ADVANCES IN THE STUDIES OF THE MAGNETIC DESIGN FOR THE FINAL FOCUS QUADRUPOLES OF THE SUPERB

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Abstract

In this paper we present the improvement of the magnetic design of the focusing elements closest to the interaction point (IP) of the SuperB accelerator. These magnets have to provide pure quadrupolar fields on each of the two beams to decrease the background rate in the detector which would be produced by the over-bend of the off-energy particles if a dipolar component were present. Very good field quality is also required to preserve the dynamic aperture of the rings. Because of the small separation of the two beams and the high gradient required by the SuperB final focus, neither a permanent magnet design nor a multi-layer configuration are viable solutions. A novel design, based on helical-type windings, has therefore been investigated. In this paper we will present the improved magnetic design and its performances evaluated with a three dimensional finite element analysis.

INTRODUCTION

SuperB is a second generation asymmetric B-factory aimed to achieve a luminosity one hundred larger with respect to the present facilities ($10^{36}cm^{-2}s^{-1}$) by colliding extremely low emittance beams fully exploiting the so called “crab waist” scheme [1]. One of the key points of this configuration is to lower the vertical β function at the IP (β_y) down below one millimetre. Such a small β_y requires strong focusing quadrupoles placed very close to the IP to lower the vertical chromaticity of the final doublet. A first design of the interaction region (IR) where a single, shared quadrupole vertically focuses both beams was investigated [2]. It was readily apparent that the dipolar component seen by the off-axis beams is detrimental both for the machine performances (emittance growth, dynamic aperture) and for the machine background in the detector. A design with two separate quadrupoles for each beam line has therefore been studied. Further progresses on the SuperB IR design [3] aiming to increase the beam stay clear (BSC), and hence the physical aperture, required a new design for the QD0. The requirements are reported in Table 1.

Table 1: QD0 specifications for HER and LER part.

Parameter	HER	LER
Energy (GeV)	7.0	4.0
Gradient (T/m)	1190	520
Magnetic center (mm)	22	-20

Internal radius (mm)	23.5
Distance from the IP (m)	0.58
Magnetic length (m)	0.40
Half crossing angle (mrad)	30

The internal radius and mechanical axis position are driven by the collision crossing angle and by the radial beam size at the QD0 exit as shown in Fig. 1.

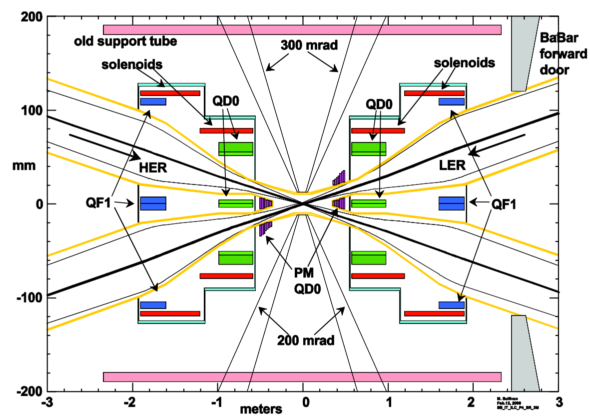

Figure 1: IR design horizontal cross section. QD0 in green, beam pipe in yellow, reference orbits and 30 σ_x BSC in black.

The double-helix design, which can produce theoretically a perfect multipolar field [4] was chosen. The very small distance between the beam lines (about 2 cm) makes the cross talk between the QD0 of the HER and the LER not negligible, as it can be seen in Fig. 2.

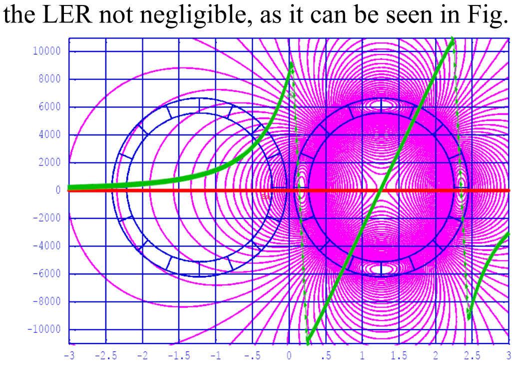

Figure 2: Two adjacent cos(2ϕ) quadrupoles of the dimensions of the SuperB QD0. The vertical component of the magnetic field of the right coil when it is the only one which transport current is shown.

Furthermore the space limitation doesn't allow to use a multilayer design, so a novel algorithm to compensate the cross talk has been studied. More detail can be found in [5].

