Status of magnets studies for ATF

M. Modena CERN

Acknowledgments:

CERN CLIC Magnets Study Team: ***A. Aloev, A. Bartalesi, E. Solodko, P. Thonet, A. Vorozhtsov***

International Workshop on Future Linear Colliders

LCWS13

11-15 November 2013, The University of Tokyo

Outline:

4) A QD0 possible upgrade for ATF

5) OCTUPOLES for ATF

Following the proposal for an ATF upgrading to achieve a ultra low-β scheme, that would be largely beneficial for the study of CLIC and ILC FF systems, requirements for a new QF1 and QD0 were proposed:

Requirements for QF1 and QD0*

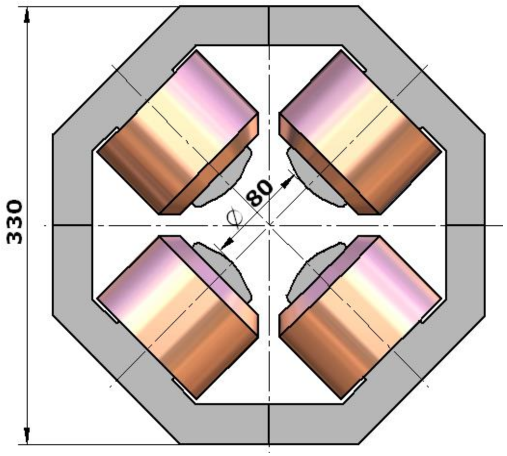
Magnet Name	**QF1FF**	**QD0FF**	**Units**
Gradient Nom. / Ultra low	6.772 / 6.791	12.45 / 12.46	T/m
Magnetic length	475		mm
Nom. Integrated gradient	3.226	5.919	T
Tuning range	±5		%
Aperture radius	> 35		mm
Good Field Region radius	20		mm
Constrains	Top half of the magnet has to be dismountable		
Field quality requirements			
Harmonic №:	Skew an=An/B2	Normal bn=Bn/B2	
3	0.124	0.748	units@r_{GFR}
4	0.344	4.12	units@r_{GFR}
5	0.665	2.76	units@r_{GFR}
6	1.57	9.82	units@r_{GFR}

(*H. Garcia, E. Marin. R. Tomas. “ATF2 QD0FF and QF1FF specifications”, CERN, 26/07/2011).

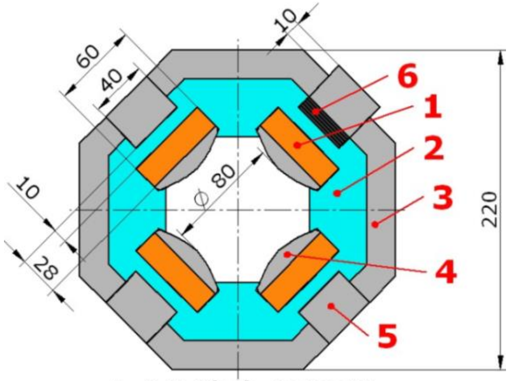
Upgrade of QD0 for ATF

Some magnet design options (studied in 2011)

1) EM quadrupole:

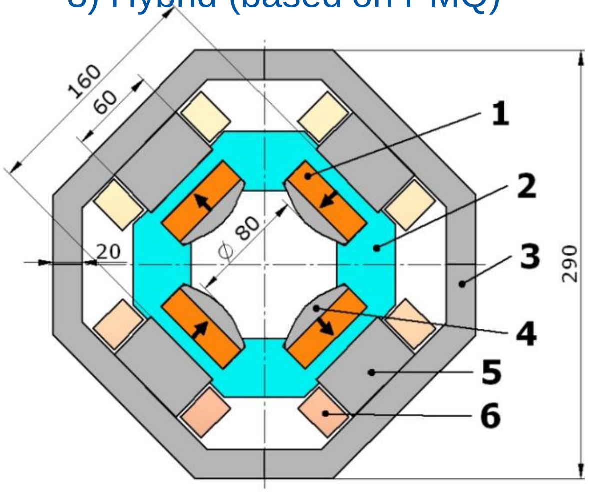


2) PMQ



1- P.M. Block, Sm2Co17
2- Aluminium core
3- Return Yoke, AISI 1010
4- Pole Tip, AISI 1010
5- Tuning block, AISI 1010
6- Spacers, Stainless steel

3) Hybrid (based on PMQ)



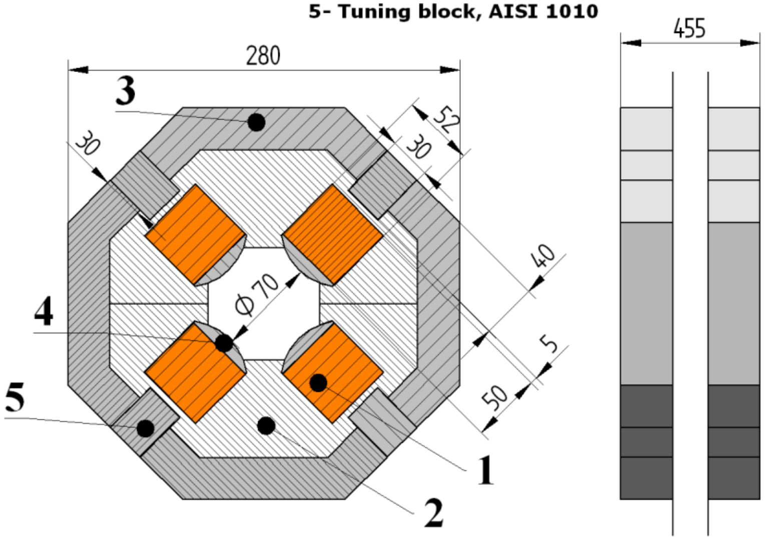
ADVANTAGES of a PMQ solution respect of an EMQ one:

- Compactness.
- No vibration of the magnet induced by an active water cooling system.
- Increased reliability (minimum maintenance required, no electrical failure expected).
- Minimum operational costs.
- PMQ central structure can be built in one or two pieces only → better field quality (error sources limited).
- The proposed PMQ design has the possibility to suppress the eventual higher order multipole errors by fine tuning (or shimming) of the blocks, while for the EMQ additional trim coils and independent power supplies are needed.
- The EMQ and hybrid solutions look preferable for frequent and remote gradient setting.
- Coils can be water cooling free (higher reliability and minimum technical services requirement); but this has an impact on the dimensions and weight.

