High Energy

High Intensity

Hadron Beams

A LOW GRADIENT TRIPLET QUADRUPOLE LAYOUT COMPATIBLE WITH NbTi MAGNET TECHNOLOGY AND $\beta*$ = 0.25m

Riccardo de Maria, Oliver Sim Brüning, CERN, Geneva, Switzerland
Pantaleo Raimondi, INFN-LNF, Frascati, Italy

Abstract

The paper presents a triplet layout option with long (about 100 m total triplet length), low gradient (45T/mto70T/m) quadrupole magnets. Assuming a maximum magnet diameter of 200 mm, the peak coil field at the magnet coils still remains below 7T which is still compatible with conventional NbTi magnet technology. The peak beta function inside the triplet magnets reaches 22 km and the configuration therefore requires an additional chromaticity correction scheme similar to a dipole first layout option. However, at the same time, the presented solution provides an interesting alternative to a high gradient triplet layout which requires the new Nb3Sn magnet technology.

Contribution to the EPAC’06, Edinburgh, UK

Work supported by the European Community-Research Infrastructure Activity under the FP6 “Structuring the European Research Area” programme (CARE, contract number RII3-CT-2003-506395).

EU contract number RII3CT-2003-506395 CARE Conf-06-046-HHH

A LOW GRADIENT TRIPLET QUADRUPOLE LAYOUT COMPATIBLE WITH NbTi MAGNET TECHNOLOGY AND $\beta^* = 0.25\mathrm{m}$ *

Riccardo de Maria, Oliver Sim Brüning CERN, Geneva, Switzerland

Abstract

The paper presents a triplet layout option with long (about $100\mathrm{m}$ total triplet length), low gradient ($45\mathrm{T/m}$ to $70\mathrm{T/m}$) quadrupole magnets. Assuming a maximum magnet diameter of $200\mathrm{mm}$, the peak coil field at the magnet coils still remains below 7T which is still compatible with conventional NbTi magnet technology. The peak beta function inside the triplet magnets reaches 22km and the configuration therefore requires an additional chromaticity correction scheme similar to a dipole first layout option. However, at the same time, the presented solution provides an interesting alternative to a high gradient triplet layout which requires the new Nb3Sn magnet technology.

INTRODUCTION

The aim of the LHC luminosity upgrade is to increase the luminosity from $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ to $10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ by increasing the number of protons per bunch, increasing the number of bunches, reducing the longitudinal beam size and reducing β^* by upgrading the insertion region [1].

The upgrade of the interaction regions (IR) of the main experiments ATLAS and CMS (IR1 and IR5 respectively) is expected to provide a β^* of $25\mathrm{cm}$ increasing the luminosity by a factor 2.

The present layout, designed for β^* of $55\mathrm{cm}$, is not able to provide a β^* of $25\mathrm{cm}$ because the triplet quadrupoles can not fulfill the required specifications on mechanical aperture. In addition the lifetime of the triplets is estimated to be limited to 7 years at the nominal luminosity due the radiation [1] coming from the IP. If no relevant changes in the design with respect to the radiation protection is performed, this time is reduced by an order of magnitude at the upgraded luminosity implying a triplet replacement on a year basis.

LAYOUT AND OPTICS

We propose a quadrupole first layout compatible with NbTi technology.

Figure 1 shows the layout and the corresponding beam envelope. Figure 2 and 3 show the collision optics for Beam 1 and Beam 2.

Table 1 summarizes the main quantities of the layout.

The triplet magnets are highly optimized for aperture or low peak field (max $4.2\mathrm{T/m}$) in order to cope with the radiation coming form the IP (high temperature margin or room for internal shielding).

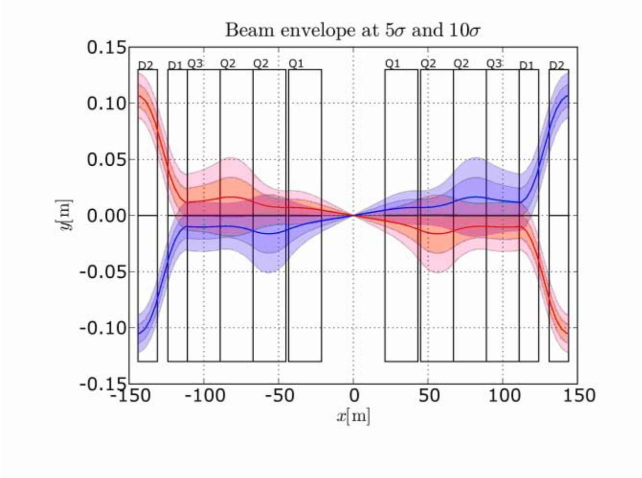

Figure 1: Beam envelope at 5σ and 10σ.

