Magnet technology at MAX IV

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MAX IV Laboratory

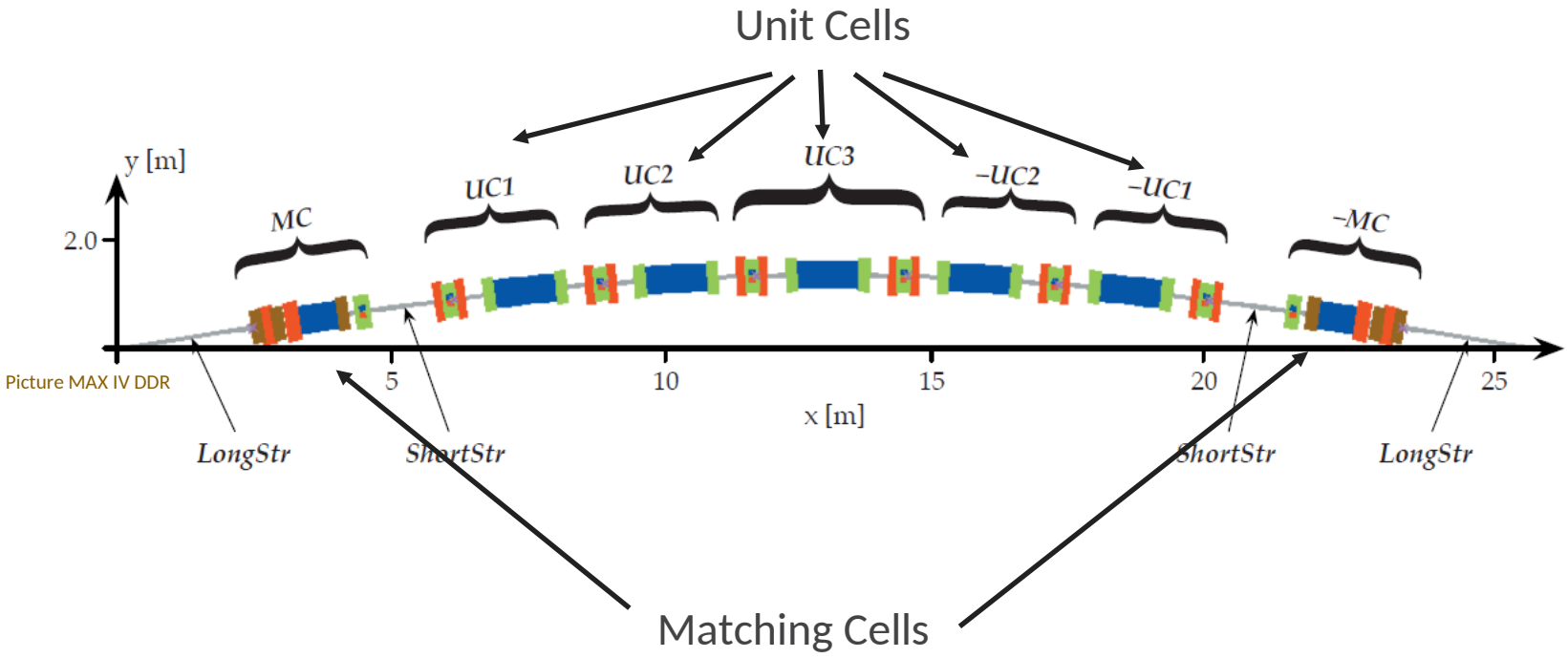
Outline

- Overview
- Manufacturing and Installation
- Field measurement results
- Summary