QD0 PMQ: Permanent Quadrupole Magnet (PMQ) with adjustable strength

QD0 magnet for ATF3

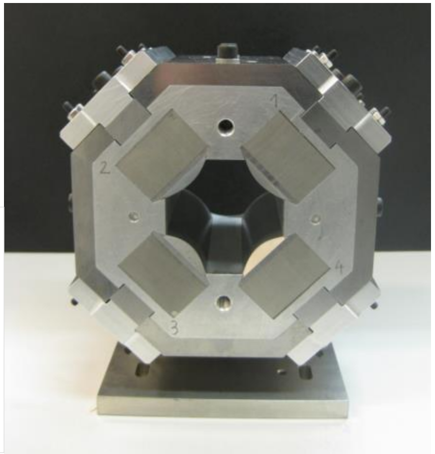
1- P.M. Block, Sm2Co17
2- Aluminium core
3- Return Yoke, AISI 1010
4- Pole Tip, AISI 1010
5- Tuning block, AISI 1010



1. P.M. blocks -as a flux generators
2. Aluminum ring (made in a 2 pieces: only 3 degree of freedom) -as a support structure, p.m. blocks and pole nose will be mechanically clamped by this ring.
4. Pole tip made of soft iron material- to smooth the effects of possible differences, among the p.m., in terms of easy axis orientation.
5. Tuning blocks (movable mechanically at 10 mm (max), independently per pole) - to compensate the possible p.m. inequalities, to set the field gradient (max at 12.5% from the nominal value), to suppress the sextupole field components b3,a3
6. Spacers the exact position of the block will be regulated by the non-magnetic spacers of different thickness.

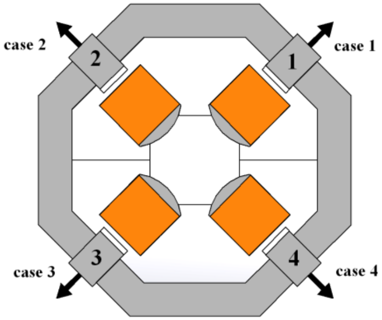
	QD0
Aperture radius	35 mm
Magnet length	475 mm
Yoke height ×width × length	280 mm × 280 mm × 455 mm
Magnet weight	165.3 kg
Effective length	473.1 mm
Nom. field gradient at Z=0 mm	12.5 T/m
Nom. Integrated field gradient	5.91 T
Tuning range	7%

Ex. An hibrid prototype built for LINAC4:
Aperture: 45 mm
Gradient: 16 T/m

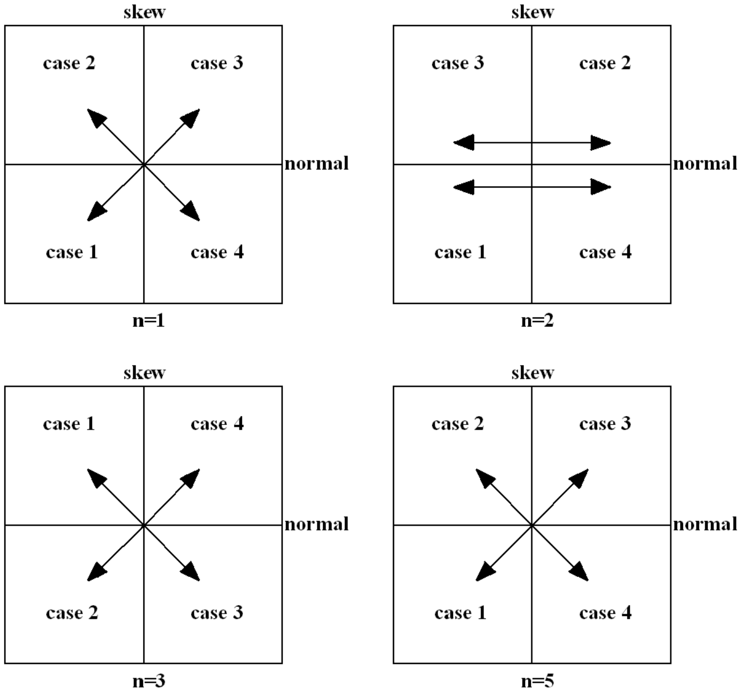


Field quality aspects:

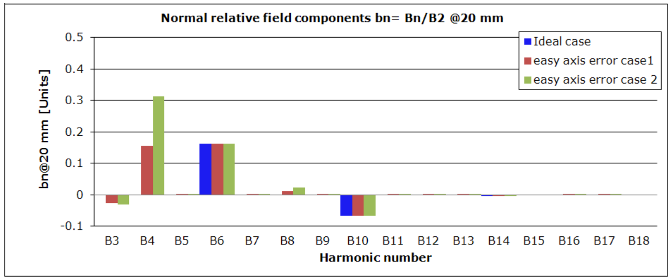
1. Field components suppression: field components can be suppressed by tuning of magnetic reluctance on each individual pole performed by radial offset of the tuning blocks (at 45^0, 135^0, 225^0, and 315^0) .

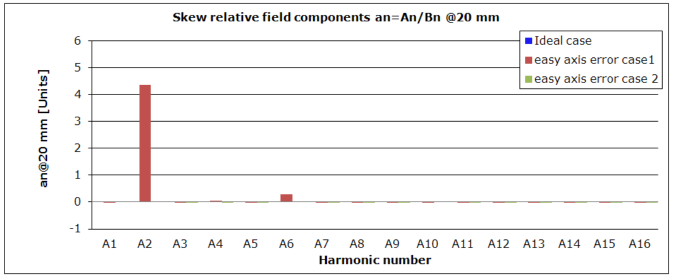


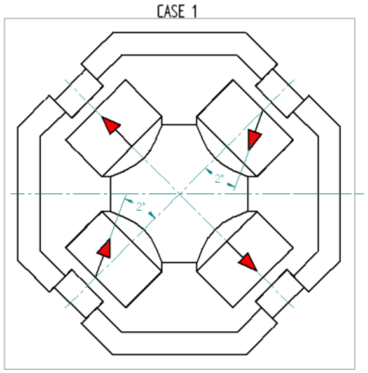
Vectors of field components in normal-skew phase plane, generated by tuning blocks for the four cases (K. Halbach**):

