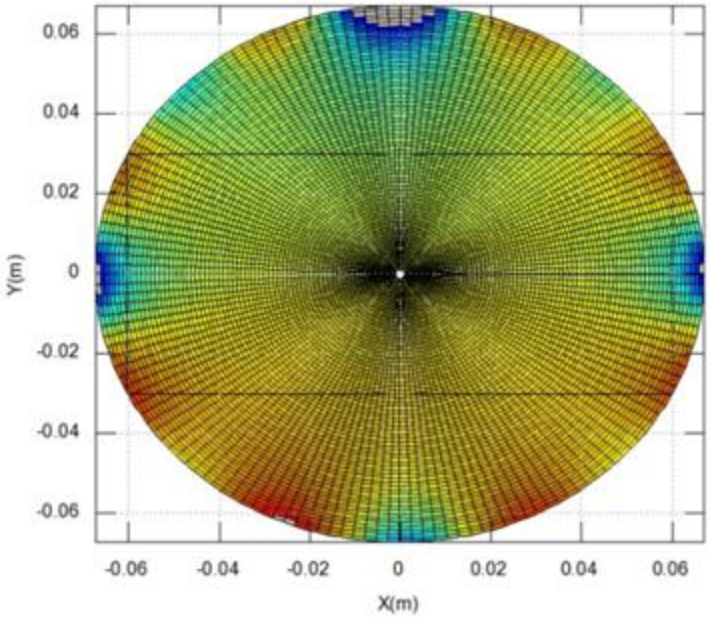
+ 6.12 / -7.97 (R67)



09/01/2013 MQZC2 @ Inom

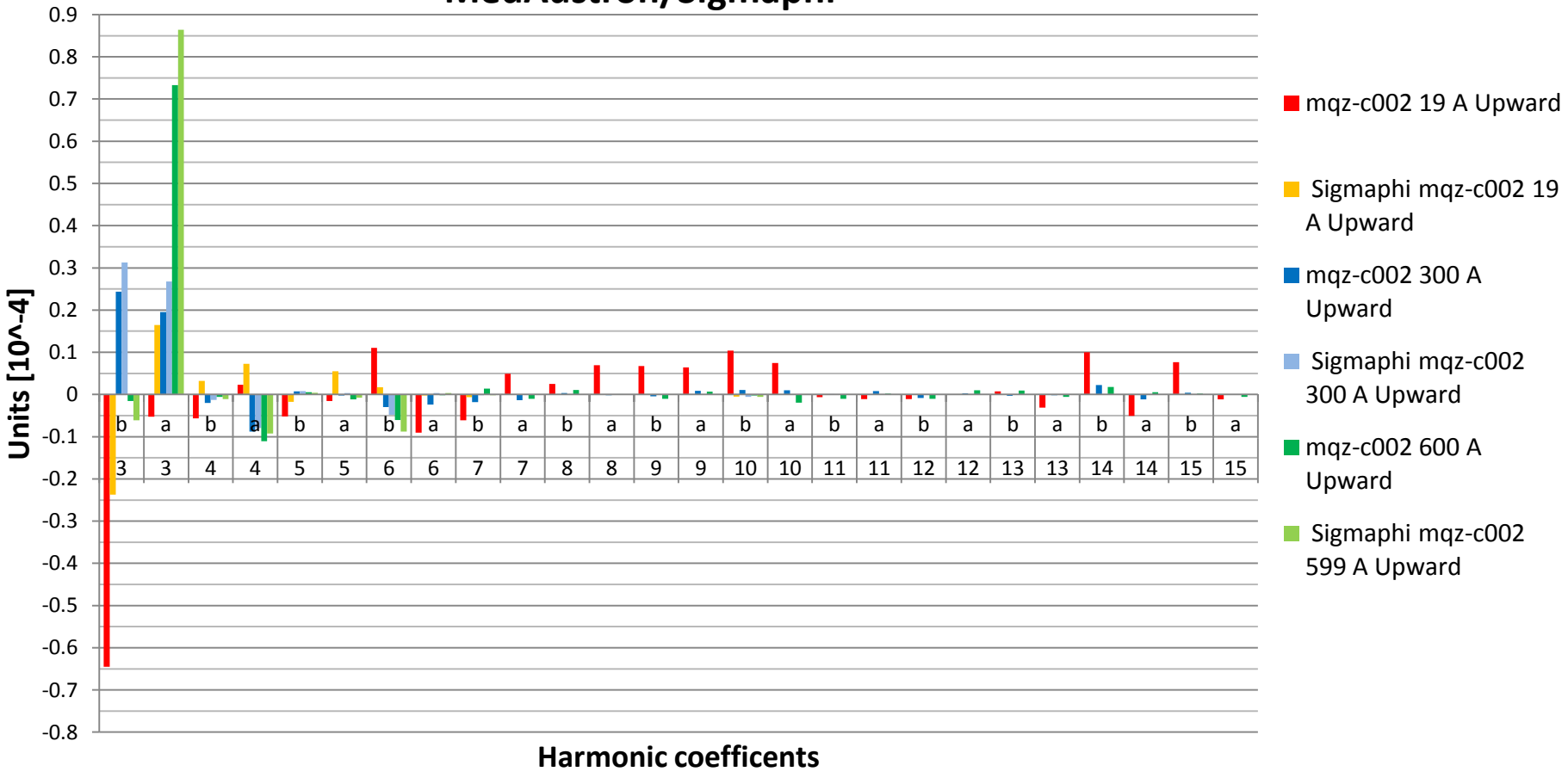


+ 5.71 / -8.00 (R67)

