# Status of Magnet R&D for the CLIC "2-Beams Modules"

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University of Texas at Arlington, USA
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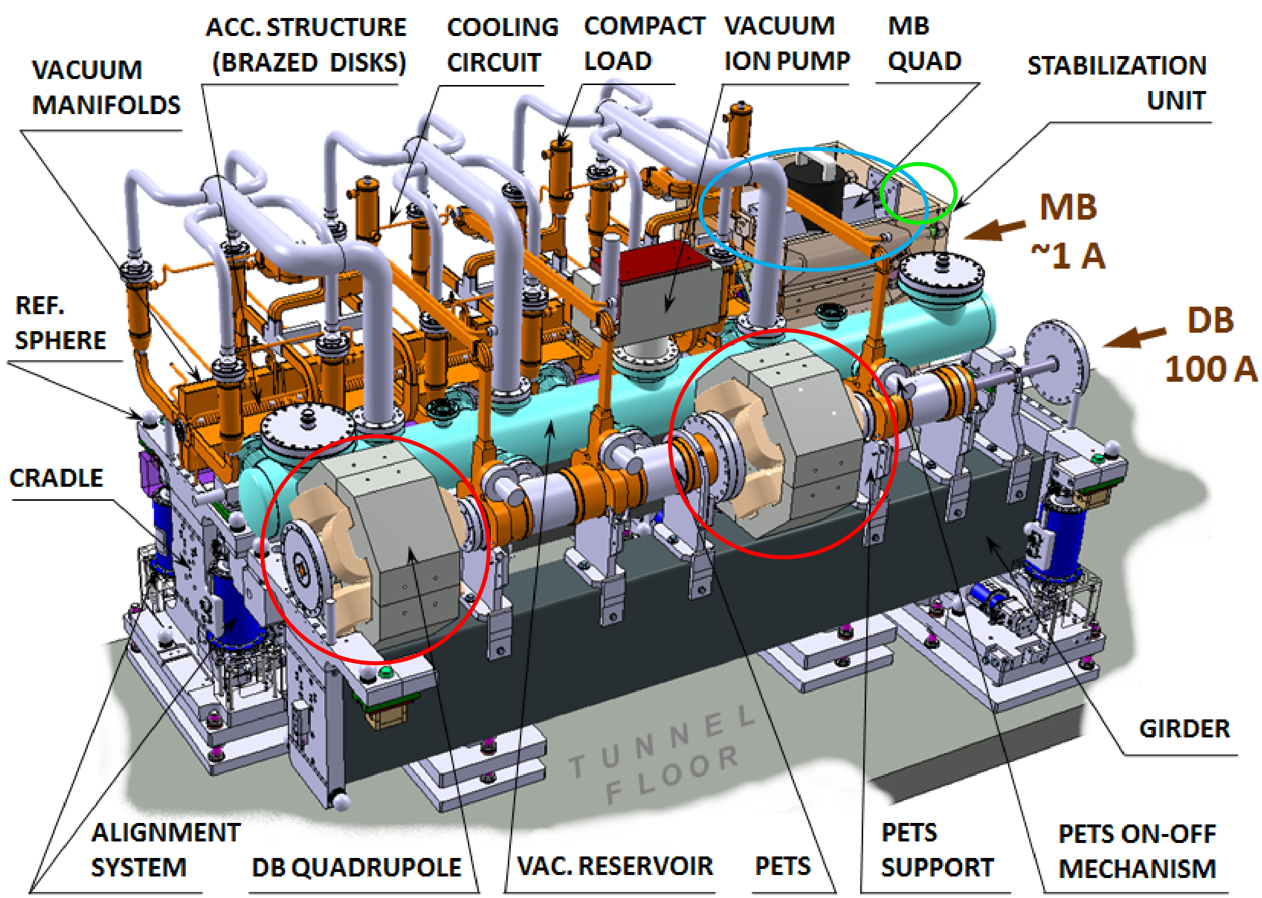
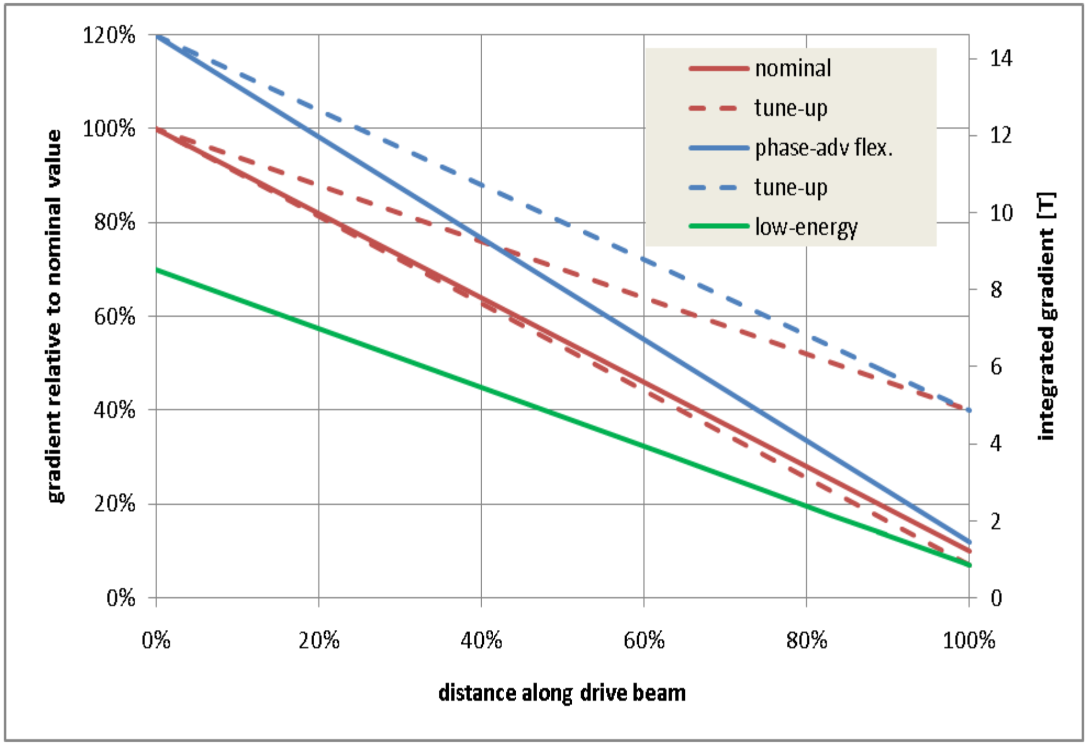
*Three types of magnet are present on the CLiC Modules:*

a) *Drive Beam Quadrupoles (DBQ)*
b) *Main Beam Quadrupoles (MBQ)*
c) *Steering correctors for the MBQ*