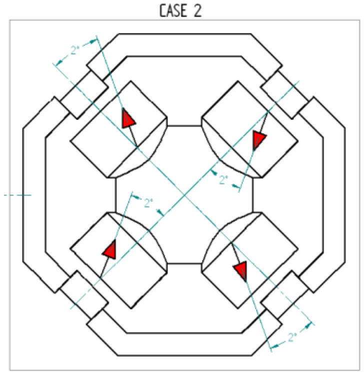


2. P.M. easy axis orientation errors: The effects of possible permanent blocks inequalities due to the easy axis orientation errors were computed by introducing an angular deviation from the nominal value in the range of $\pm 2^0$, representing an upper limit according to the permanent magnet blocks manufacturer









** K. Halbach "First order perturbation effects in iron-dominated two-dimensional symmetrical multipoles", 1969

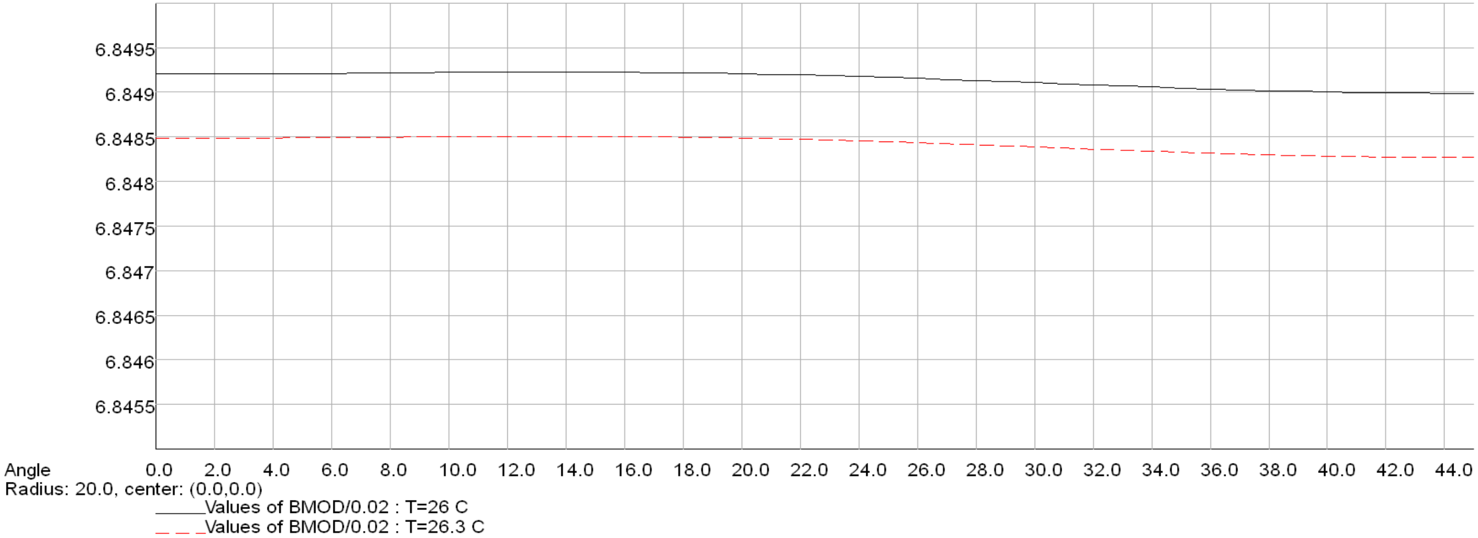
Magnet stability (temperature dependence)

Questions about this point were raised in occasion of a presentation at:
"FJPPL-FKPPL Workshop on ATF2 Accelerator R&D" (Paris, March 2012):

Temperature at installation site estimated at T=26 ^{0}C, Temperature variation : ΔT = 0.3 ^{0}C

Permanent magnet material: Sm2Co17 RECOMA® 30S

- α(Br): Reversible temperature coefficient of induction, provided by Suppliers (α(Br = -0.035%/^{0}C) but as a constant for a wide temperature range (20-150 ^{0}C)
- In our case: Br=1.12 [Tesla] @ 20 ^{0}C => $\Delta Br \approx 1.2\times10^{-4}$ [Tesla] for the ΔT of 0.3 ^{0}C

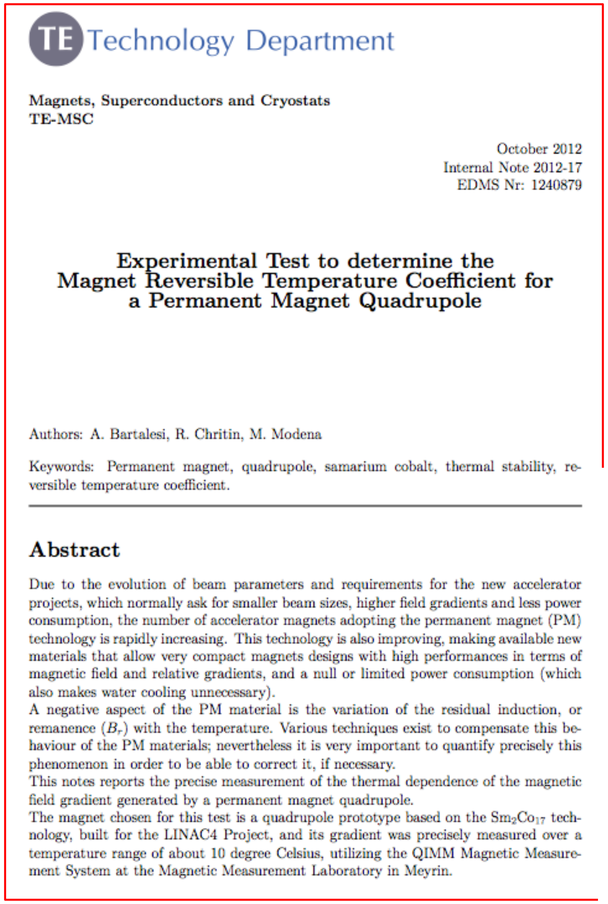


In the plot: Field gradient QF1 for two simulation cases:
1) T=26 ^{0}C
2) T=26.3 ^{0}C

Upgrade of QD0 for ATF

So, in Summer 2012 we decided to perform a dedicated test to check this aspect:

(see CERN, TE-MSC Internal Note 2012-17 EDMS Nr: 1240879: A. *Bartalesi, R. Chritin, M. Modena: «Experimental Test to determine the Magnet Reversible Temperature Coefficient for a Permanent Magnet Quadrupole».*



TE Technology Department

Magnets, Superconductors and Cryostats
TE-MSC

October 2012
Internal Note 2012-17
EDMS Nr: 1240879

Experimental Test to determine the Magnet Reversible Temperature Coefficient for a Permanent Magnet Quadrupole

Authors: A. Bartalesi, R. Chritin, M. Modena

Keywords: Permanent magnet, quadrupole, samarium cobalt, thermal stability, reversible temperature coefficient.