Magnet technology at MAX IV

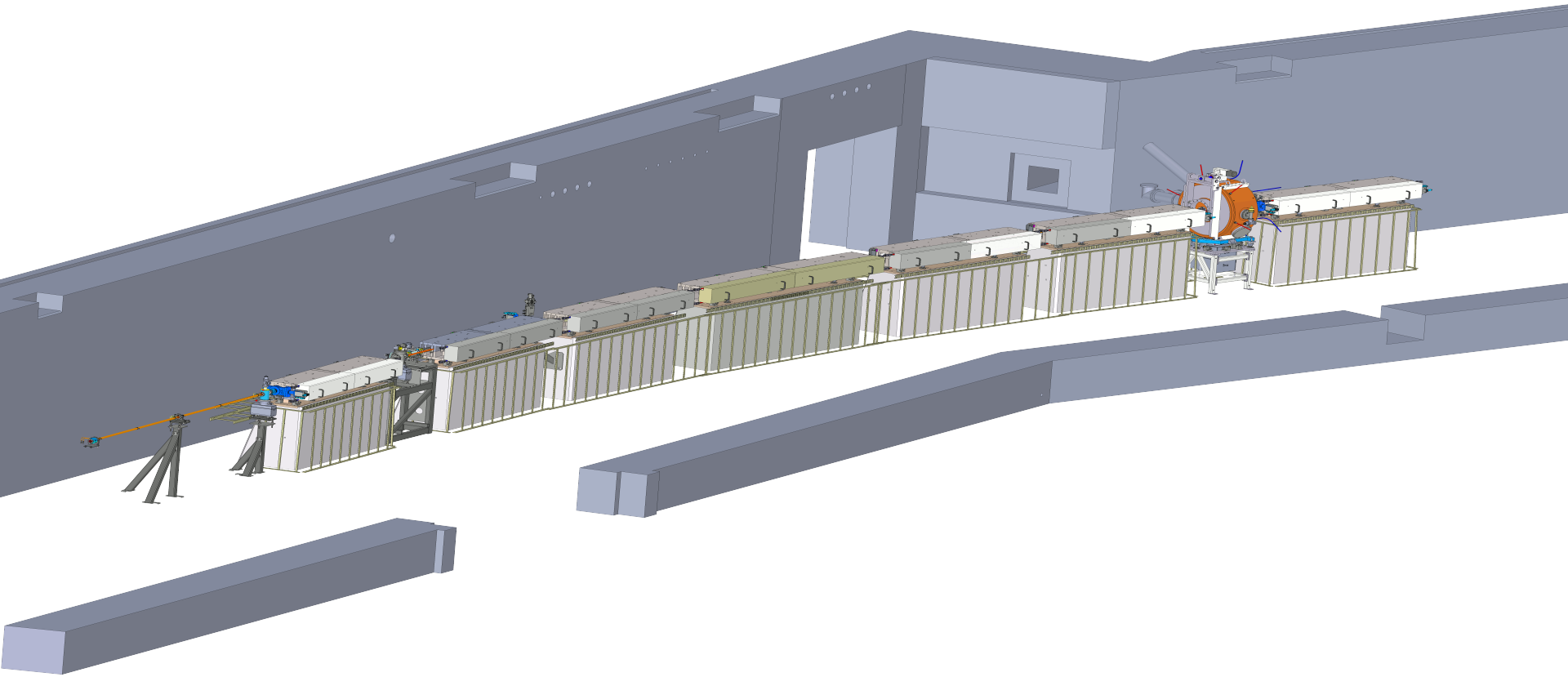
Overview

MAX IV 3 GeV ring lattice

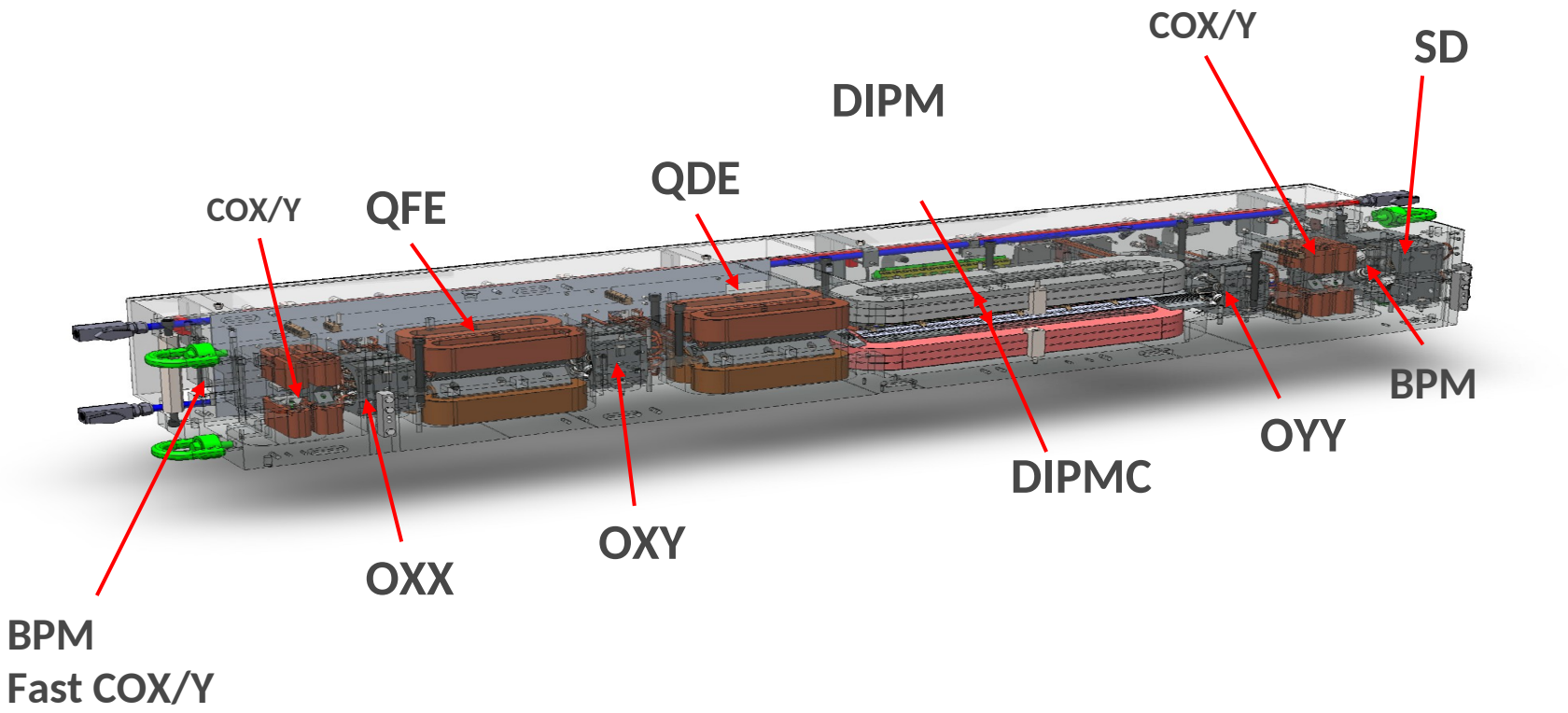


Picture MAX IV DDR

MAX IV 3 GeV ring achromat



Matching cell magnet block (M2)



Magnet project strategy

- Magnetic and Mechanical Design by MAX IV Lab.
- Production and Magnetic Measurements contracted out to industry (two companies).
- Suppliers deliver fully assembled units ready for installation.
- Suppliers are responsible for mechanical tolerances / Maxlab is responsible for magnetic performance.
- Tolerances (dipole surf. and quad/6pole/8pole guiding surf.): ±20 µm.
- MAX IV provided the material (ARMCO grade 4) for the yokes for the two manufacturers.
- Integrated magnet concept:
  - Common yoke allows achieving tight relative alignment within block.
  - Lean design pushes up eigenfrequencies
  - System integration done by industry allows streamlined installation
  - *Assumption: mechanical behaviour defines the magnetic behaviour*