*For all them we have launched an R&D followed by prototype procurement.*

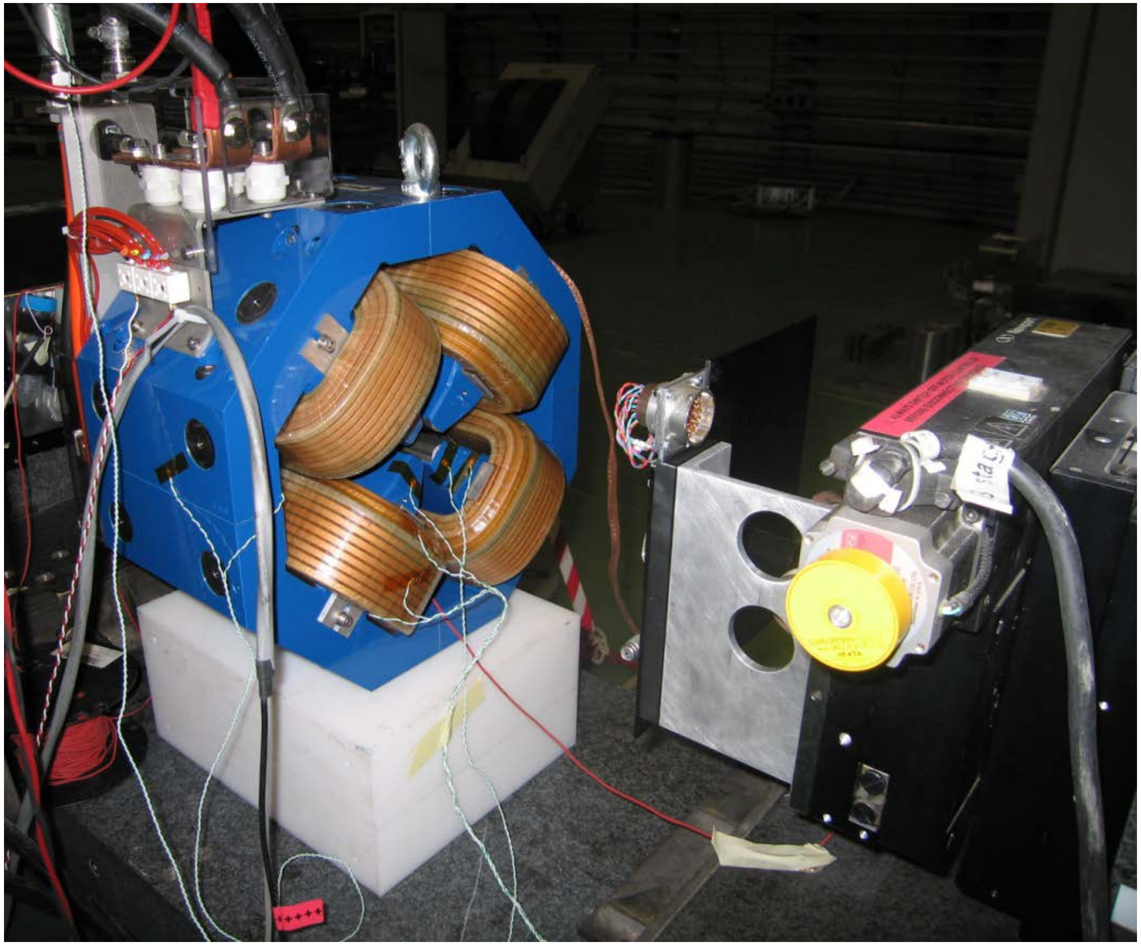


# 1) **Drive Beam Quadrupole** R&D Status:



# a) Electro-Mechanical Design Prototypes procurement:

- 2 first units (over 8) delivered to CERN from Danfysik (DK)
- Magnetic Measurements ongoing: first results very positive
- The MM results will give the OK to proceed (or to modify the pole profiles) on the commplition of the other 6 units.
- Pole profile final machining done by EDM technique on the 4 quadrants together.



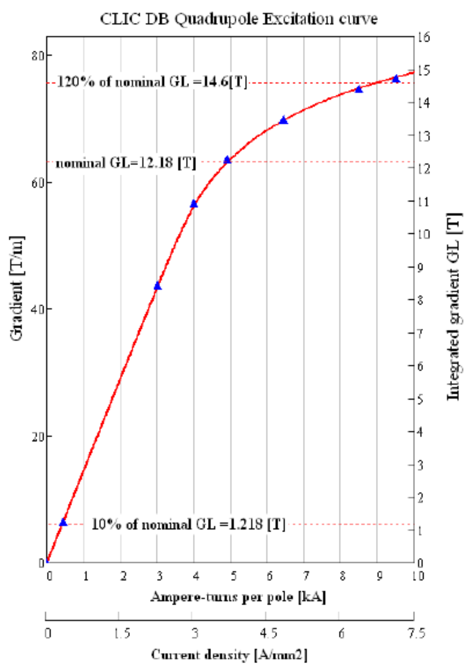
# a) Electro-Mechanical Design Prototypes procurement:

*Very successful Power Test results of this week*: final optimization of the magnet done with Danfysik was very efficient!

| Main Parameters | |
|---|---|
| Aperture Ø | 26 mm |
| Mag. Length | 192 mm |
| Nom. Grad. | 61 T/m |
| Nom Gdl | 12.18 T |
| Max. Gdl | 14.6 T |
| Nom. Length | 281 mm |
| Nom. Width | 390 mm |
| Weight | ~ 170 kg |
| Meas.Nom. Gdl | 12.18 T |
| Max. Meas. Gdl | 14.73 T |
| Meas. Current | 82.6 |
| Meas. Voltage | 6.87 |
| Meas. Nom. Power | 567 W |
| Max. Power (at 120%) | 1055 W |
| Cu conduct. | 6X6 mm$^2$ |
| N. Of turn | 208 |
| Nom. Water flow | 1.8 l/min |
| Nom. Press.drop | 3 bar |
| Nom. Δ T | 4 °C |