Abstract

Due to the evolution of beam parameters and requirements for the new accelerator projects, which normally ask for smaller beam sizes, higher field gradients and less power consumption, the number of accelerator magnets adopting the permanent magnet (PM) technology is rapidly increasing. This technology is also improving, making available new materials that allow very compact magnets designs with high performances in terms of magnetic field and relative gradients, and a null or limited power consumption (which also makes water cooling unnecessary).

A negative aspect of the PM material is the variation of the residual induction, or remanence (B_r) with the temperature. Various techniques exist to compensate this behaviour of the PM materials; nevertheless it is very important to quantify precisely this phenomenon in order to be able to correct it, if necessary.

This notes reports the precise measurement of the thermal dependence of the magnetic field gradient generated by a permanent magnet quadrupole.

The magnet chosen for this test is a quadrupole prototype based on the Sm_2Co_{17} technology, built for the LINAC4 Project, and its gradient was precisely measured over a temperature range of about 10 degree Celsius, utilizing the QIMM Magnetic Measurement System at the Magnetic Measurement Laboratory in Meyrin.

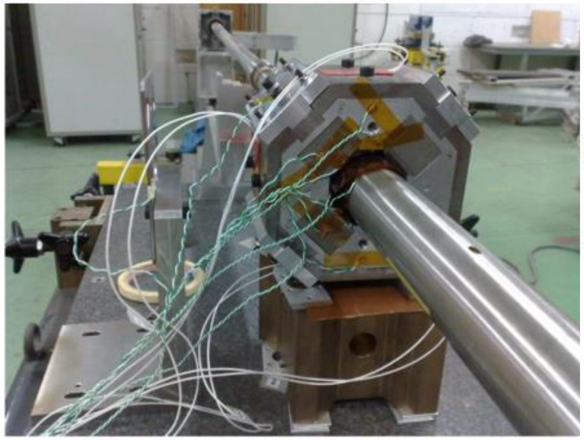


Figure 14: The experiment layout (magnet, thermocouples and measuring probe).

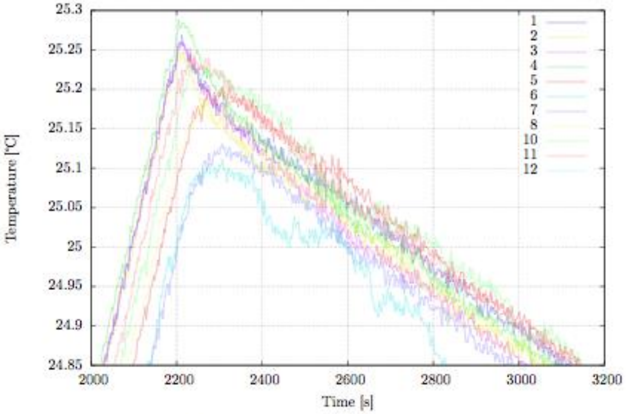


Figure 13: Temperatures (corrected), gradient inversion.

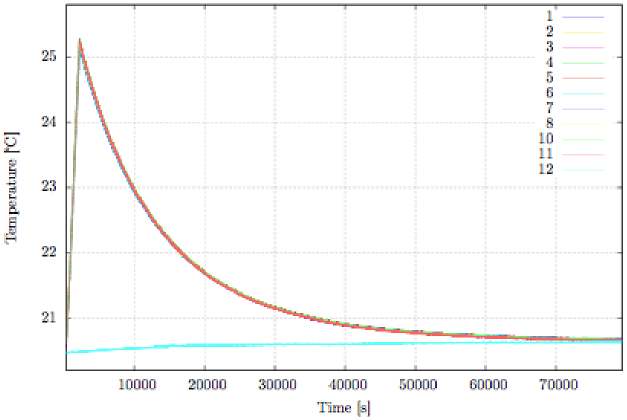


Figure 10: Temperature readouts in I8, after the correction.

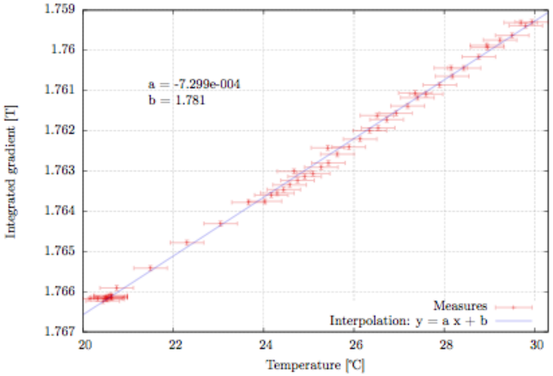


Figure 18: The magnet reversible gradient coefficient.