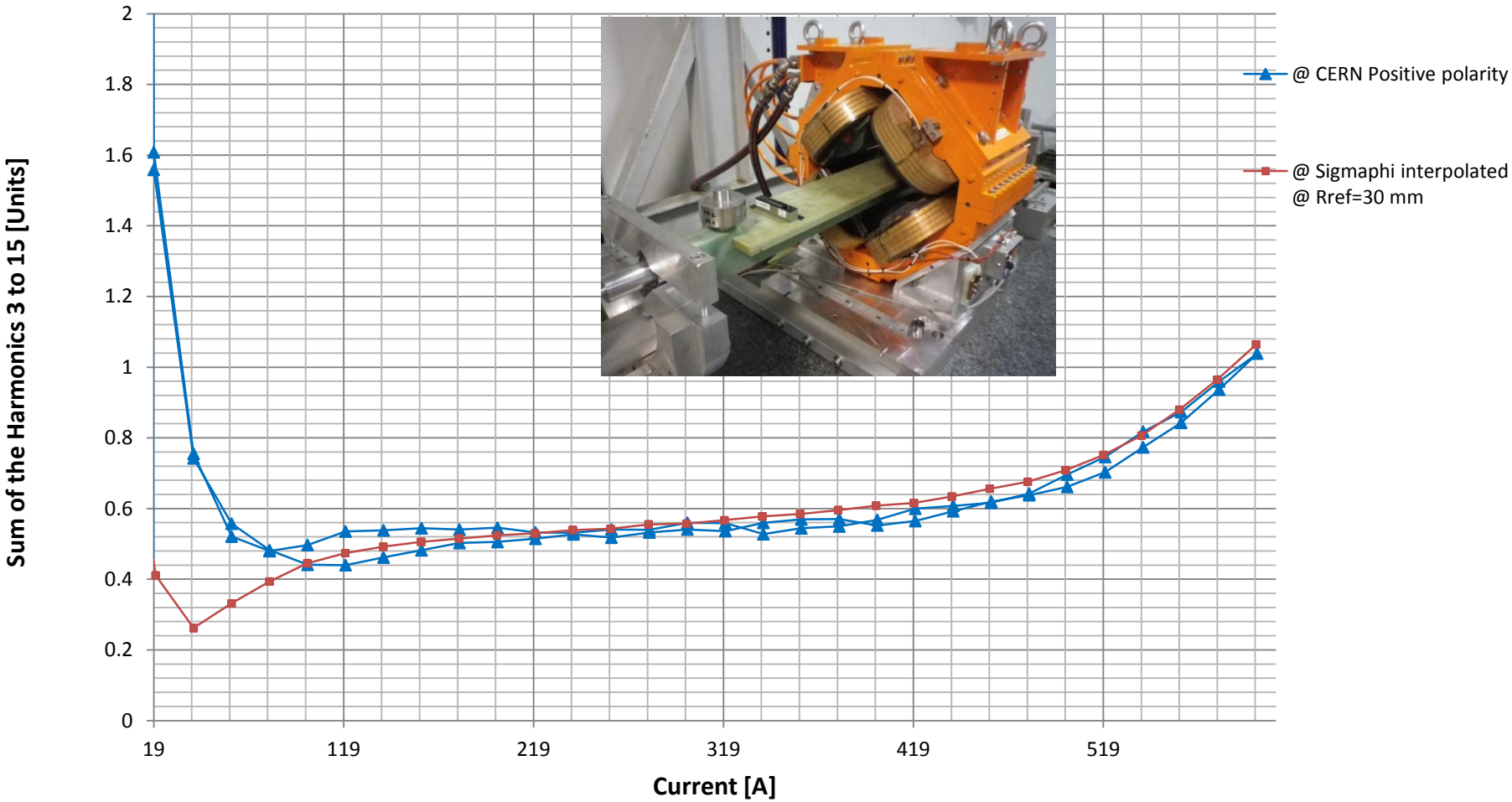


28/02/2013 MQZC2 @ Inom
After opening test (x5)