*(Estimation from 1st magnet design as presented at LCWS11 in Granada)*

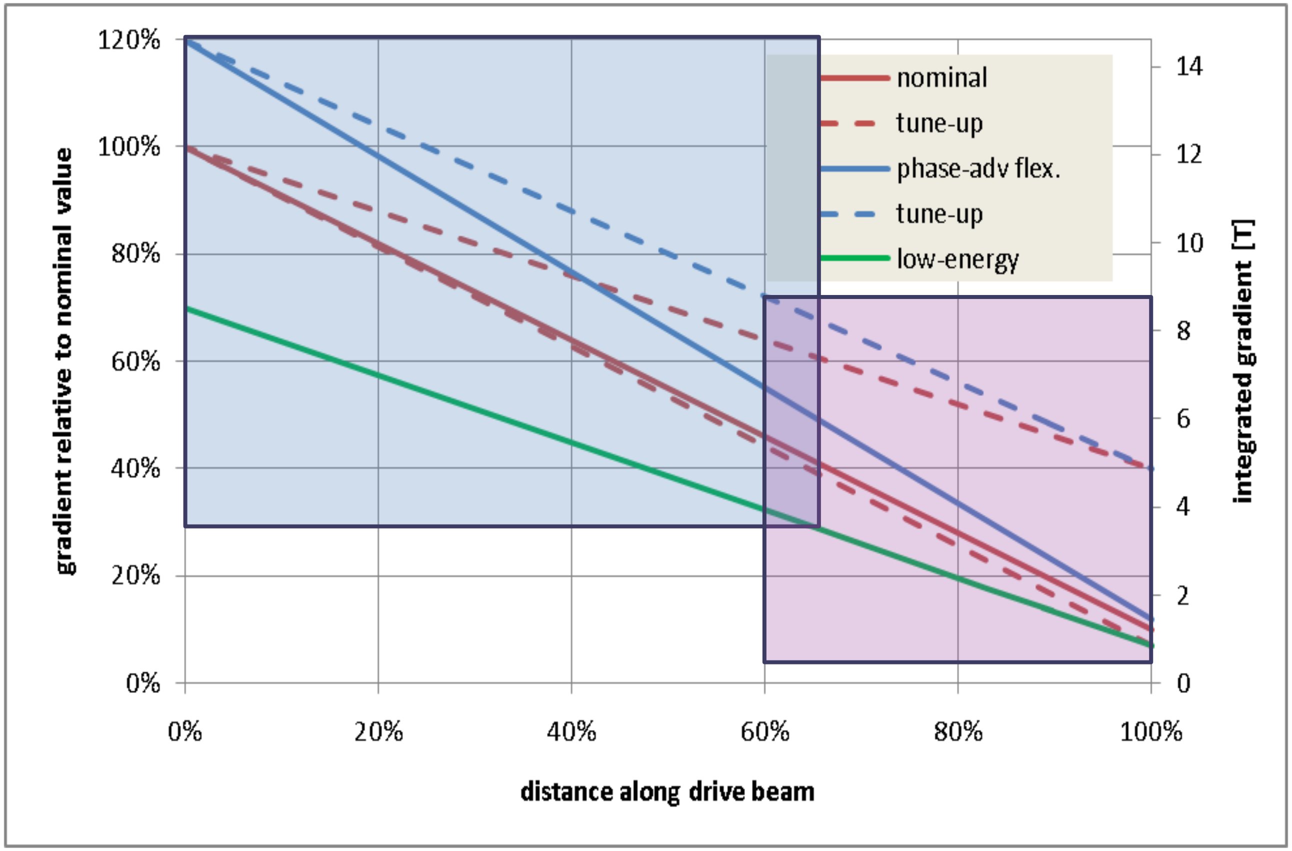
## Excitation curve & main parameters



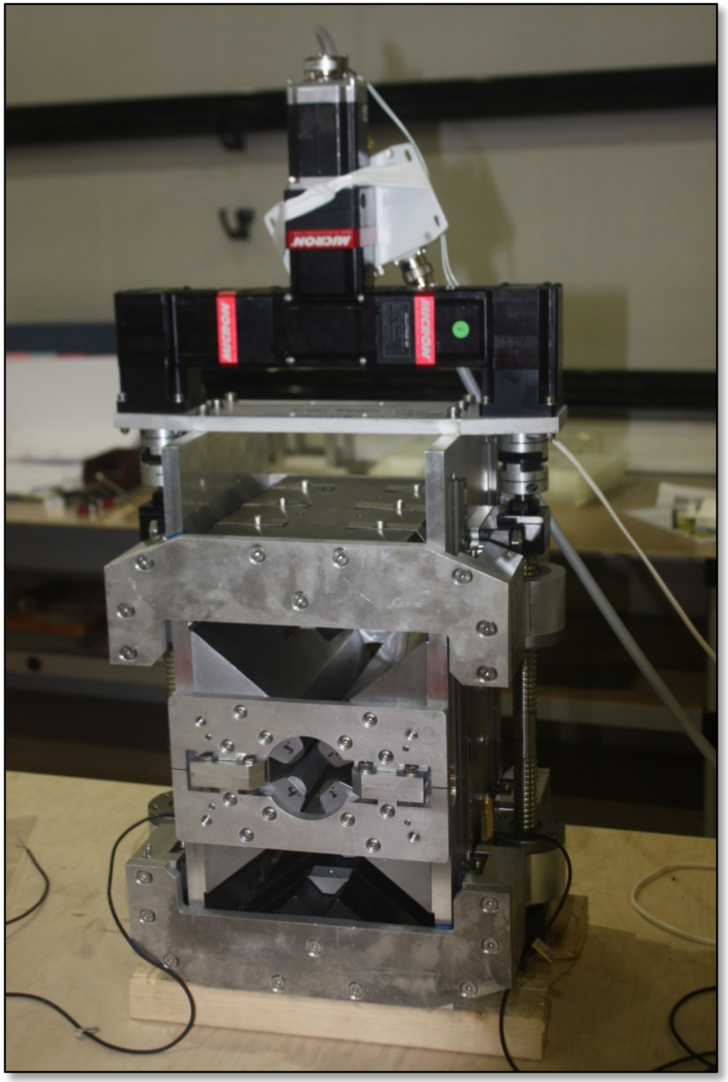

| CLIC DB Quadrupole Parameters | Units | | | |
|---|---|---|---|---|
| **MAGNET** | | | | |
| Magnet size H×S×L | [mm×mm×mm] | 390×390×286 | | |
| Magnet mass | [kg] | 149.2 | | |
| Full aperture | [mm] | 26 | | |
| Good field region(GFR) diameter | [mm] | 11×2=22 | | |
| **YOKE** | | | | |
| Yoke size H×S×L | [mm×mm×mm] | 390×390×180 | | |
| Yoke mass | [kg] | 29.4×4=117.6 | | |
| **COIL** | | | | |
| Hollow Conductor size | [mm] | 6×6, Ø=3.5 | | |
| Number of turns per coil | | 52 | | |
| Total conductor mass | [kg] | 31.6 | | |
| | | **Operation mode** | | |
| | | **10% of nominal** | **Nominal** | **120% of nominal** |
| Effective length | [mm] | 194.7 | 194 | 192.5 |
| Gradient at Z=0 | [T/m] | 6.26 | 62.78 | 75.85 |
| Integrated gradient ∫Gdl | [T] | 1.218 | 12.18 | 14.6 |
| Integrated gradient quality in GFR | % | 0.04 | 0.01 | 0.02 |
| **Electrical parameters** | | | | |
| Ampere turns per pole | [A] | 432 | 4840 | 9100 |
| Current | [A] | 8.3 | 93 | 175 |
| Current density | [A/mm$^2$] | 0.3 | 3.6 | 6.8 |
| Total resistance | [mOhm] | 99 | 99 | 99 |
| Total inductance | [mH] | 40 | 40 | 40 |
| Voltage | [V] | 0.82 | 9.2 | 17.3 |
| Power | [kW] | 0.007 | 0.86 | 3.03 |
| **COOLING** | | **Air (natural convection)** | **Water** | **Water** |
| Cooling circuits per magnet | | | 4 | 4 |
| coolant velocity | [m/s] | | 1.1 | 1.9 |
| cooling flow per circuit | [l/min] | | 0.6 | 1.1 |
| Pressure drop | [bar] | | 2.2 | 5.7 |
| Reynolds number | | | 4122 | 8210 |
| Temperature rise | [K] | | 5 | 10 |

# b) Tunable Permanent Magnet Design Prototypes procurement by Cockcroft Institute *(Ben Shepherd, Norbert Collomb, Jim Clarke, Neil Marks)*

Two Versions, a STRONG and a WEAK are under design and procurement to cover the full range of gradient needed along the Decelerators (Drive Beam) for the CLIC 3TeV layout