Succesful conclusions of the work :

- *A "magnet reversible temperature coefficient" was determined for the PM quadrupole and estimated as −0.041 % per °C*
- *The effect is linear and no measurable hysteresis on the ferromagnetic elements of the magnet was observed.*

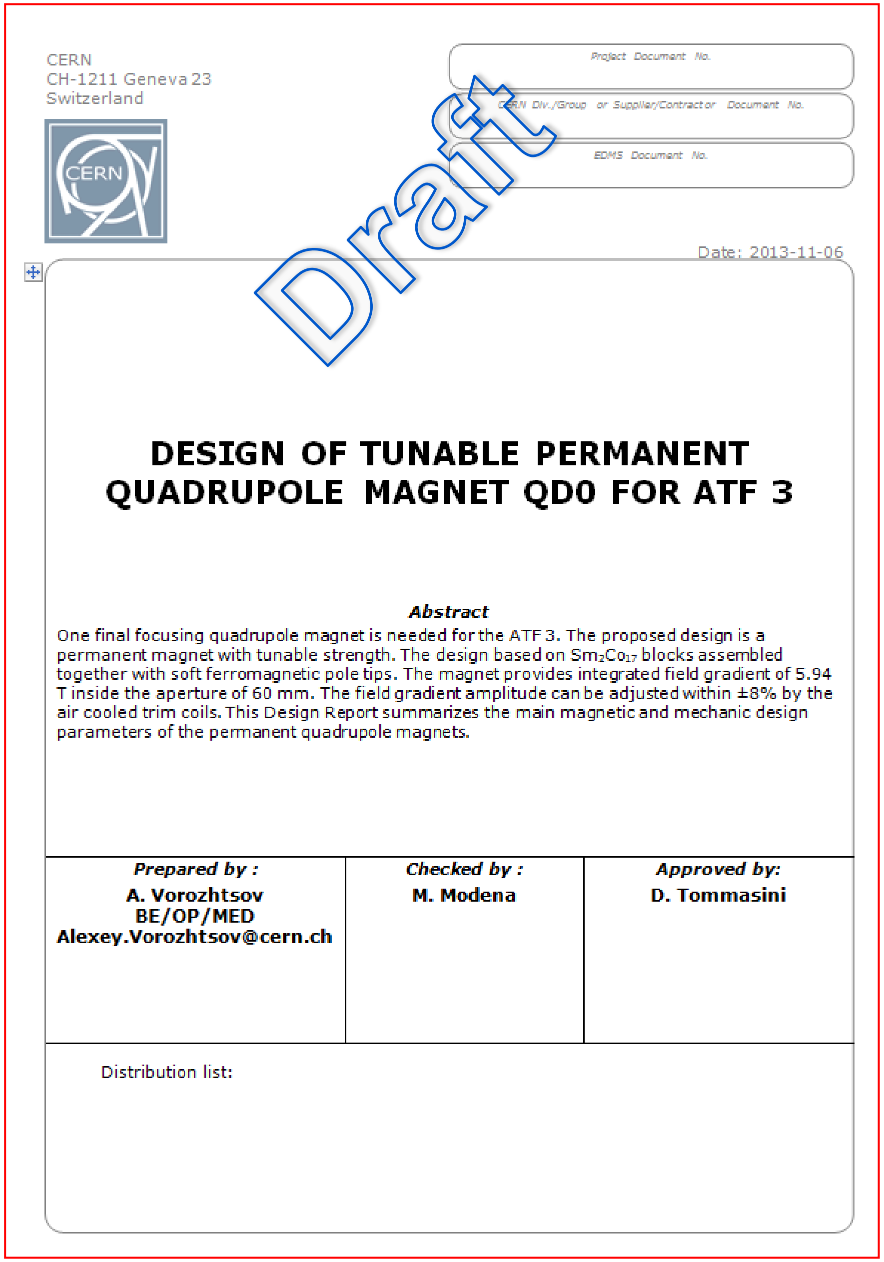
Upgrade of QD0 for ATF

Sice 2011 situation has evolved:
in 2012 a solution for a new ATF QF1 was found recovering a quadrupole of the PEP *B*-Factory at SLAC.

For QD0, in 2013 we revised the specification (private discussion with R. Tomas) mainly looking at the magnet aperture and field quality requirements and we agreed on the following revised specification table:

Table 1: Requirements for the quadrupole magnet

Parameter			Units
Mechanical aperture ø	>50		mm
Field gradient $B'_{(0,0,0)}$	12.5		T/m
Magnetic length	475		mm
Integrated field gradient $\int B'_{(0,0,z)}dz$	5.94		T
Tuning range	± 5		%
Good Field Region(GFR) radius	20		mm
Integrated field quality:			
Harmonic №	Skew a_n	Normal b_n	
3	<0.124	<0.748	units@r_{GFR}
4	<0.344	<4.120	units@r_{GFR}
5	<0.665	<2.760	units@r_{GFR}
6	<1.5790	<9.820	units@r_{GFR}



CERN
CH-1211 Geneva 23
Switzerland

Project Document No.

CERN Div./Group or Supplier/Contractor Document No.

EDMS Document No.

Date: 2013-11-06

Draft

DESIGN OF TUNABLE PERMANENT QUADRUPOLE MAGNET QD0 FOR ATF 3

Abstract

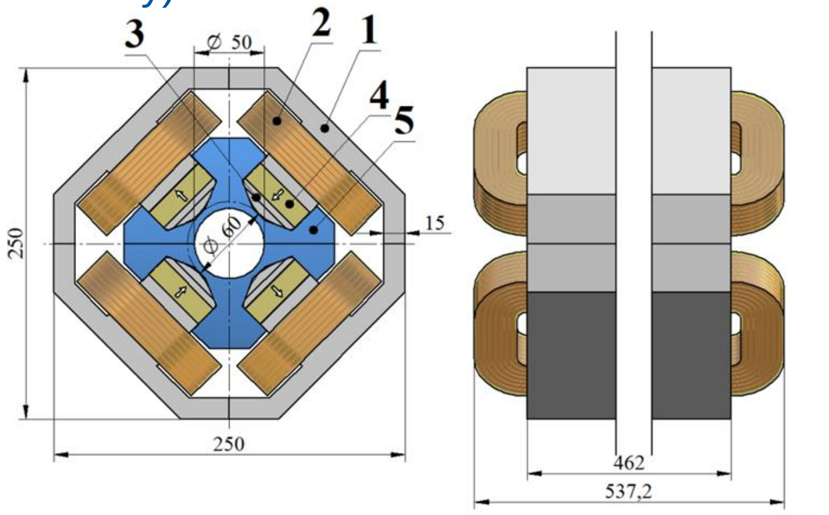
One final focusing quadrupole magnet is needed for the ATF 3. The proposed design is a permanent magnet with tunable strength. The design based on Sm_2Co_{17} blocks assembled together with soft ferromagnetic pole tips. The magnet provides integrated field gradient of 5.94 T inside the aperture of 60 mm. The field gradient amplitude can be adjusted within ±8% by the air cooled trim coils. This Design Report summarizes the main magnetic and mechanic design parameters of the permanent quadrupole magnets.