Harmonics of the MQZ-C002 @ R=30 mm @ comparison MedAustron/Sigmaphi

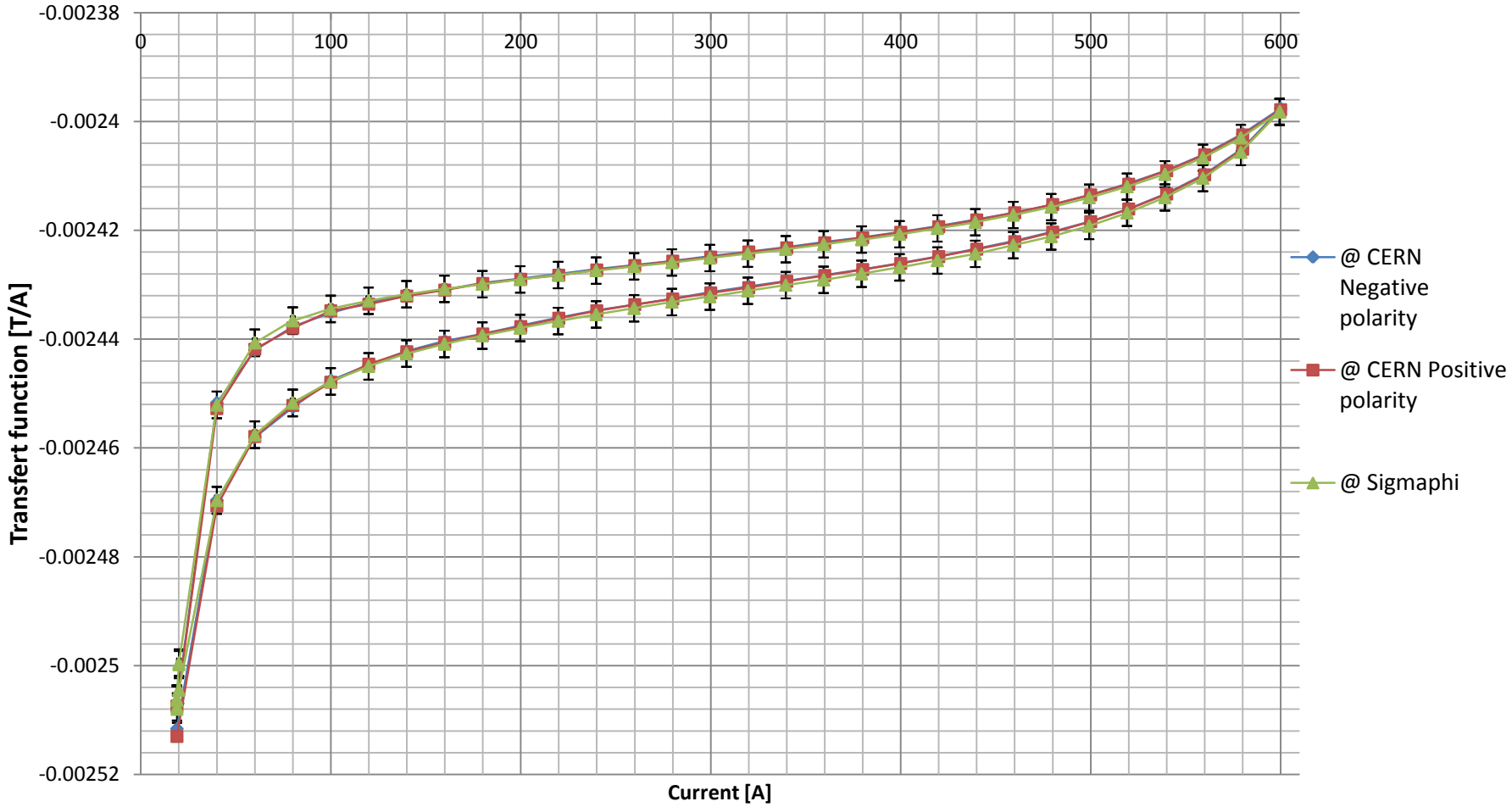


MQZ-C002 Field quality @Rref=30 mm (CERN/SIGMAPHI)