Magnet technology at MAX IV

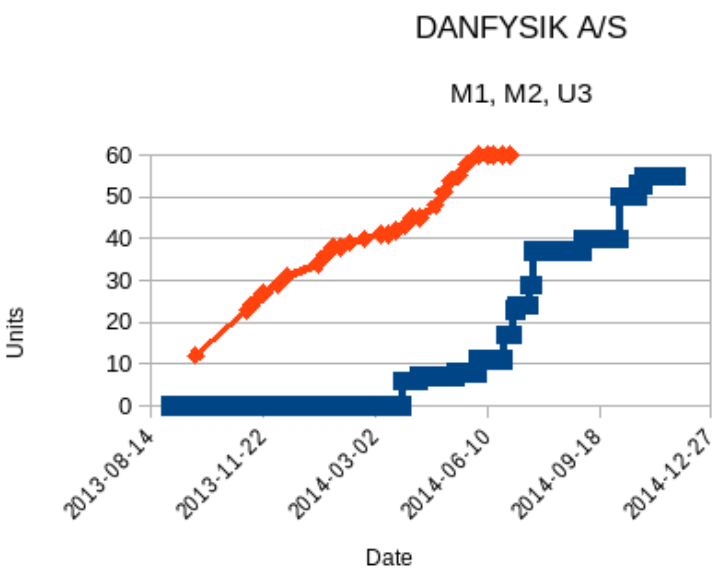
Manufacturing and installation

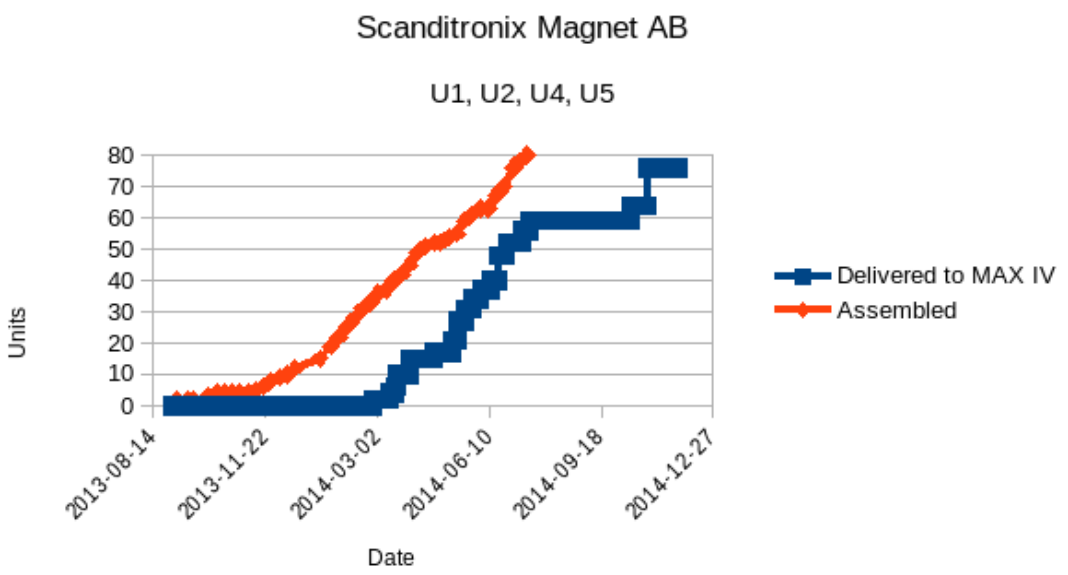
Manufacturing

Originally anticipated challenges:

- Achieving acceptable production throughput for precise yoke machining and mechanical measurements.
- Verifying/Certifying magnetic measurement capabilities at the suppliers.
- Integration with Vacuum/Support designs.