Prepared by :	***Checked by :***	***Approved by:***
A. Vorozhtsov **BE/OP/MED** **Alexey.Vorozhtsov@cern.ch**	**M. Modena**	**D. Tommasini**

Distribution list:

Upgrade of QD0 for ATF

Following the confirmation on preferred interest for an EASILY and REMOTELY tunable magnet, we finally propose an HYBRID solution (PM blocks + electromagnetic coils for tunability):



1- Return Yoke
2- Coils
3- Pole
4- PM blocks
5- Non magnetic half-rings

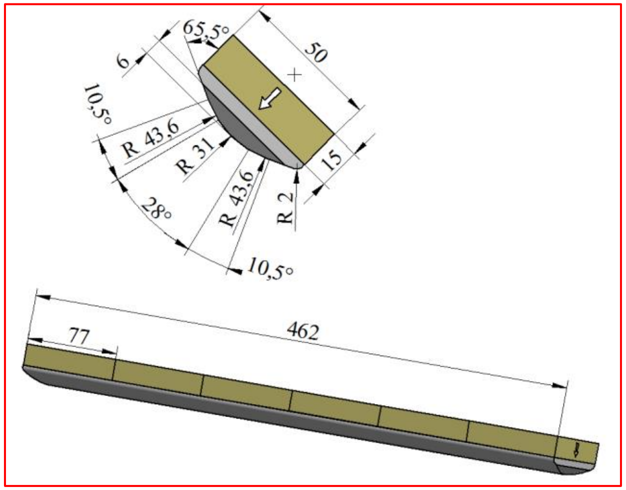
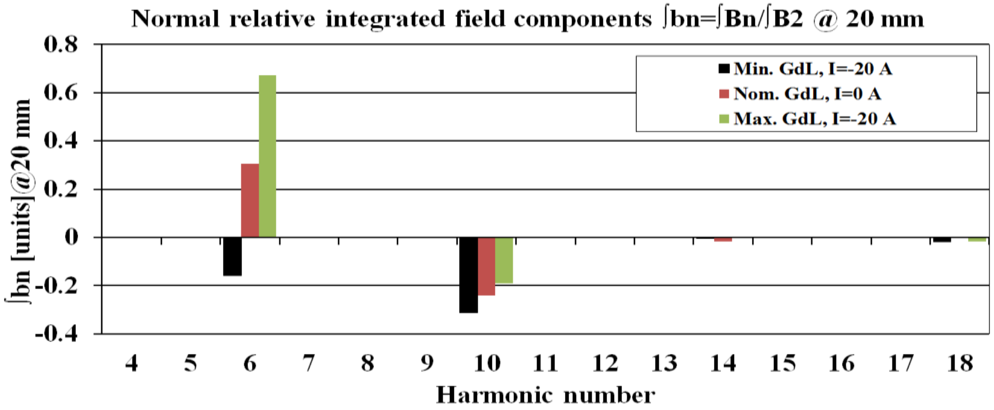


Figure 1: Preliminary layout of the quadrupole magnet, arrows indicate the direction of magnetization of the permanent magnet blocks.



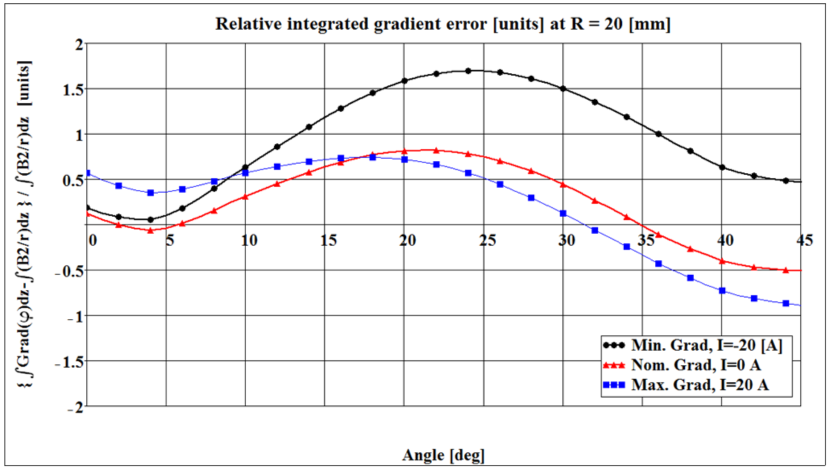
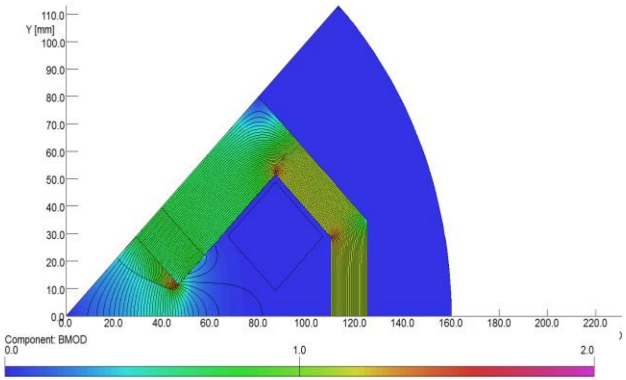
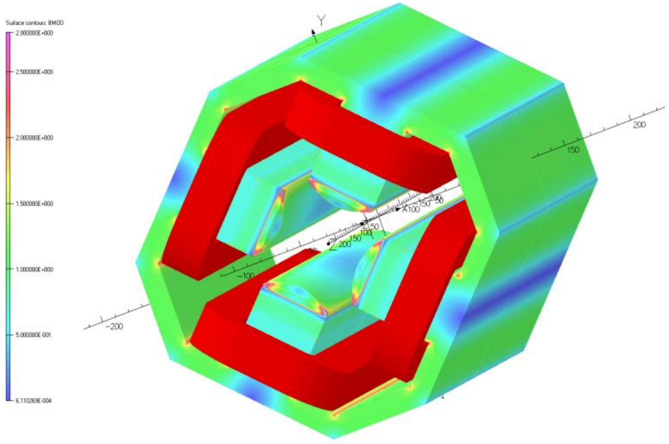


Figure 8: Integrated gradient homogeneity [units] at GFR

Upgrade of QD0 for ATF

A full set of design and working parameters is available for the preliminary conceptual design.