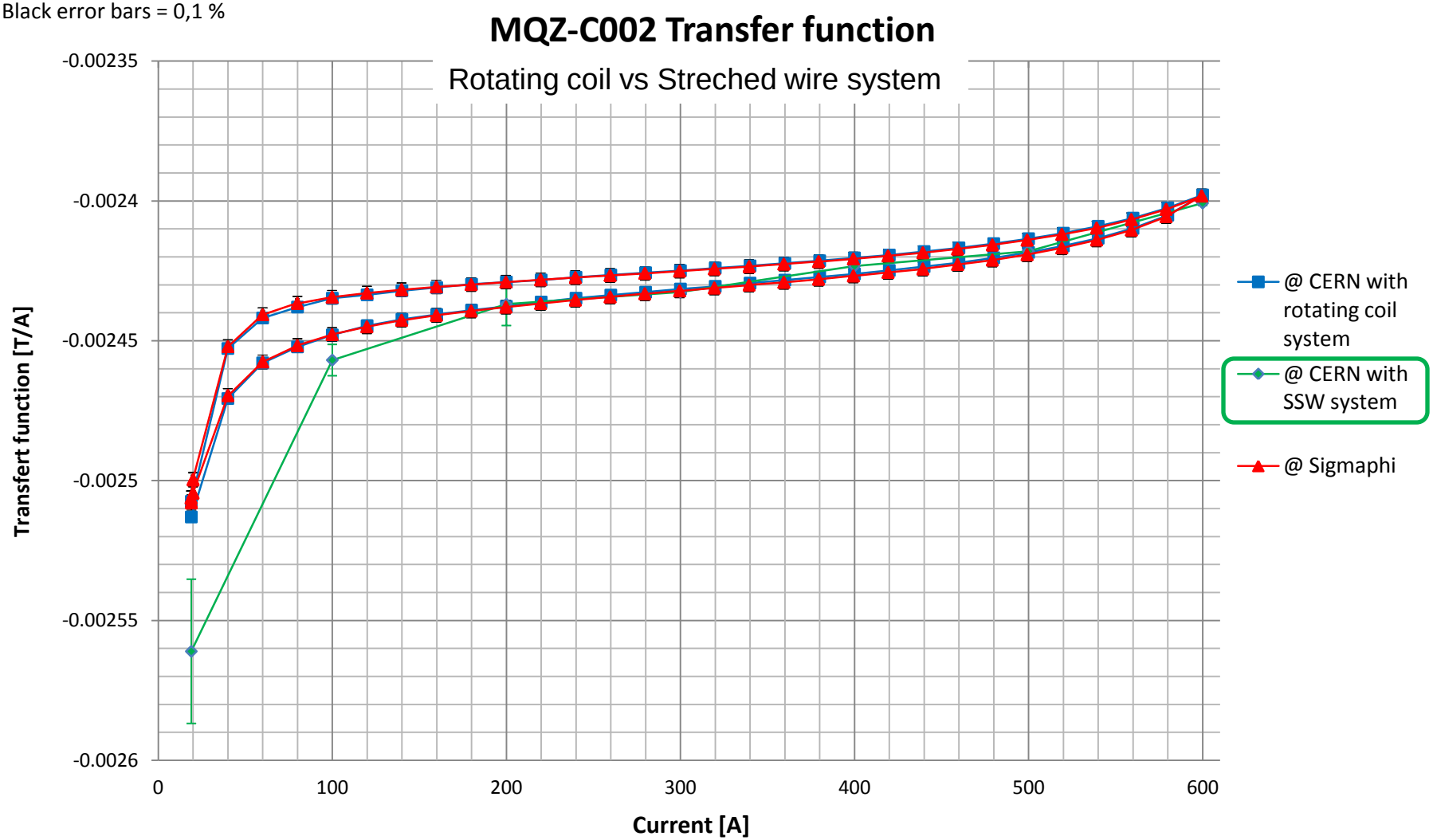


Error bars = 0,1 %

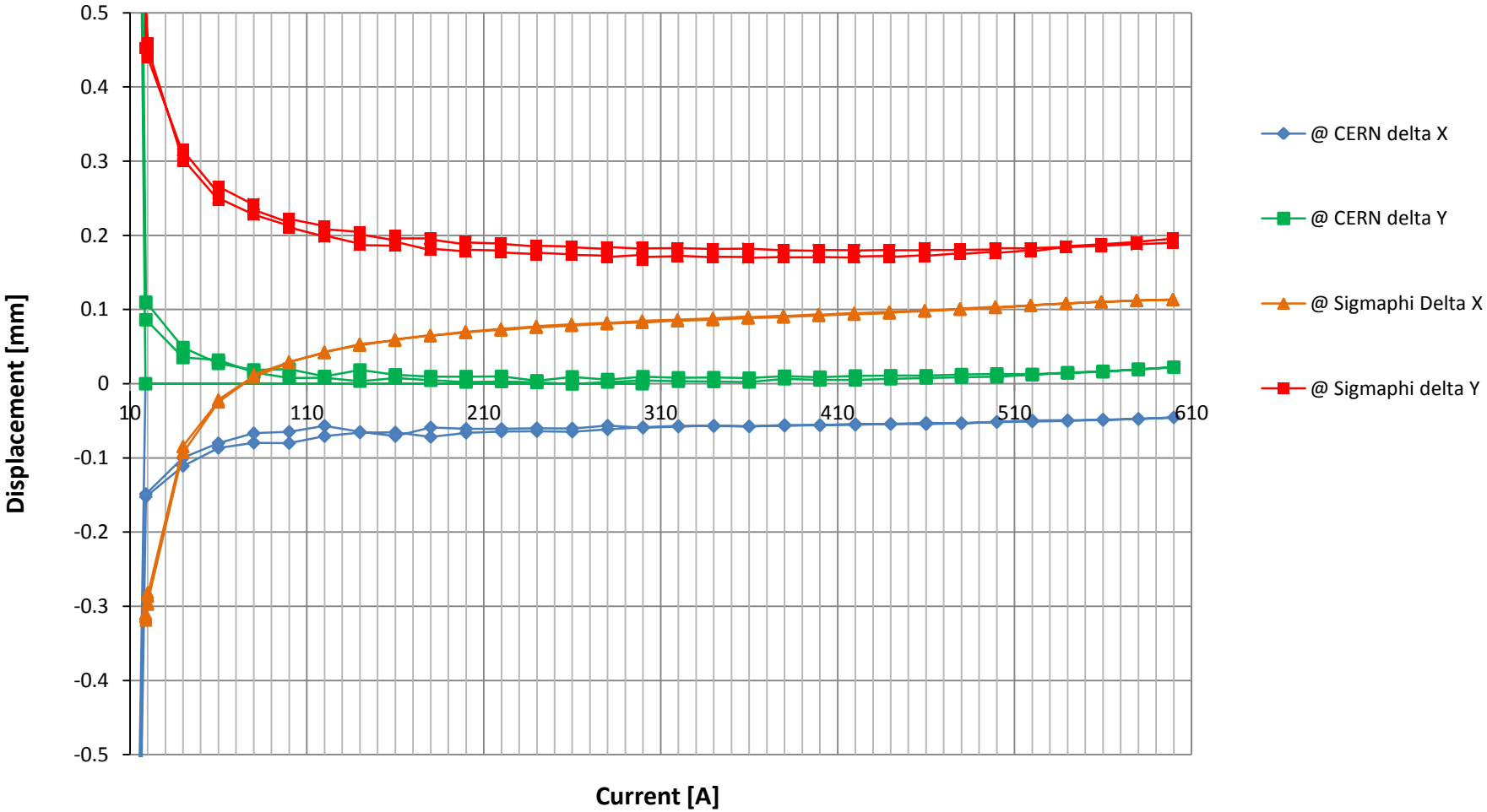
MQZ-C002 Transfer function - Comparison CERN/SIGMAPHI