Magnet production

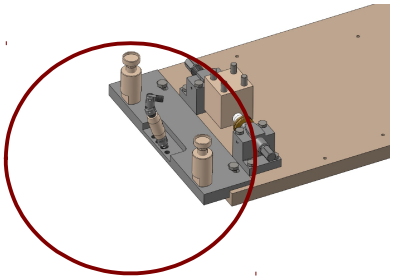


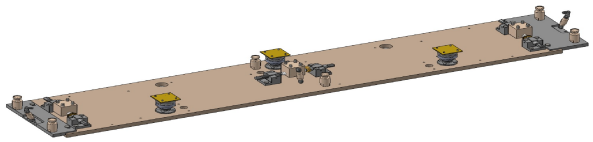


Status as of 2014-11-24:
3 units remaining to be delivered

Installation procedure

- Cabling and piping installed on achromat concrete stands
- Magnet block placed on top of the concrete stand
- Magnet block aligned
- Extra adjustment mechanism mounted
- Top yoke removed
- Bottom yoke straightness adjustment
- Vacuum installation
- Top yoke placed
- Magnet block bolted together
- Extra adjustment mechanism removed
- Final straightness check
- Cabling connected to block
- Cooling connected to block
- Final alignment check





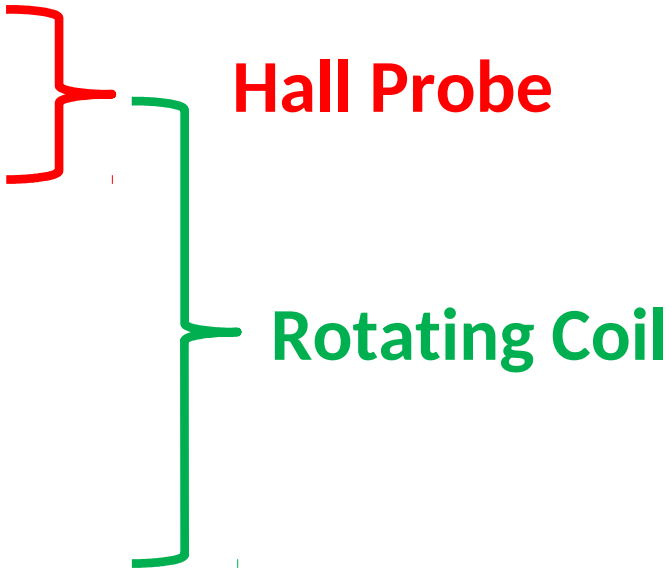
Measurement gauges used throughout to preserve straightness.

Magnet technology at MAX IV

Field measurements

Main field measurement campaigns

Magnet type	Amount
Dipoles	140
Quadrupoles	320
Sextupoles	360
Octupoles	120
Correctors (slow)	380
Trim coils	200
TOTAL	1520



Highlights, field strengths by family

	MAX deviation to average within any family [0.1%]	Standard Deviation over all families [0.1%]
QFEs	1.4	0.6
QDEs	1.5	0.8
QFm	0.8	0.6
QF	0.9	0.2
SXDE	2.4	1.2
SXFm	4.1	2.1
SXFo	2.7	1.6
SXFi	4.2	1.2
SD	8.5	4.5
OXX	3.0	3.1
OXY	7.5	3.2
OYY	5.3	1.8

INTEGRATED DIPOLE		
	MAX deviation to average within family [0.1%]	Standard Deviation over family [0.1%]
M blocks	3.7	1.1
U blocks	2.6	0.9
INTEGRATED QUADRUPOLE		
M blocks	3.1	1.2
U blocks	3.4	1.1

Very limited need for shunting/trim coils/floating ps for achieving the required RMS spread.