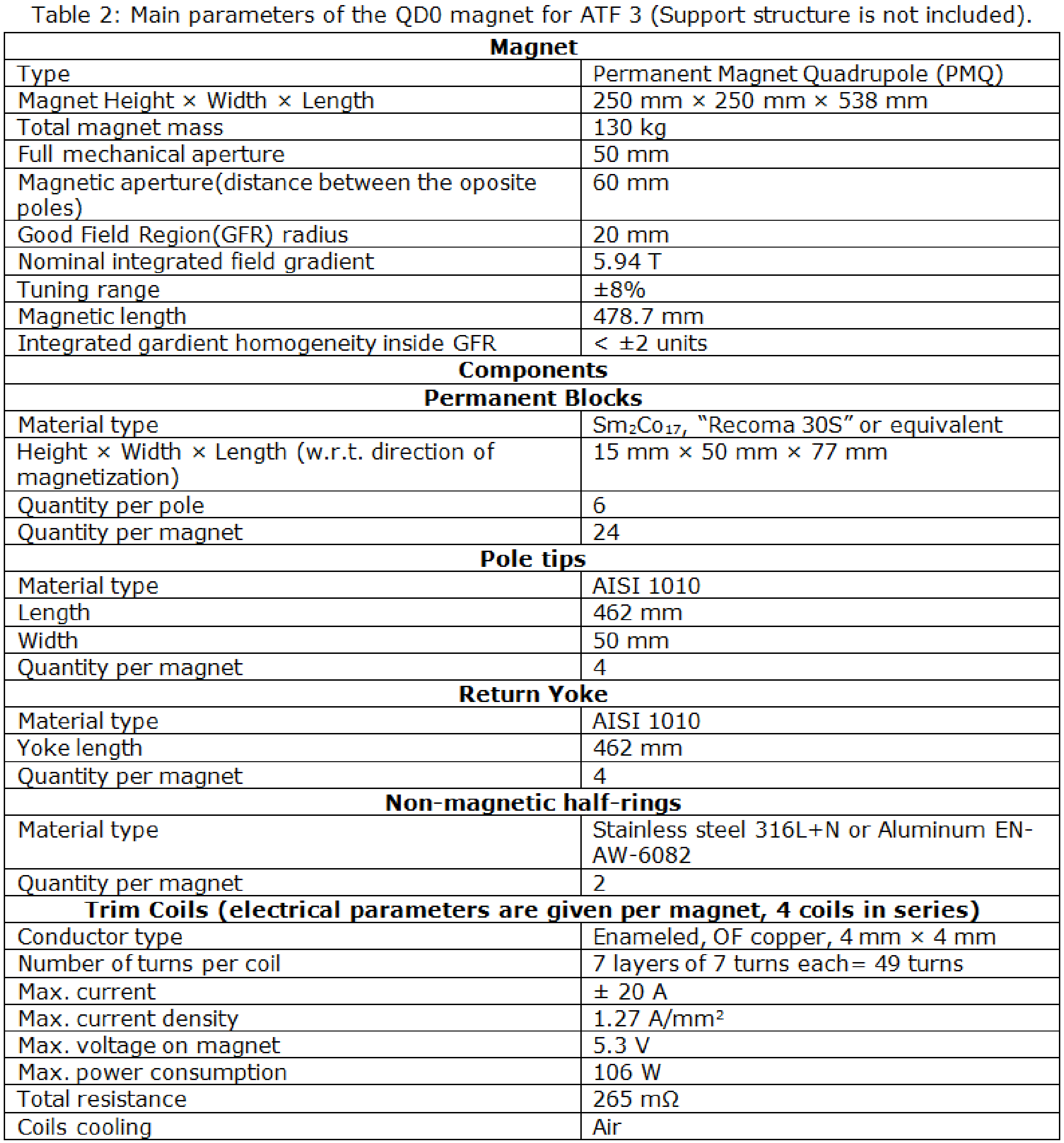


Table 2: Main parameters of the QD0 magnet for ATF 3 (Support structure is not included).

Magnet	
Type	Permanent Magnet Quadrupole (PMQ)
Magnet Height × Width × Length	250 mm × 250 mm × 538 mm
Total magnet mass	130 kg
Full mechanical aperture	50 mm
Magnetic aperture(distance between the oposite poles)	60 mm
Good Field Region(GFR) radius	20 mm
Nominal integrated field gradient	5.94 T
Tuning range	±8%
Magnetic length	478.7 mm
Integrated gardient homogeneity inside GFR	< ±2 units
Components	
Permanent Blocks	
Material type	Sm_2Co_{17}, "Recoma 30S" or equivalent
Height × Width × Length (w.r.t. direction of magnetization)	15 mm × 50 mm × 77 mm
Quantity per pole	6
Quantity per magnet	24
Pole tips	
Material type	AISI 1010
Length	462 mm
Width	50 mm
Quantity per magnet	4
Return Yoke	
Material type	AISI 1010
Yoke length	462 mm
Quantity per magnet	4
Non-magnetic half-rings	
Material type	Stainless steel 316L+N or Aluminum EN-AW-6082
Quantity per magnet	2
Trim Coils (electrical parameters are given per magnet, 4 coils in series)	
Conductor type	Enameled, OF copper, 4 mm × 4 mm
Number of turns per coil	7 layers of 7 turns each= 49 turns
Max. current	± 20 A
Max. current density	1.27 A/mm²
Max. voltage on magnet	5.3 V
Max. power consumption	106 W
Total resistance	265 mΩ
Coils cooling	Air

Outline:

4) Upgrade of QD0 for ATF
5) OCTUPOLES for ATF

OCTUPOLES for ATF

We were recently asked for a possible contribution to future ATF program with 2 octupole magnets, (R. Tomas: private communication, July 2013).