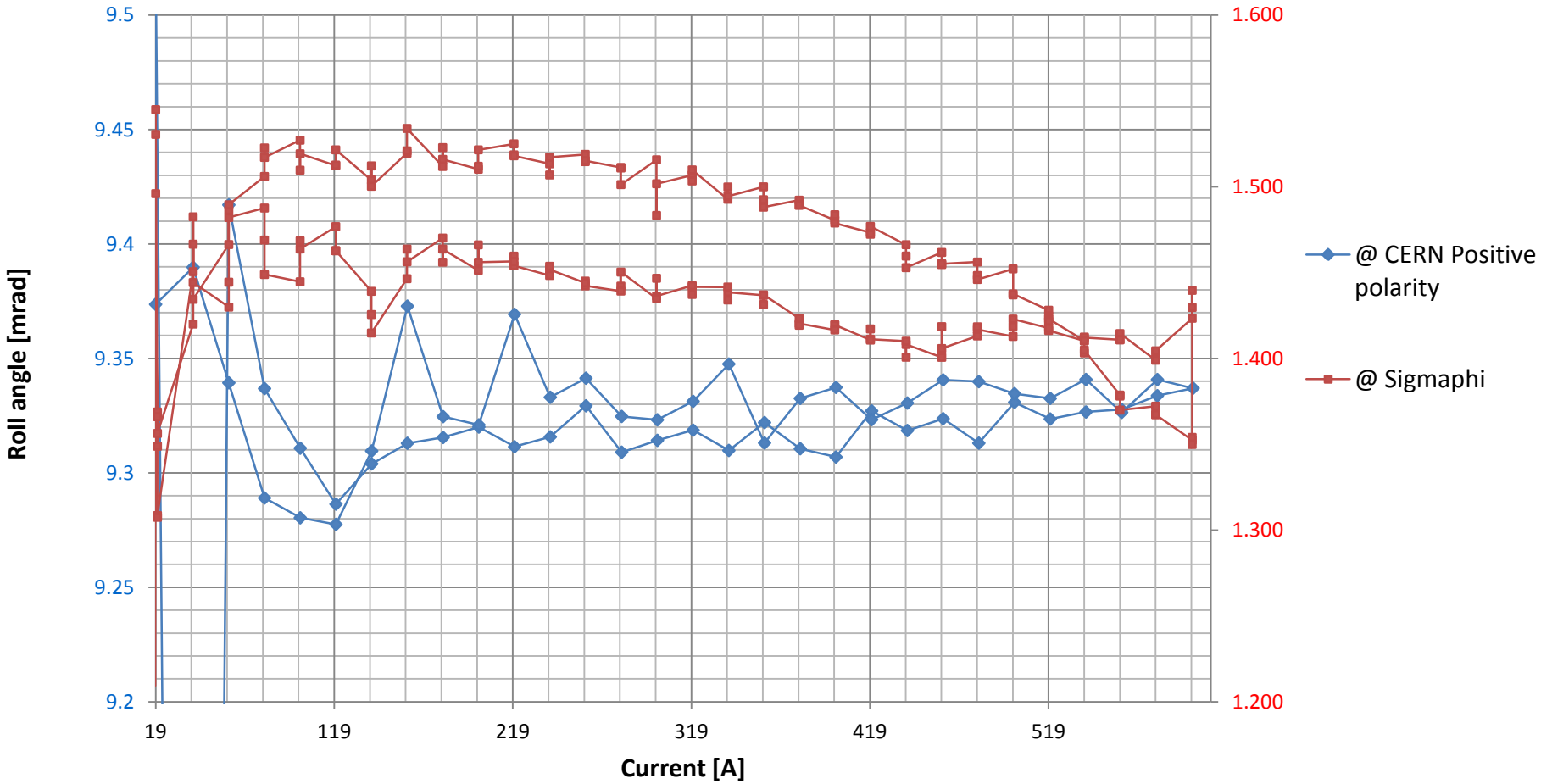
Black error bars = 0,1 %



MQZ-C002 Magnetic axis displacement (CERN/SIGMAPHI)



MQZ-C002 Field direction (CERN/SIGMAPHI)