Highlights, quad multipole errors

Integrated Normal Multipole Components in Quadrupoles [1E-4 of main field component @ 10 mm]					
		QFEs	QDEs	QFms	QFs
Sextupole	Average	0.78	-0.17	1.10	0.02
	St Dev	1.87	1.83	2.79	3.05
Octupole	Average	-0.47	0.68	-2.88	-0.69
	St Dev	2.64	3.03	2.22	3.41
12-pole	Average	-9.17	-9.24	1.76	0.16
	St Dev	0.44	0.51	0.55	1.89
20-pole	Average	-1.46	-1.53	3.12	0.40
	St Dev	0.07	0.16	0.17	2.98

Highlights, internal alignment

Magnet block	Magnet elements	Evaluated [pcs]	Relative alignment	Min [µm]	Max [µm]	RMS [µm]	Comment
M1, M2	OXX-QFE-OXY-QDE	40/40	*dx*	-38	23	4.8	
			dy	-27	20	9.4	Includes rotating coil sag
U1, U2, U4, U5	QFm-SFm-QFm, QF-SFo-QF	80/80	*dx*	-16	33	5.0	
			dy	-31	30	6.8	Includes rotating coil sag
U3	QF-SFi-QF-SD	20/20	*dx*	-10	13	4.7	
			dy	-18	22	7.3	Rotating coil sag compensated

	RMS Misalignment	
	Horizontal [µm]	Vertical [µm]
Quads	4.5	12.7
Sexts	5.0	9.7
Octupoles	4.1	9.5

	RMS Roll Angles [mrad]
QFEs	0.42
QDEs	0.26
QFs	0.38
QFMs	0.40

M. Johansson et al., "Magnet design for a low-emittance storage ring", J Synchrotron Radiat. 2014 Sep.

Additional measurements

After the main measurement campaigns a few magnet blocks are kept at the manufacturer for further characterization of the final blocks. Currently those measurements focus on cross-talk behaviour.

Summary

- Main field measurement campaigns completed for 3 GeV storage ring
- Deliveries essentially complete
- Lattice analysis of measurement results underway
- Very limited action needed before commissioning (shunting/trim coils/floating power supplies)
- Additional characterization measurements underway