# b1) Tunable Permanent Magnet Design Prototypes procurement: STRONG Version:

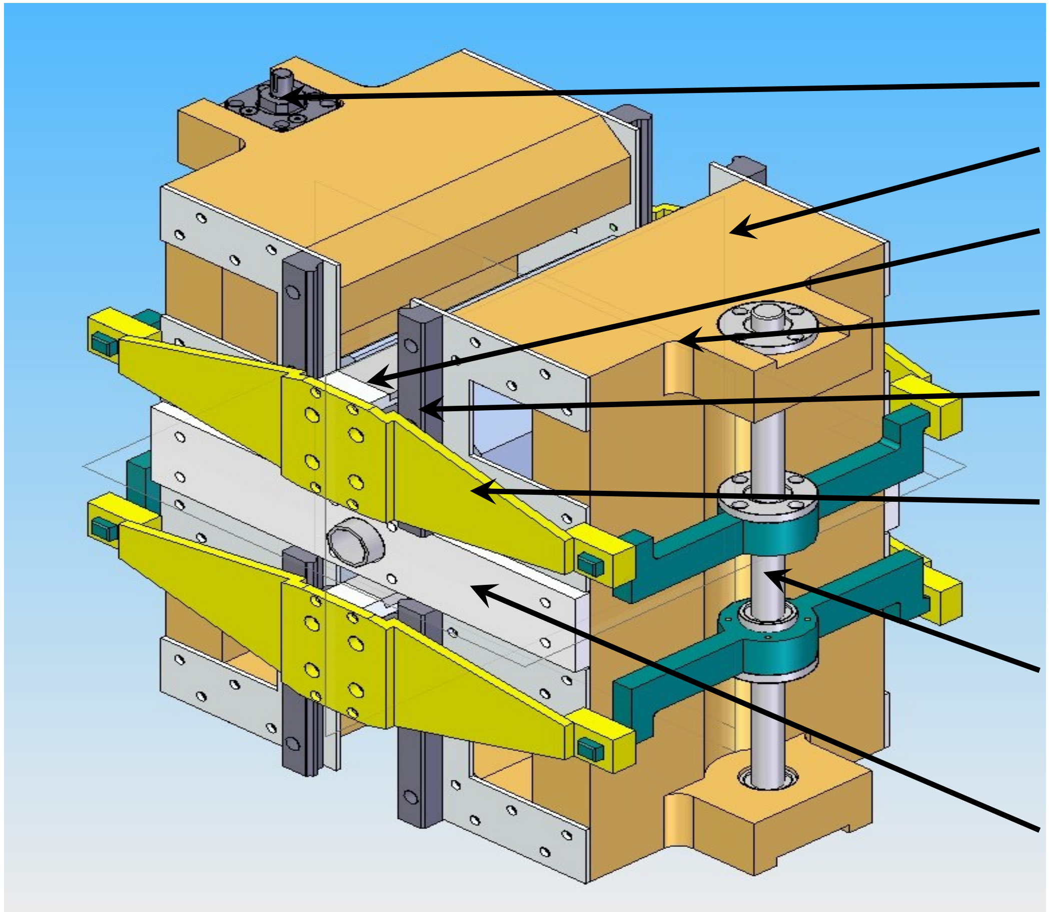



- Completed Phase 1 assembly (i.e. complete assembly, commissioning of actuators, gearbox, linear encoders, etc.)
- MM with Hall probe done
- Analyzing data and improving mechanics: some mechanics modification on iron poles fixation was needed and is under going
- Complete re-assembly and 2$^{nd}$ commissioning are ongoing
- Magnet measured at Cockcroft by Hall probes system.

Prototype it is now at CERN and will be measured at the beginning of November by stretched wire and rotating coil MM Systems.

# b2) Tunable Permanent Magnet Design Prototypes procurement: WEAK Version

- Conceptual Design completed
- Magnet modelling and CAD ongoing
- First interaction with CERN for Modules integration checks.
- Delivery to CERN expected in 2013



# 2) **Main Beam Quadrupole** R&D Status:

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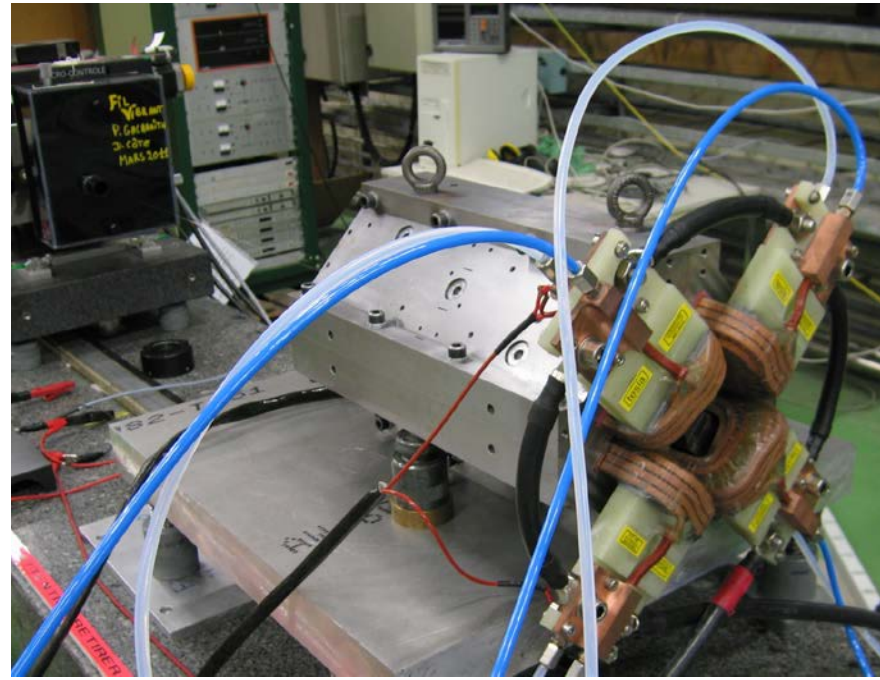


| TYPE1 | |
|---|---|
| Aperture (Ø) | 10 mm |
| Length | 420 mm |
| Gradient | 200 T/m |
| Current density | 6.1 A/mm2 |
| Current | 126 A |
| Voltage | 8 V |
| Power | 990W |
| Weight | 85 kg |
| Cooling circuit per magnet | 1 |
| Coolant velocity [m/s] | 1.12 m/s |
| Cooling flow [l/min] | 0.69 l/min |
| Pressure drop [bar] | 4.26 bar |
| Reynolds number | 6147 |
| Temperature rise [K] | 20 K |

| TYPE2 | |
|---|---|
| Aperture (Ø) | 10 mm |
| Length | 920 mm |
| Gradient | 200 T/m |
| Current density | 6.1 A/mm2 |
| Current | 126 A |
| Voltage | 16 V |
| Power | 1980 W |
| Weight | 170 kg |
| Cooling circuit per magnet | 2 |
| Coolant velocity [m/s] | 1.12 m/s |
| Cooling flow [l/min] | 0.69 l/min |
| Pressure drop [bar] | 4.26 bar |
| Reynolds number | 6147 |
| Temperature rise [K] | 20 K |

| TYPE3 | |
|---|---|
| Aperture (Ø) | 10 mm |
| Length | 1420 mm |
| Gradient | 200 T/m |
| Current density | 6.1 A/mm2 |
| Current | 126 A |
| Voltage | 24 V |
| Power | 2970 W |
| Weight | 280 kg |
| Cooling circuit per magnet | 4 |
| Coolant velocity [m/s] | 0.87 m/s |
| Cooling flow [l/min] | 0.53 l/min |
| Pressure drop [bar] | 2.06 bar |
| Reynolds number | 4757 |
| Temperature rise [K] | 20 K |

| TYPE4 | |
|---|---|
| Aperture (Ø) | 10 mm |
| Length | 1920 mm |
| Gradient | 200 T/m |
| Current density | 6.1 A/mm2 |
| Current | 126 A |
| Voltage | 30.4 V |
| Power | 3831 W |
| Weight | 370 kg |
| Cooling circuit per magnet | 4 |
| Coolant velocity [m/s] | 1.12 m/s |
| Cooling flow [l/min] | 0.69 l/min |
| Pressure drop [bar] | 4.26 bar |
| Reynolds number | 6147 |
| Temperature rise [K] | 20 K |

The first 2 prototypes TYPE1 and TYPE4 (1st Generation) procured in 2010. …Poles profiles were not of the required quality.