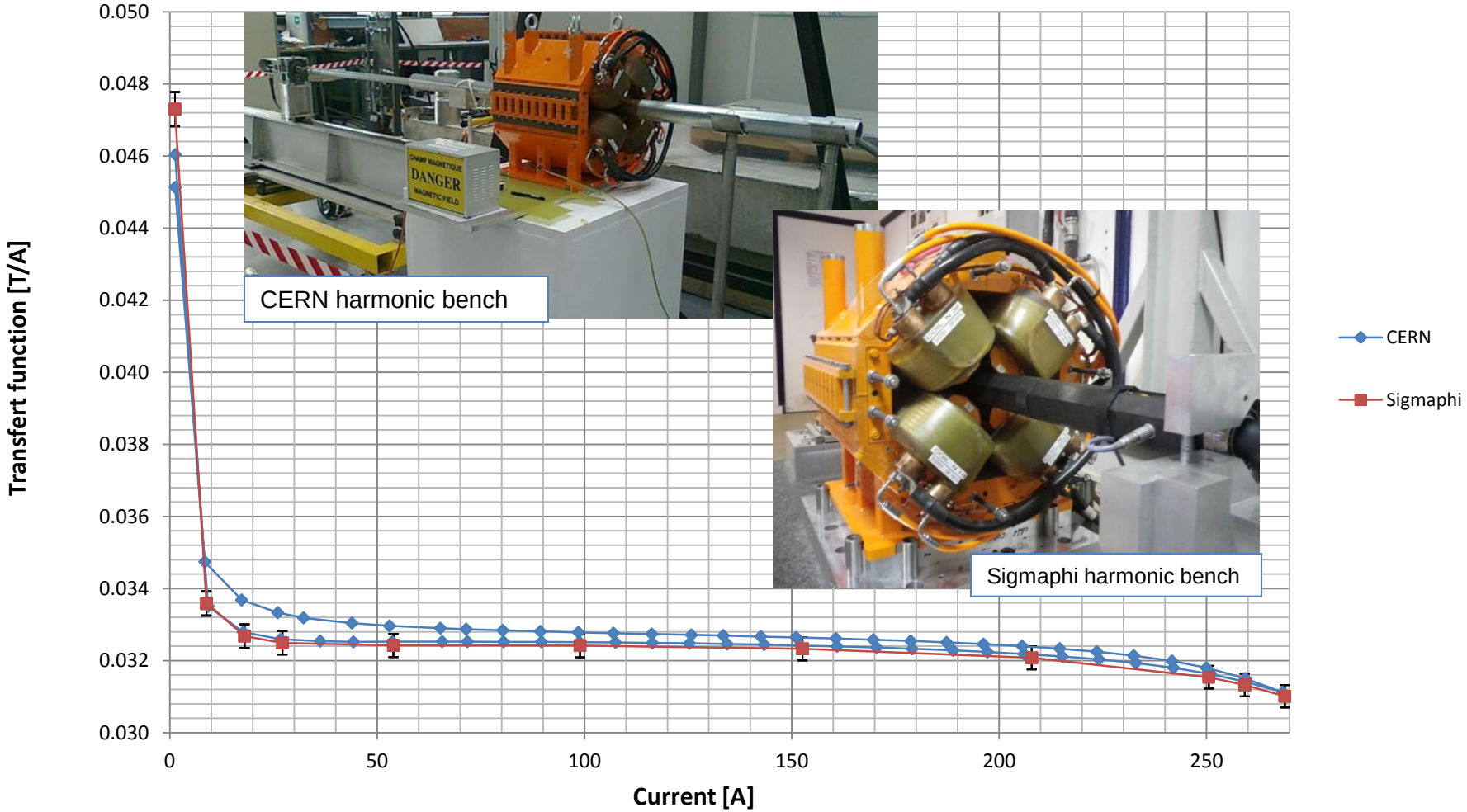


MQZ-C 002 Comparison with CERN measurements / summary

Parameters @ Inom	SIGMAPHI Results @ R67	SIGMAPHI Results @ R30	CERN Results @ R30
Transfer function	/	-0.0023983	-0.0023978
c3	1.9 unit	b3=-0.06 a3=+0.86	b3=-0.05 a3=+0.74
c4	0.45 unit	b4=0 a4=-0.09	b4=0 a4=-0.1
c6	2.2 unit	b6=-0.08 a6=0	b6=-0.07 a6=0
c10	3.6 unit	b10=0 a10=0	b10=+0.01 a10=+0.01
c14	0.22 unit	b14=0 a14=0	b14=+0.013 a14=+0.0
$\sum$ c3 to c15	8.85 unit	1.07	1.05 +/-0.02
Field reconstruction	+6 /- 8unit @ R67 < +/- 5 unit GFR	/	/

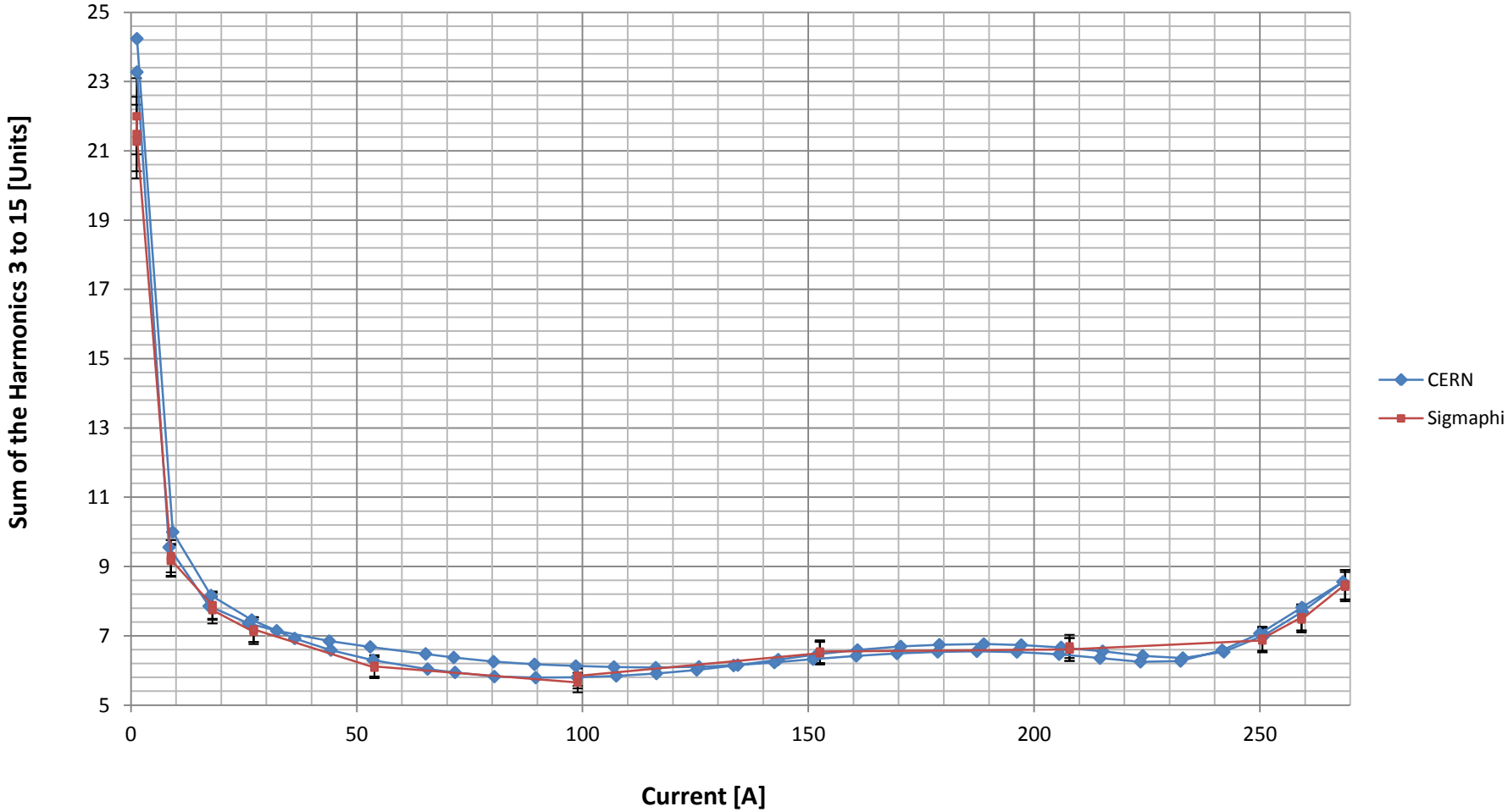
MQZ-E001 Transfer function (CERN vs SIGMAPHI)