The End

Thank you for your attention

For those that are still awake…

EXTRA SLIDES

Magnet characterization, Hall bench

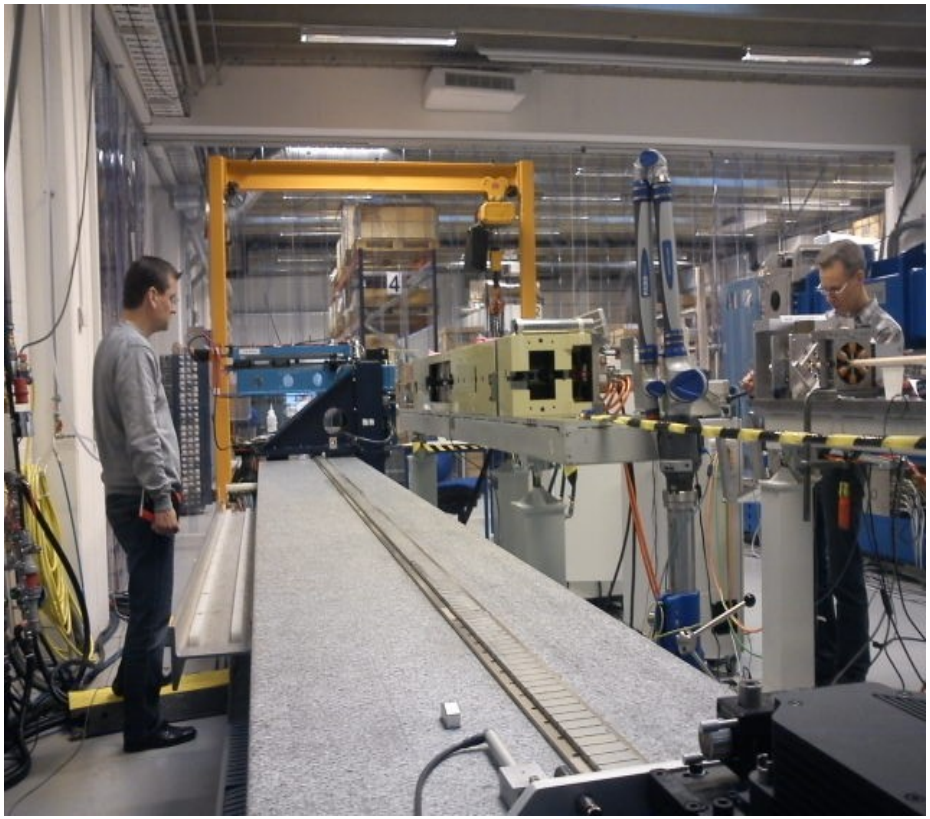


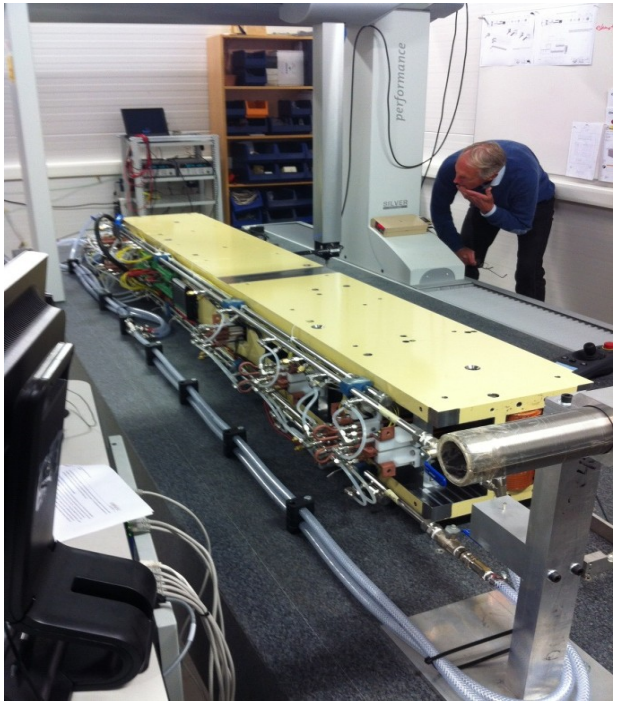
Photo: Danfysik

DF: Adapted ID bench from ADC

Magnet characterization, Hall bench

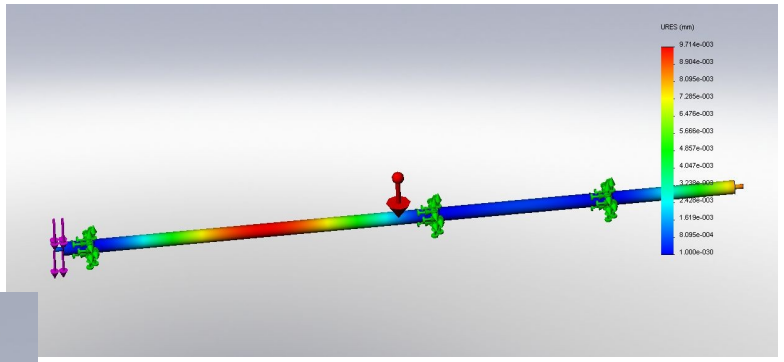
Photo: Scanditronix

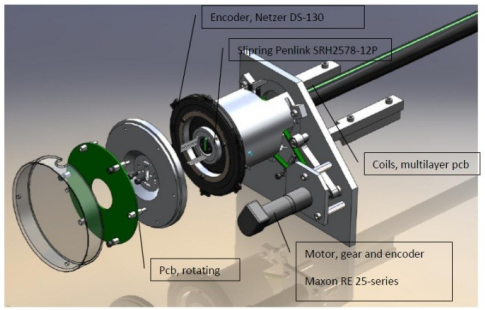
ScxM: Adapted 3D Measuring machine from Hexagon

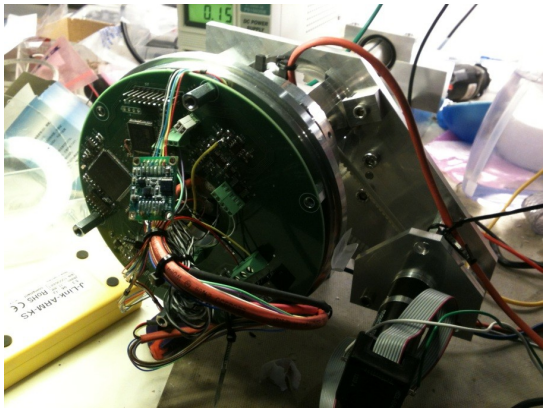


Magnet characterization, rot. coil

- Radial coils w. bucking.
- Carbon fiber shaft.
- Custom made electronics.