# 2) Main Beam Quadrupole R&D Status:

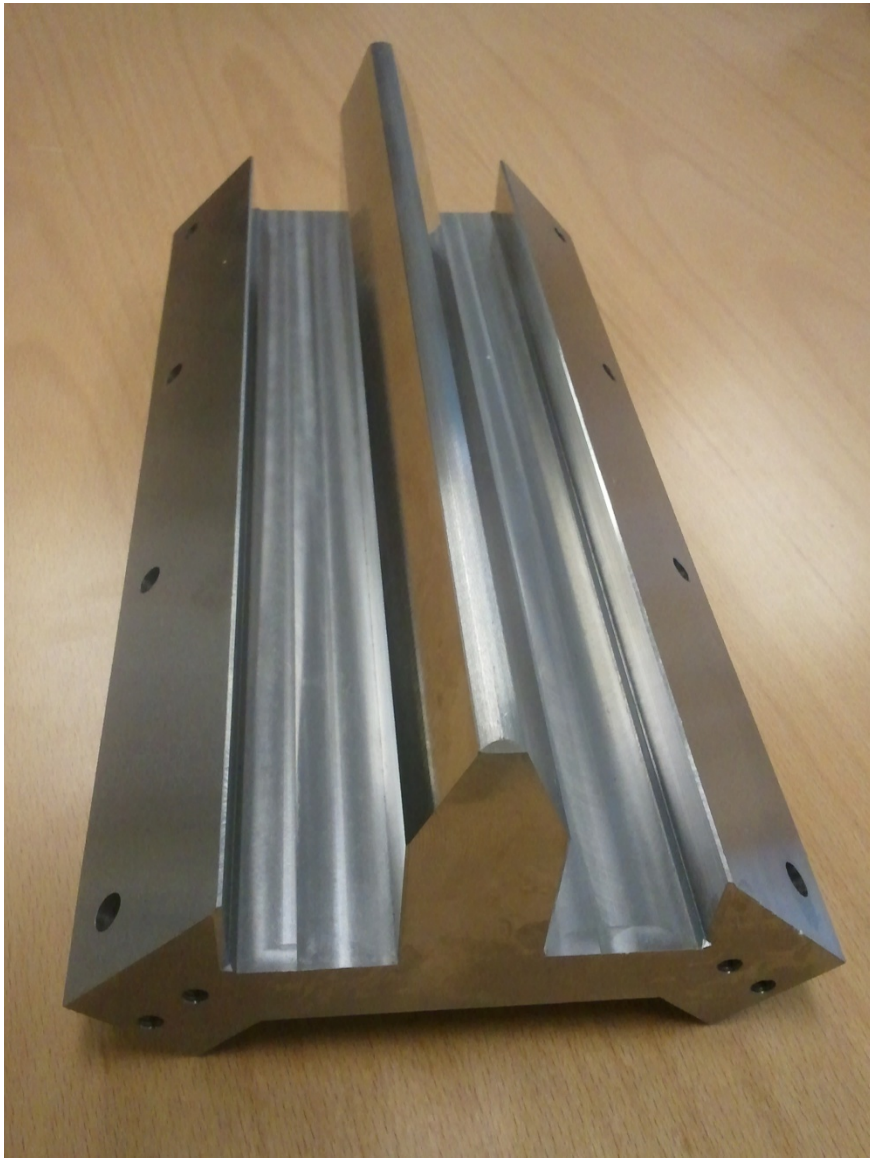
The 2nd generation MBQ Type 1 prototypes quadrants were delivered after the Summer 2012 from two Suppliers (DMP and Ostroj) and were precisely measured at CERN Metrology Lab.

Especially the quadrants from DMP seems very well machined (inside a tolerance of ±10μ).
The quadrants of Ostroj seems to be all inside a ±30μ tolerance.

In respect to 1st MBQ generation this two prototypes has a revised pole profile (set of circular segments instead of hyperbola + tips) and the one of DMP has also a revised (more massive) external cross section.

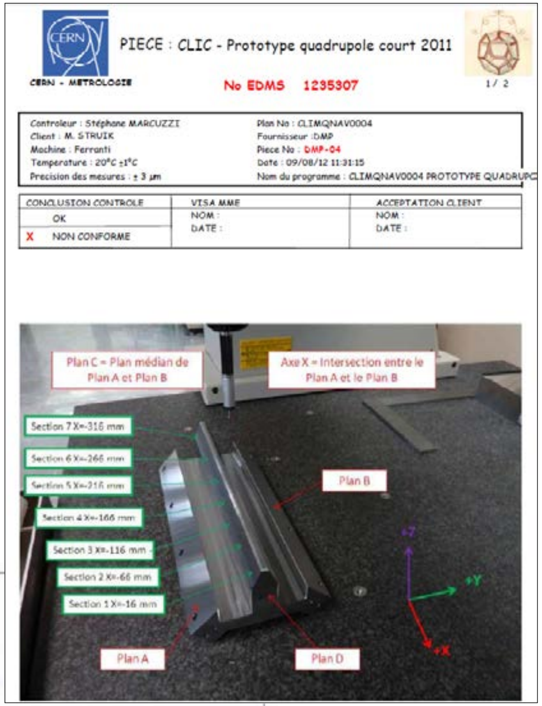
A special campaign, supported by ad-hoc test pieces, is ongoing to find the most efficient and precise assembly method to guarantee the micrometric assembly of the quadrants.

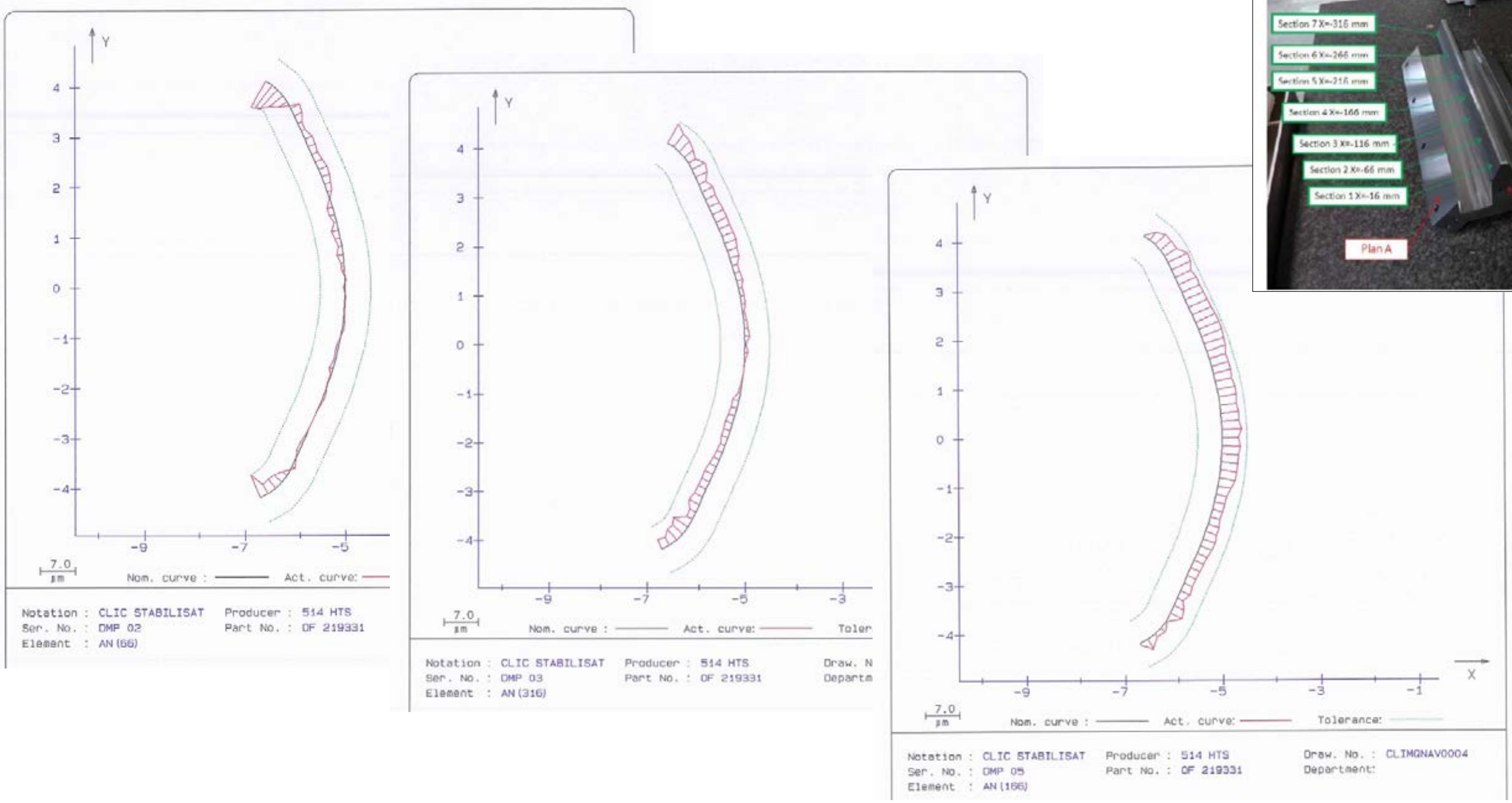
Magnetic measurements will follow.