Error Bars = 1%

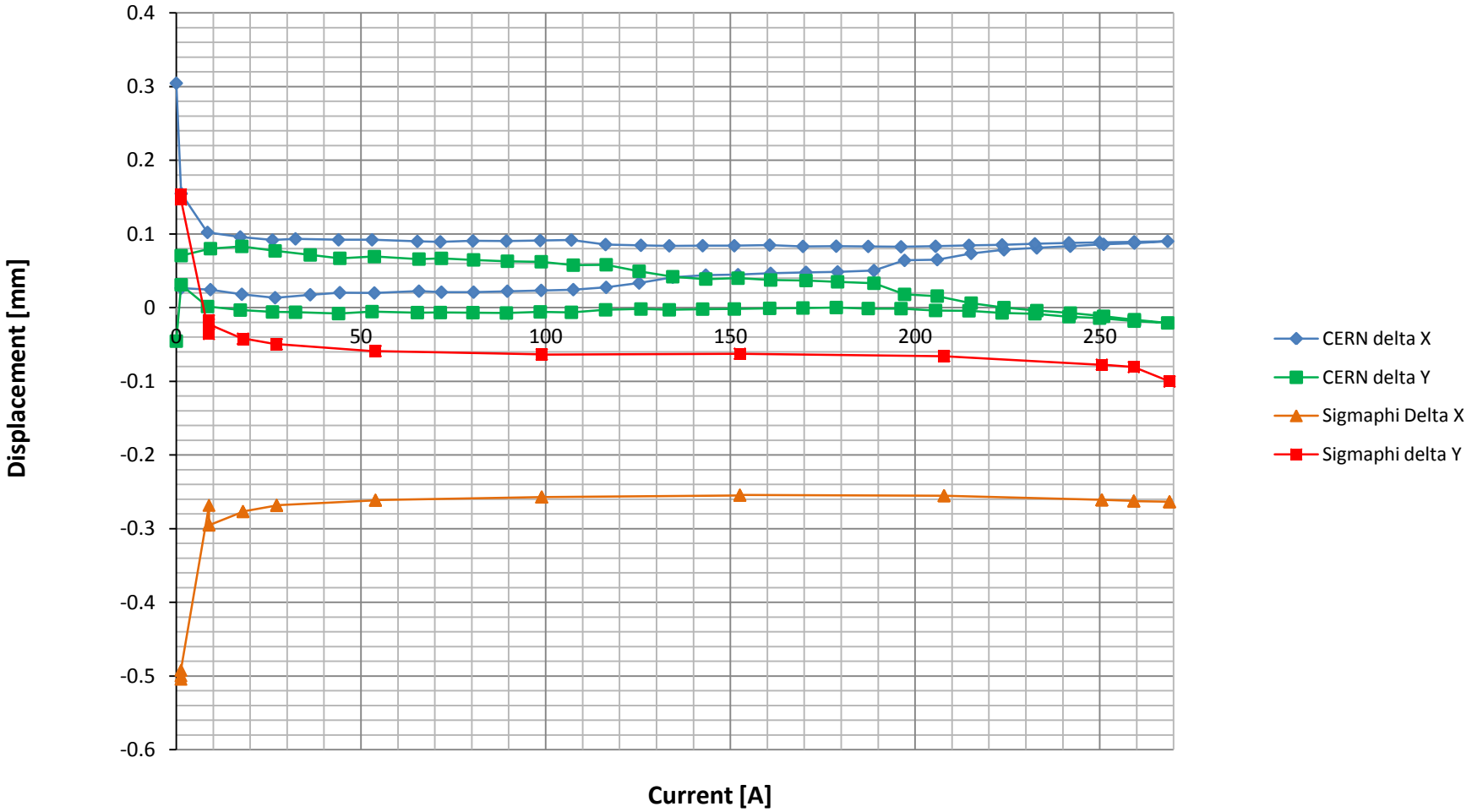


MQZ-E001 Field quality (CERN vs SIGMAPHI)