THE OPTIMIZATION

3D finite elements models (Tosca [6]) have been simulated to check the validity of the algorithm, to further optimize the field quality in 3D and to calculate the margin to quench.

The double helix coils can be arranged in several configurations to build the QD0. The two quadrupoles can be put one close to the other one, as schematically shown in Fig. 3.

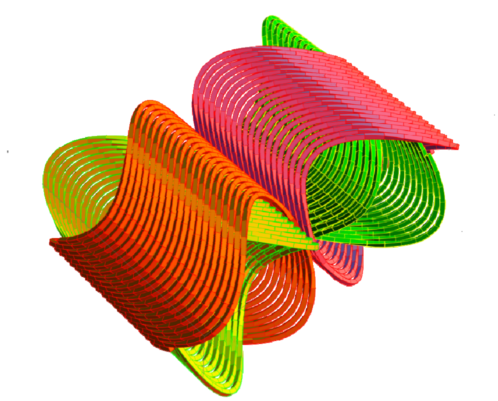

Figure 3: First double helix quadrupoles configuration (qq configuration).

After a scan over the angle of the wire with respect to the axis of the coils, a field quality of the order of 10^{-5}, which could be eventually further optimized, confirmed the validity of the cross talk compensation algorithm. Assuming 1 mm x 1 mm commercial NbTi strand (single layer) with copper over superconductor ratio (Cu/SC) equal to 1, this configuration allows to obtain 125 T/m with an internal radius of about 1.7 cm at 4.2 K and the same gradient with internal radius equal to 1.9 cm at 1.9 K with 20 % margin to quench. The necessary 120 T/m with internal radius of about 2.4 cm requested for the SuperB final quadrupole cannot be achieved not even at 1.9 K neither using the Nb3Sn, because the current density is so large that the working point of the magnet would be in the flux jump instability region [4].

A sketch of another possible configuration for the QD0 is shown in Fig. 4.

In this case two quadrupoles wound according to the double helix cross talk compensated algorithm (qq) are immersed in the gradient generated by another quadrupole (Q). Let for example the ratio between the internal and the external gradient be equal to 1, then the same gradient is obtained using only half of the current in the internal coils (point B in Fig. 3).

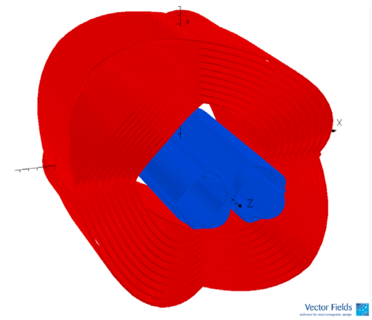

Figure 4: Nested quadrupoles configuration for the QD0 (Q&qq configuration).

Furthermore the maximum field in the conductor is given by the sum under quadrature of the three field components, therefore also the maximum field in the conductor is decreased because the longitudinal component is reduced (point C in Fig. 5).

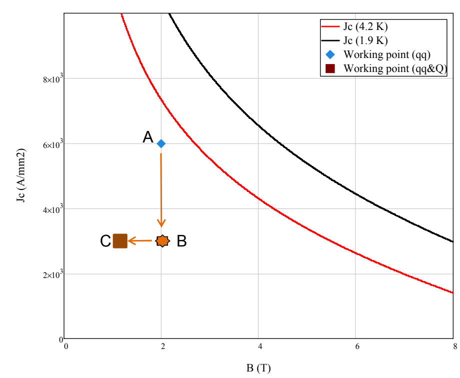

Figure 5: Q&qq configuration: the margin to quench increase. The margin to quench of the qq configuration corresponds to the A point, whereas the one of Q&qq is given by the C point. A ratio 1 between the internal and the external gradient is assumed.

In this case the field seen by the beams is the sum of a dipole plus a quadrupole superimposed to a pure quadrupolar field produced by each one of the internal q, as sketched in Fig. 6.

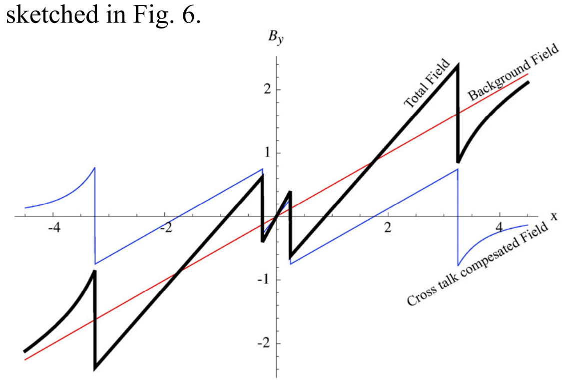

Figure 6: Q&qq configuration: the field. A ratio 1 between the internal and the external gradient is assumed.