# 2nd Generation MBQ Prototypes procurement:

Below are shown results of quadrant measurements (extracted from Manufacturer measurements).
Only magnetic measurements will say the final world about quality, from accelerator point of view, for such type of quadrants. This seems the best quality that we can reasonably achieve with grinding technique for TYPE1 quadrants.
For TYPE4 (~ 1800 mm length) the same tolerances seems not achievable, identification of best potential Suppliers is ongoing.



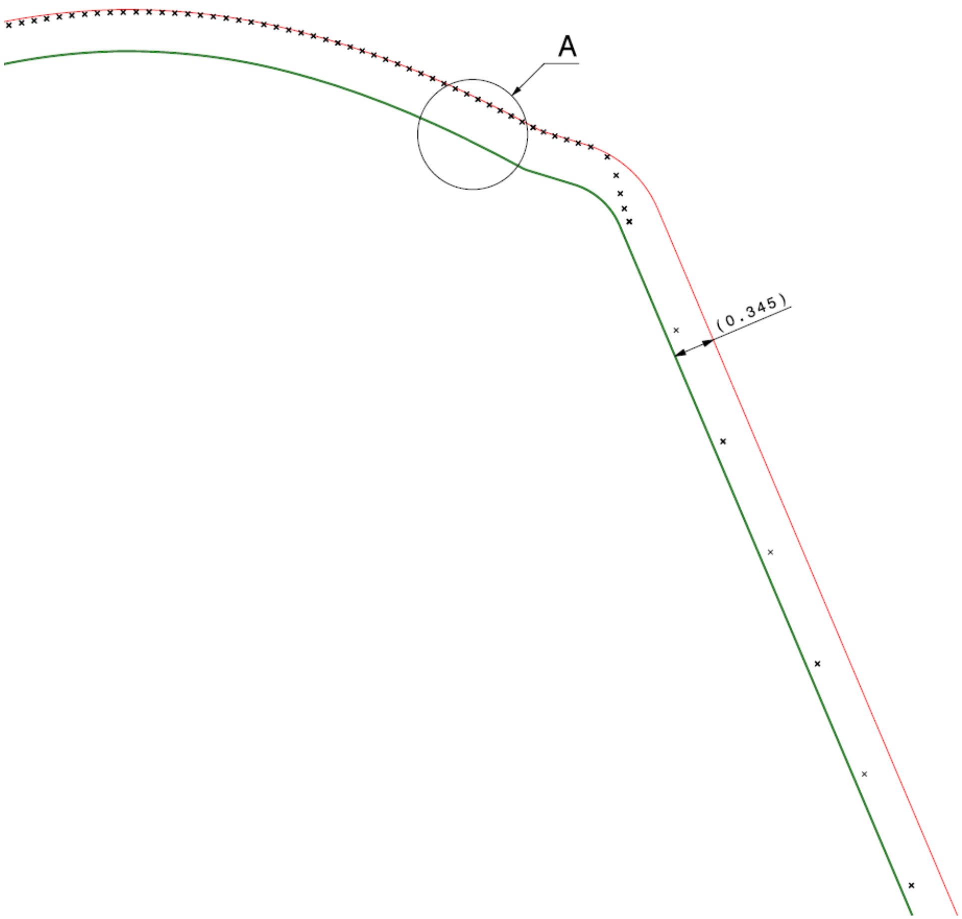



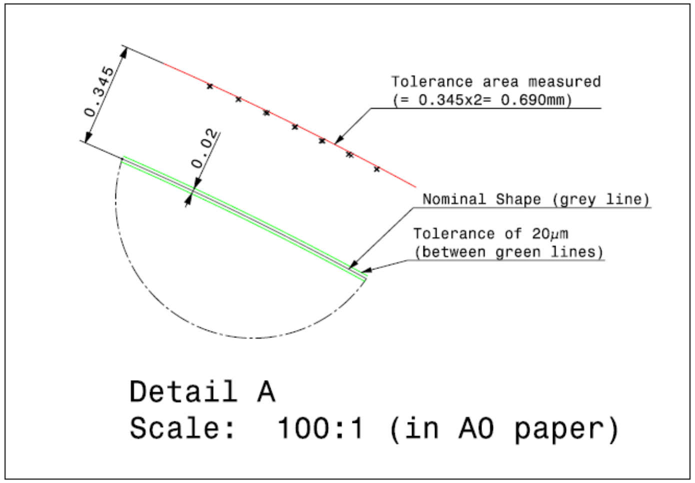
# 3 cases of (IMPROVING Quality) MBQ iron quadrants for Type1 (~ 300 mm length)

***CASE A*** *(2010): major Non Conformities in:*

*- offset of the pole profile of ~ 350 µm*

*- pole profile outside of the specified tolerance of ± 10µ*



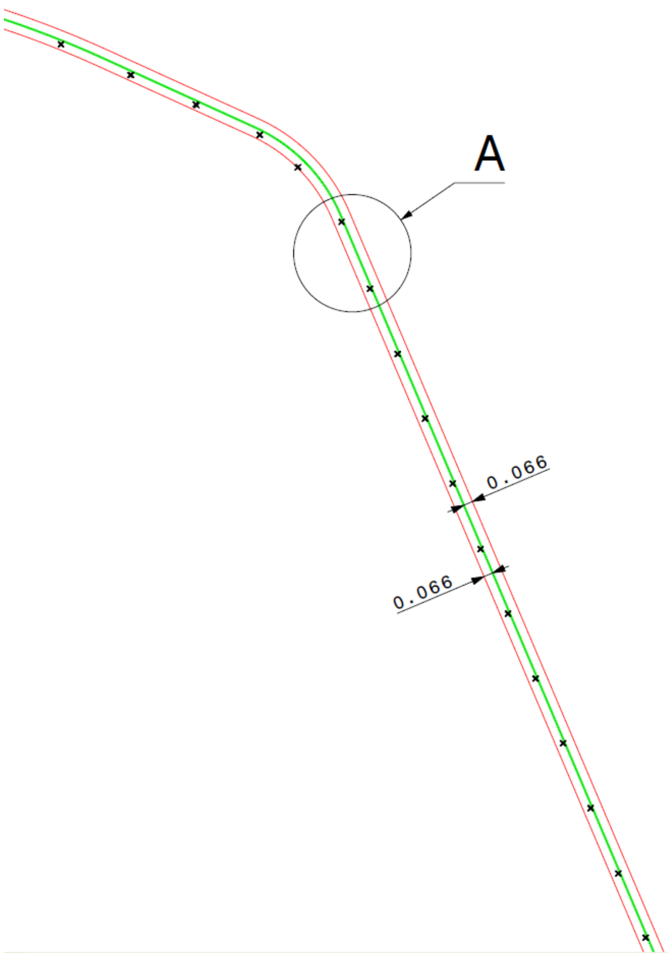



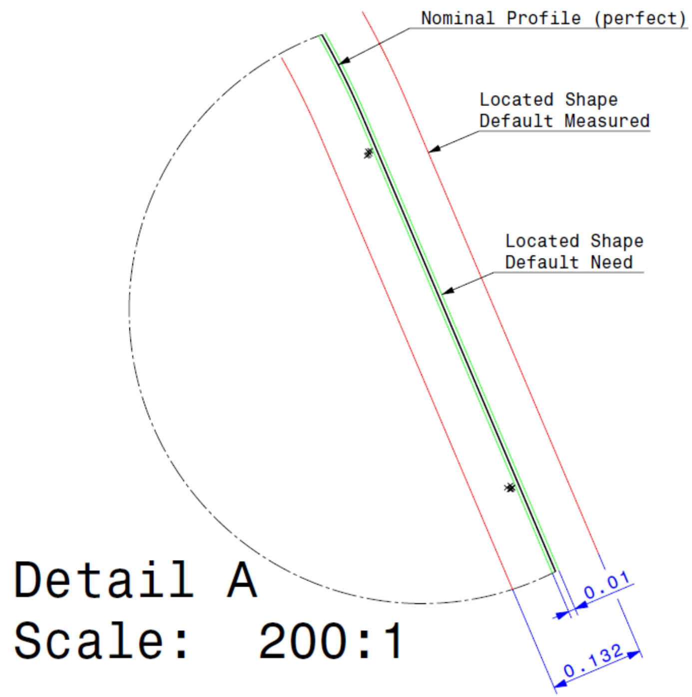
# 3 case of (IMPROVING Quality) MBQ iron quadrants for Type1 (~ 300 mm length)