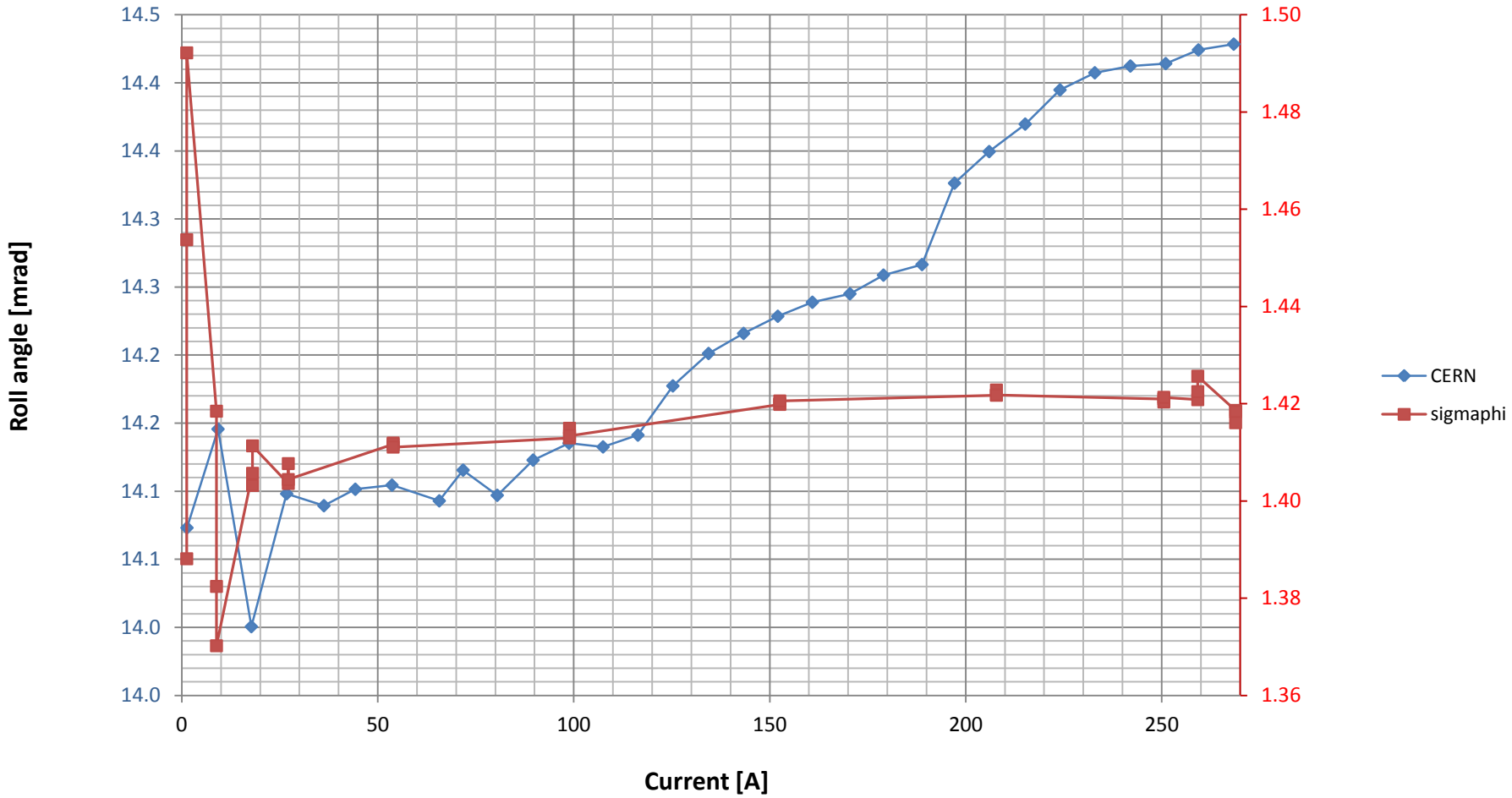
Error Bars = 5%



MQZ-E001 Magnetic axis displacement (CERN / SIGMAPHI)

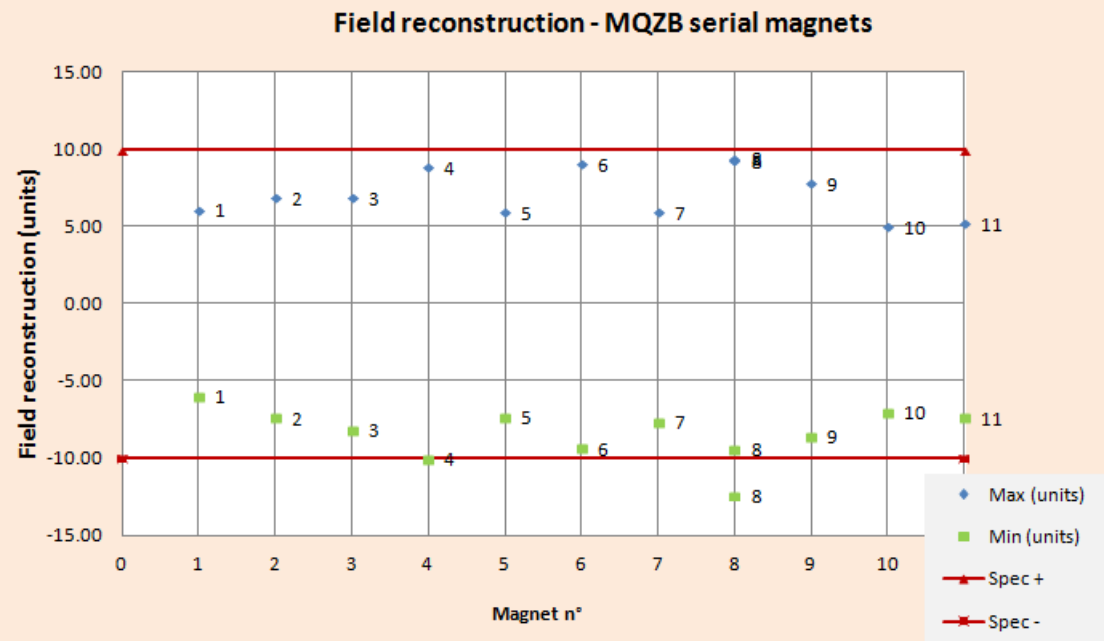


MQZ-E001 Field direction



Conclusion

- the 4 prototypes have been measured and compared with CERN, with a good agreement
- all MQZB serial magnets have been measured (9 magnets) and are within the specification (+/-10 unit for the field reconstruction)



- MQZE and MQZC serial magnets are currently in production

Thank you for your attention