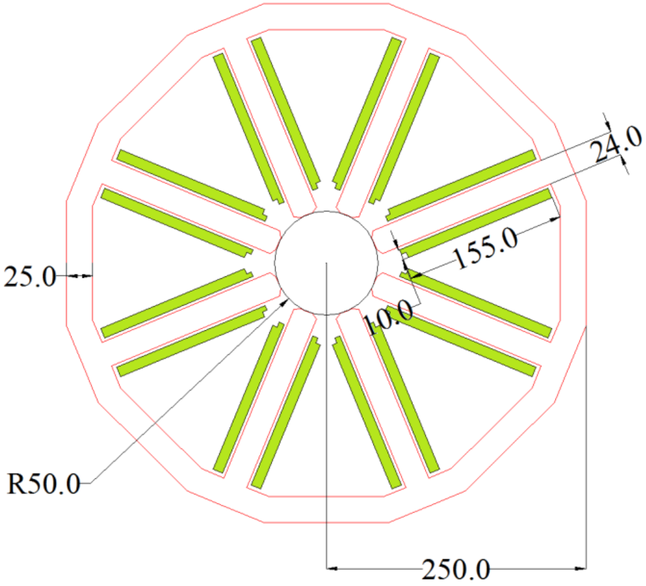
The required field quality is not yet frozen; magnets is asked to be "very good" from that point of view and field quality will be specified at a 20 mm radius.

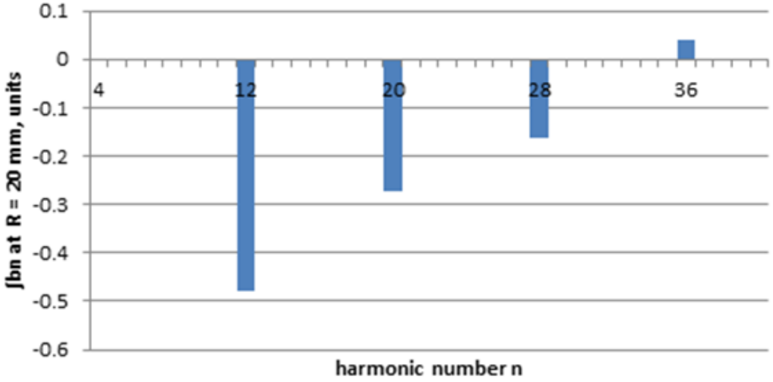
PARAMETER	*UNITS*	*VALUE*
Nominal Gradient,	**T/m^3**	**5284**
Required tunability	**%**	**-75, +20**
Integrated gradient	**T/m^2**	**560**
Aperture radius	**mm**	**50**
Iron length	**m**	**0.100**
Magnetic length	**m**	**0.106**
Coil number of turns		**61**
Conductor size	**mm x mm**	**5 x 5**
Ampere-turns	**A**	**1200**
Current	**A**	**19.7**
Resistance (per coil)	**mΩ**	**14**
Conductor length (per coil)	**m**	**19.9**
Conductor mass (per coil)	**kg**	**4.5**
Yoke mass	**kg**	**56**
Total mass	**kg**	**92**

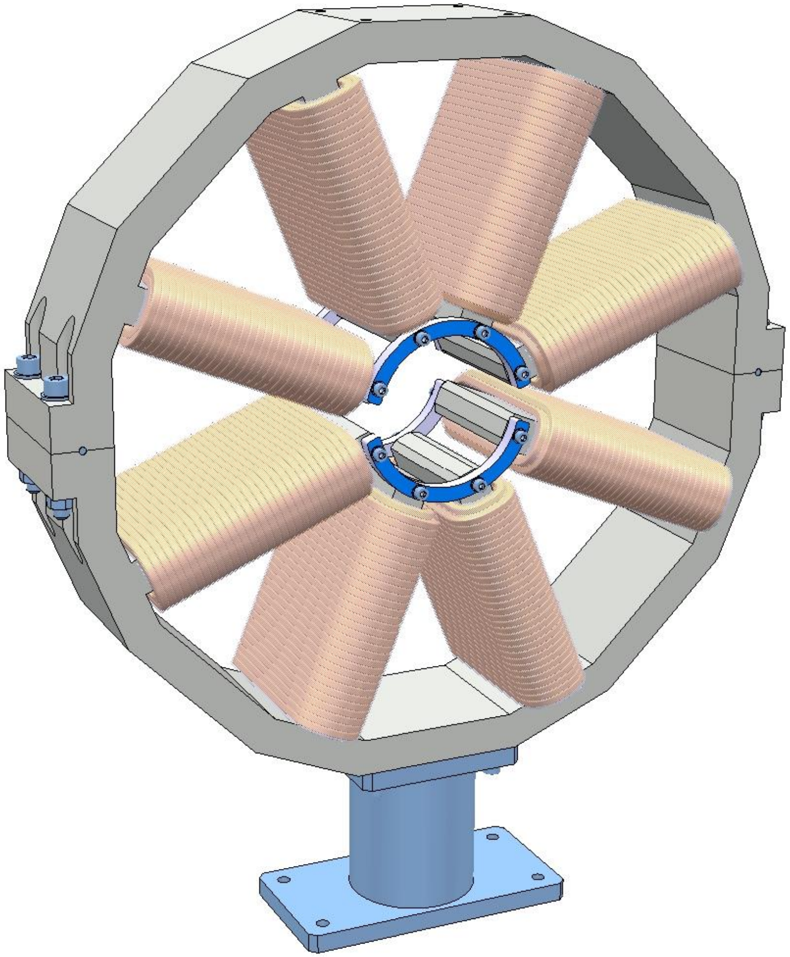
With the available parameters we have developed a conceptual magnetic design, focusing on these aspects:

- To get the best field quality the number of yokes part is a minimum (possibly two half-yokes).
- The magnet aperture will be relatively big for the following reasons:
  a. To avoid working with too low saturation (at -75% working point)
  b. To be able to insert the coils in the two half-yokes
  c. To improve the field quality at 20 mm radius.
- The outer radius is big in order to design coils with low current density.

OCTUPOLES for ATF







The achievable field quality should be quite good (computed is less of 1 unit for permitted harmonics).

Similarly to what propose and done for the PM and hybrid magnets, we plan to procure the main components and to produce at CERN the coils and do there the final assembly.

Some Conclusions:

- **QD0 for ATF:**
  - Conceptual magnetic and mechanical designs available:
  - We are checking some technical aspects (mainly manufacturing tolerances and assembly).

- **Octupoles for ATF:**
  - Conceptual magnetic design defined.
  - Basic mechanical design also available

- **For both magnets:**
  - We are now waiting comments and better definition of requirements from the ATF Community, in order to finalize the designs.
  - CERN TE Magnet Group would be interested to work on these procurements.
- Some official statement between parties will be necessary before to start the procurement.

Thanks