***CASE B*** *(2012):*

*- pole profile close to the tolerance of ± 10μ*

*- extremely good longitudinal behavior on the measured 7 cross-sections ; each "x" is in fact a cluster of 7 "x" (practically coincident)*



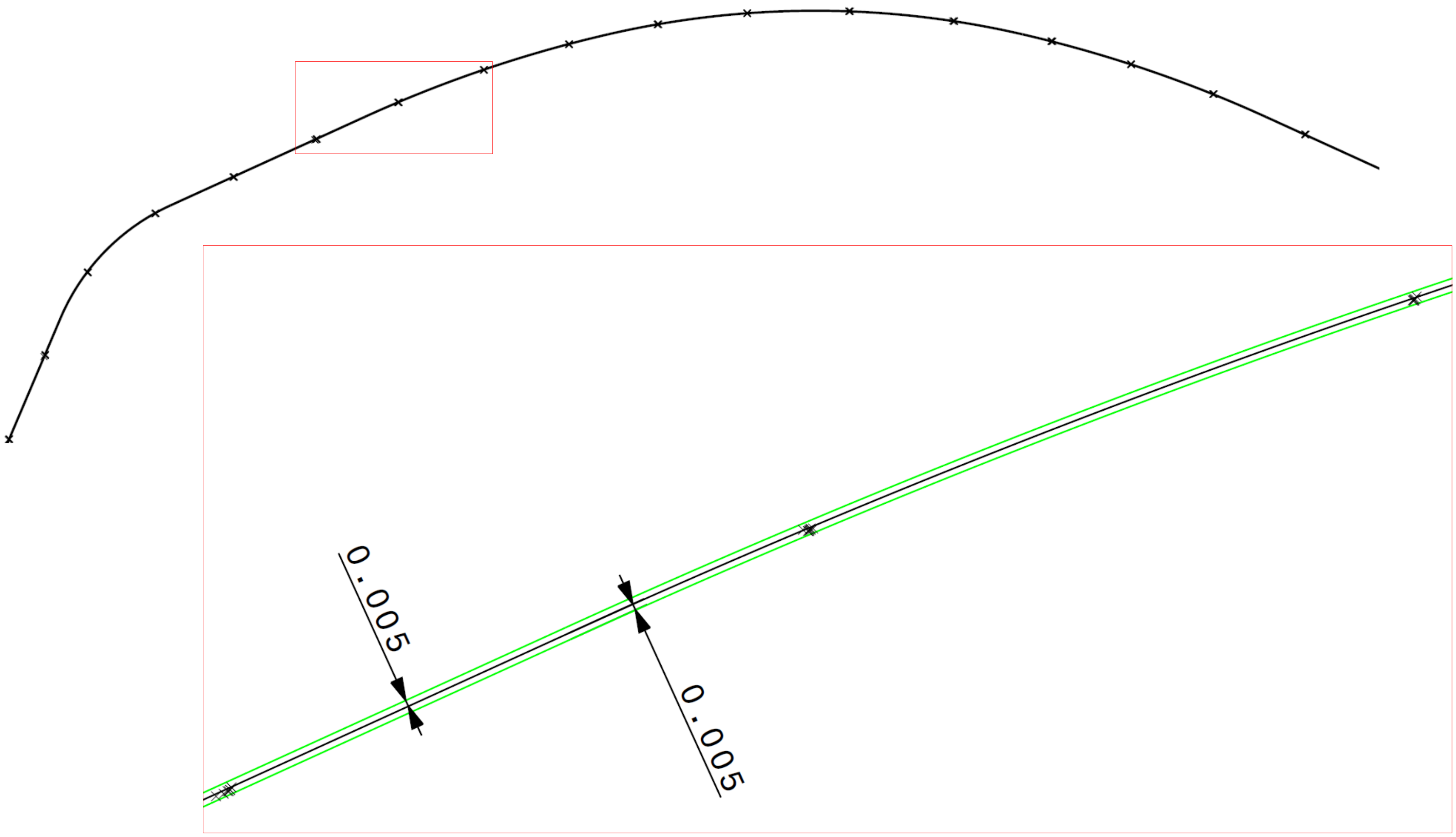



# 3 case of (IMPROVING Quality) MBQ iron quadrants for Type1 (~ 300 mm length)

***CASE C*** *(2012):*

*- pole profile INSIDE a tolerance of ± 7µ*

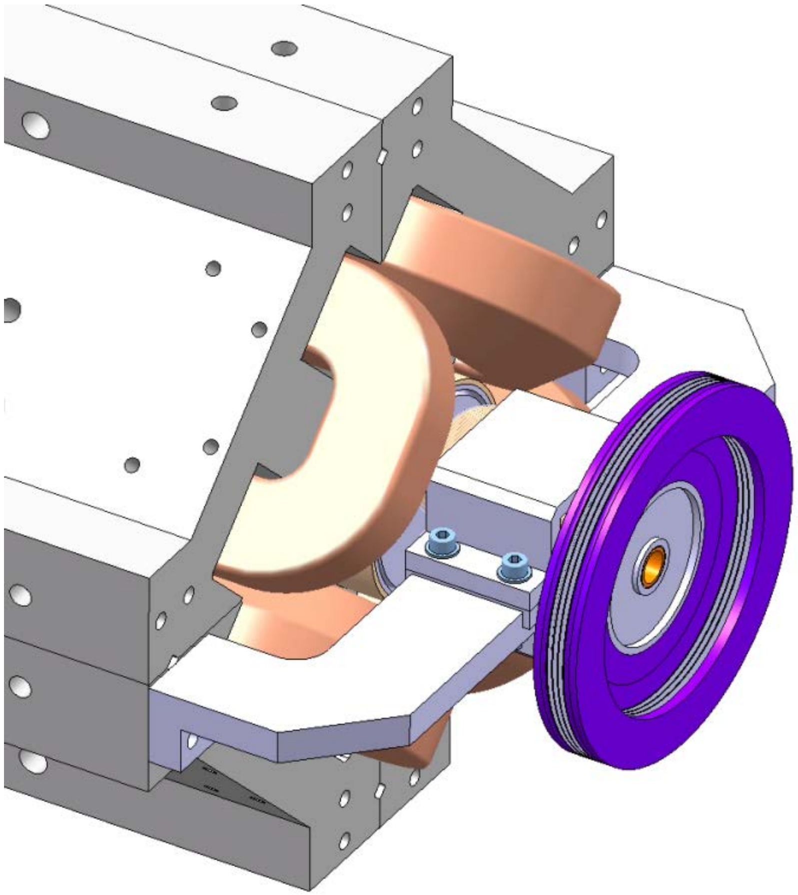
*- extremely good longitudinal behavior on the measured 7 cross-sections ; each "x" is in fact a cluster of 7 "x" (practically coincident)*