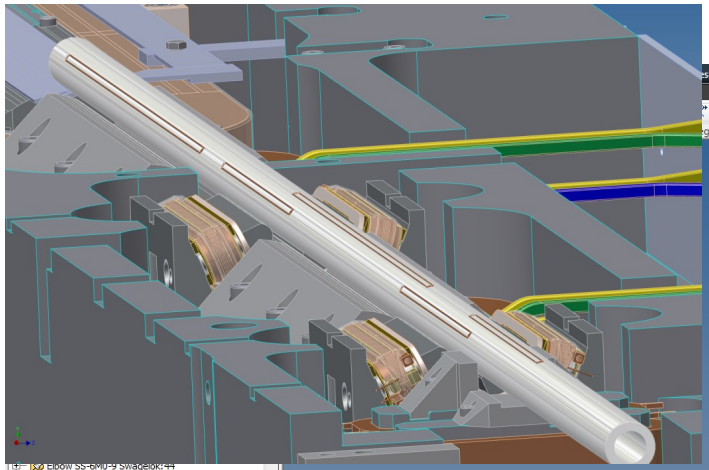




Pictures: Scanditronix Magnet

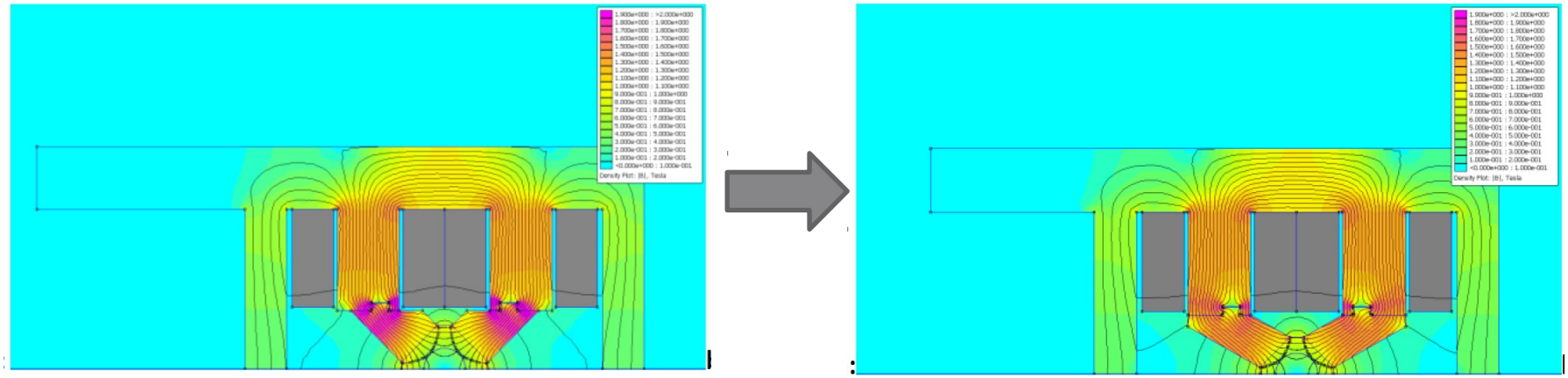
Magnet characterization, rot. coil

- Tangential coils, no bucking
- Ceramic shaft
- Commercial elect.



Quadrupole Design Update

Early measurements indicated saturation problems in QF, QFms and led to a new design.



Images: Martin Johansson

Quadrupole Design Change