Once fixed the parameters reported in Table 1, several quantities can be varied to maximize the margin to quench. Up to now a scan over the background field gradient, G_Q, and the axis position of the external quadrupole, x_Q, has been done. The linear current density given by the Ampere law:

$$\frac{\Delta I}{L} = \frac{\Delta B}{\mu_0} \quad (1)$$

is plotted as a function of G_Q in Fig. 7 and as a function of x_Q in Fig. 8.

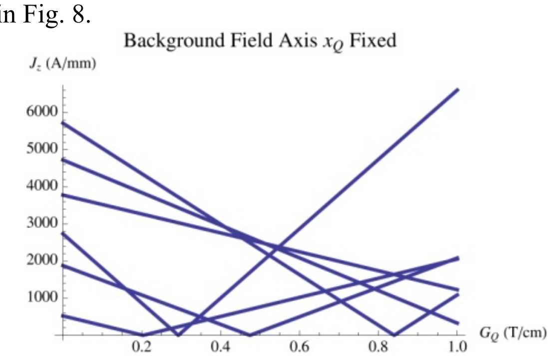

Figure 7: Q&qq configuration: the optimization (fixed background gradient).

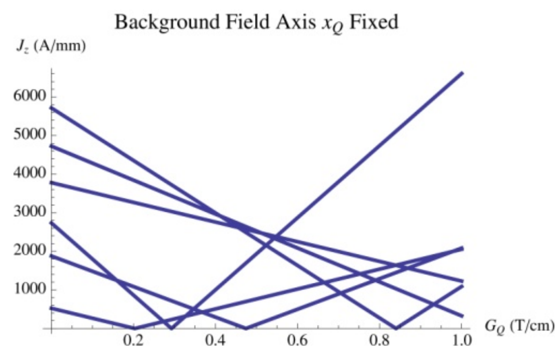

Figure 8: Q&qq configuration: the optimization (fixed axis position of the external quadrupole).

In Table 2 the maximum linear current density of the configuration Q&qq before and after the optimization compared with the qq configuration is shown.

Table 2: Maximum Linear Current Density for the Several Configurations.

Configuration	Linear current density
qq	5770 A/mm
Q&qq (starting configuration)	3937 A/mm
Q&qq (after the optimization)	2772 A/mm

In Fig. 9 the sketch of the result of this optimization is given.

This configuration would allow to satisfy the very demanding requests for the SuperB QD0 with a margin to quench of 20 % using NbTi strand at 1.9 K or with more than 30 % at 4.4 K using Nb3Sn wire [7], because the reduction of the current density necessary to produce the required gradient makes the working point moving far away from the flux jump instability.

It has to be noticed that there are still some knobs which can be used to further increase the margin, like the ratio between the current density of the internal quadrupoles and the possibility to study a hybrid configuration.

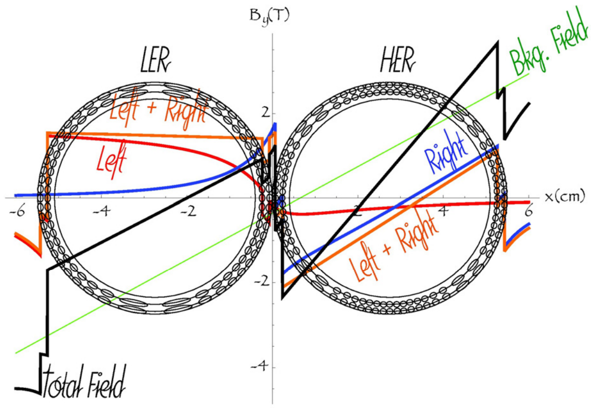

Figure 9: Q&qq configuration: the optimized configuration.

Recently preliminary studies on the mechanical support for the magnets have been started by F. Bosi and M. Massa (Pisa University).

CONCLUSIONS

To reduce the high background generated by the off-energy particles in the SuperB final quadrupoles, a scheme based on one quadrupole for each beam has been considered. The short distance of the QD0 of the two rings made the cross-talk between them absolutely not negligible. An algorithm to compensate this effect has been proposed and its validity has been confirmed by 3D finite elements simulations. Due to the high gradient/small space for the conductors, a configuration with simply one quadrupole for each beam line doesn't allow to satisfy the requests for the SuperB final quadrupole. A novel configuration where the gradient is shared between a couple of compensated double helix quadrupoles and an external quadrupole has therefore been proposed and analysed. The simulations indicate that using this configuration the requests of the SuperB QD0 can be satisfied.

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