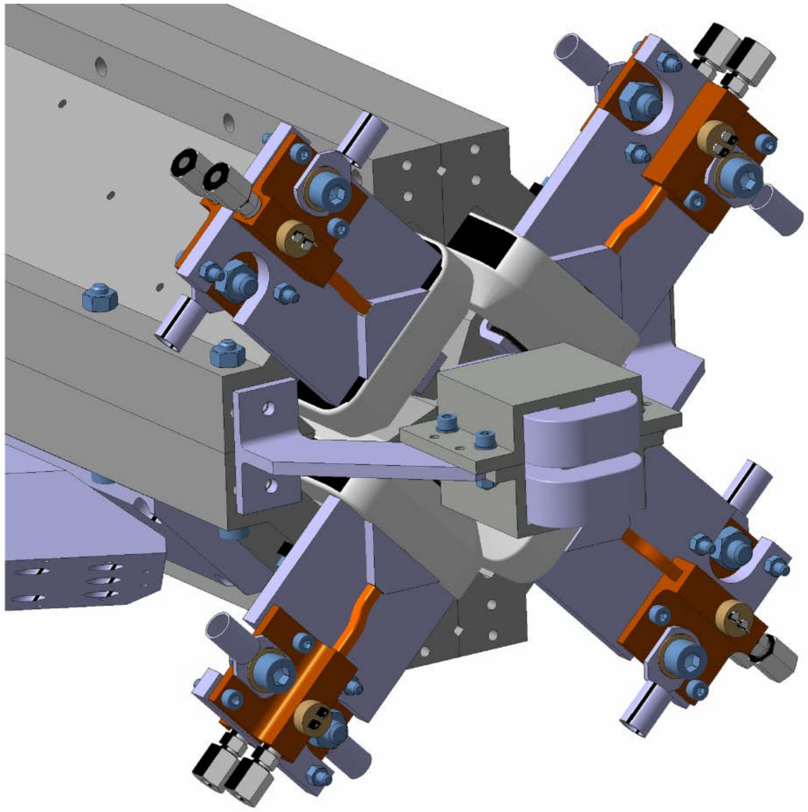


# 3) **Steering correctors** for MBQ R&D Status:

# 3) MBQ Steering correctors R&D Status:

Steering correctors for the MBQ (TYPE1 and 4) design completed and decision to procure two prototypes was taken. This mainly in order to check their functioning and impact on the stabilization system (the magnet will be pulsed at 100 Hz). Integration in the module it is also well advance. Assembly on Modules for LAB Tests Program not yet decided.





# 3) MBQ Steering correctors R&D Status:

| | |
|---|---|
| Type 1 | Dipole corrector Type 1, laminated yoke, air-cooled |
| Total magnet length | ~59 mm |
| Total magnet width × height | 48 mm x 52 mm |
| Total magnet mass | 0.61 kg |
| Vertical full aperture | 12 mm |
| Good Field Region(GFR) radius | 4 mm |
| Nominal field strength in magnet centre $B_y(0,0,0)$ | 0.0237 at 114 A |
| Nominal integrated field strength $\int B_{y(0,0,Z)}dz$ | 1.16 ×$10^{-3}$ Tm |
| Magnetic length | ~ 49mm |
| Integrated field homogeneity $\Delta\int B_y dz / \iint B_{y(0,0,Z)}dz$ inside GFR | < ± 0.03% |
| Yoke | |
| Steel type | M270-50A |
| Yoke length | 59 mm |
| Yoke width x height | 48 mm x 52 mm |
| Lamination thickness | 0.5 mm |
| Packing factor | < 97 % |
| Yoke mass | 0.208×2=0.416 kg |
| Coil | |
| Number of coils per magnet | 2 |
| Number of turns per coil | 8×14=112 |
| Conductor type, dimension | round, Ø=0.9 mm |
| Conductor mass per 1 m | 5.7×$10^{-3}$ kg/m |
| Average turn length | 0.148 m |
| Conductor length per coil | 16.6 m |
| Conductor mass per coil | 94.5×$10^{-3}$ kg |
| Conductor insulation thickness | 0.05 mm |
| Max. conductor overall diameter | 1.02 mm |
| Ground insulation thickness | 0.5 mm |
| Electrical parameters (DC) for the nominal integrated field of 1.16 ×$10^{-3}$ Tm | |
| Ampere turns per pole | 114 A |
| Current | 1.018 A |
| Current density | 1.6 A/mm$^2$ |
| Power consumption (DC) | 0.93 W |
| Voltage on magnet (DC) | 0.91 V |
| Total resistance at 20$^0$C | 896 Ω |
| Total inductance | 9.4 mH |
| Cooling | |
| Air, natural convection | |
| Operation parameters | |
| Operation mode | PULSED |
| Repetition frequency | 100 [Hz] |
| Total cycle time | 10 [ms] |
| Rise time for 25% of full scale | 2 [ms] |
| Flat top time | 2 [ms] |
| Total analyzing time at new/old level | 6 [ms] |
| Voltage on magnet at ramp end | 2.1 V |
| Max. current ramp | 127.3 A/s |

| | |
|---|---|
| Type 4 | Dipole corrector Type 4, laminated yoke, air-cooled |
| Total magnet length | ~98 mm |
| Total magnet width × height | 70 mm × 72 mm |
| Total magnet mass | ~2.1 kg |
| Vertical full aperture | 12 mm |
| Good Field Region(GFR) radius | 4 mm |
| Nominal field strength in magnet centre $B_y(0,0,0)$ | 0.0561 T |
| Nominal integrated field strength $\int B_{y(0,0,Z)}dz$ | 4.057 ×$10^{-3}$ Tm |
| Magnetic length | ~ 72.3 mm |
| Integrated field homogeneity $\Delta\int B_y dz / \iint B_{y(0,0,Z)}dz$ inside GFR | < ± 0.03% |
| Yoke | |
| Steel type | M270-50A |
| Yoke length | 60 mm |
| Yoke width x height | 70 mm × 72 mm |
| Lamination thickness | 0.5 mm |
| Packing factor | < 97 % |
| Yoke mass | 0.55 × 2=1.1 kg |
| Coil | |
| Number of coils per magnet | 2 |
| Number of turns per coil | 17×22=374 |
| Conductor type, dimension | round, Ø=0.9 mm |
| Conductor mass per 1 m | 5.7×$10^{-3}$ kg/m |
| Average turn length | 0.223 m |
| Conductor length per coil | 83.402 m |
| Conductor mass per coil | 0.475 kg |
| Conductor insulation thickness | 0.05 mm |
| Max. conductor overall diameter | 1.02 mm |
| Ground insulation thickness | 0.5 mm |
| Electrical parameters (DC) for the nominal integrated field of 4.057 ×$10^{-3}$ Tm | |
| Ampere turns per pole | 270 A |
| Current | 0.722 A |
| Current density | 1.14 A/mm$^2$ |
| Power consumption (DC) | 2.35 W |
| Voltage on magnet (DC) | 3.26 V |
| Total resistance at 20$^0$C | 4.51 Ω |
| Total inductance | 162 mH |
| Cooling | |
| Air, natural convection | |
| Operation parameters | |
| Operation mode | PULSED |
| Repetition frequency | 100 Hz |
| Total cycle time | 10 ms |
| Rise time for 25% of full scale | 2 ms |
| Flat top time | 2 ms |
| Total analyzing time at new/old level | 6 ms |
| Voltage on magnet at ramp end | 17.9 V |
| Max. current ramp | 90.2 A/s |

# 3) MBQ Steering correctors R&D Status:

2 sets of laminated iron yokes (0.5 mm lamination thickness) under procurement with two different suppliers. The key point of these small magnets is the tolerance on some surfaces (very tight; targeting the 10 μm range)
Precise pole shapes and mating surfaces are machined by wire cutting (EDM) technology.
Firs set at CERN under machining now.
Coils winding and curing are ongoing at CERN by TE/MSC-MNC Section.
Complete assembly and test expected for Spring 2013.