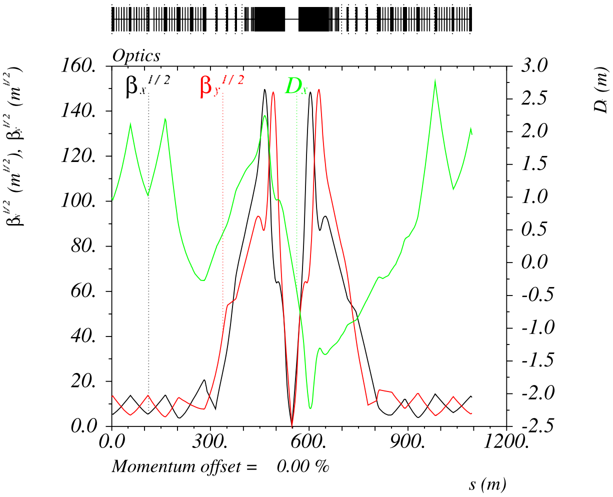

Figure 2: Collision optics for Beam 1

The presence of dispersion in the triplet can be used for a local chromaticity correction.

CHROMATICITY

For the LHC the energy acceptance of ($\frac{\Delta p}{p_0} = \delta = 0.8\,10^{-3}$) has to be preserved.

The chromaticity, tune dependence with energy $Q(\delta)$, is enhanced by high β values and if not properly corrected can lead to a limitation of the energy acceptance. In particular a positive slope of $Q(\delta)$ is required in order to avoid the head-tail instability.

In the LHC there are two interleaved sextupoles families per arcs (MS) and a family of spool pieces sextupole

---

* Work supported by CERN and EPFL

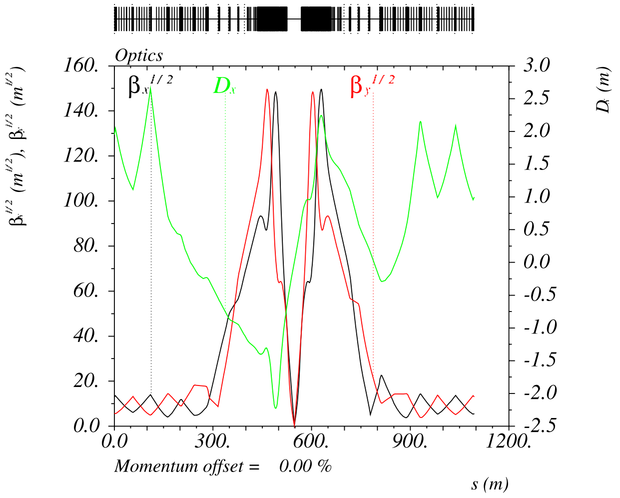

Figure 3: Collision optics for Beam 2

Table 1: Specifications of the quadrupole first layout.

Mag.	Pos.	Length	Field	Inner D.
Q1	21.251m	22m	-40.0T/m	0.12m
Q2A	45.053m	22m	69.1T/m	0.12m
Q2B	67.054m	22m	-56.0T/m	0.12m
Q3	89.055m	22m	15.5T/m	0.12m
D1	111.056m	13m	8.7T	0.12m
D2	131.056m	13m	8.7T	0.06m

correctors (MCS). They can be used to correct globally the first and the second order chromaticity and the off momentum beta-beat [2]. An attempt for a local chromaticity correction has been done using sextupoles corrector placed in front of the quadrupoles, but it was not successful due the local introduction of non linear chromaticity.

Figure 4 and 5 show the results of different correction options.

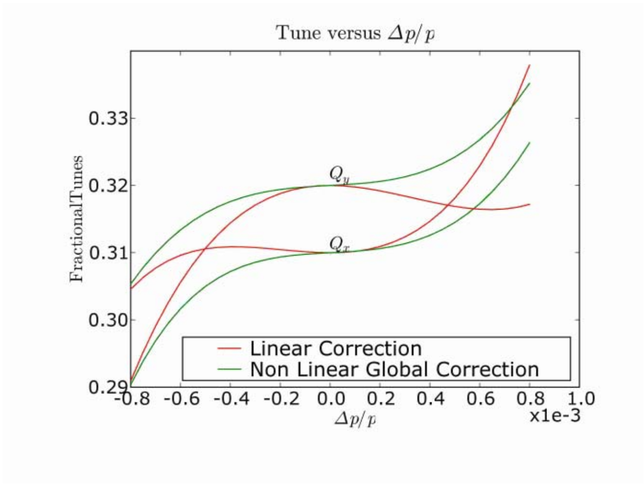

Figure 4: Horizontal and vertical chromaticity for Beam 1 after several correction options.

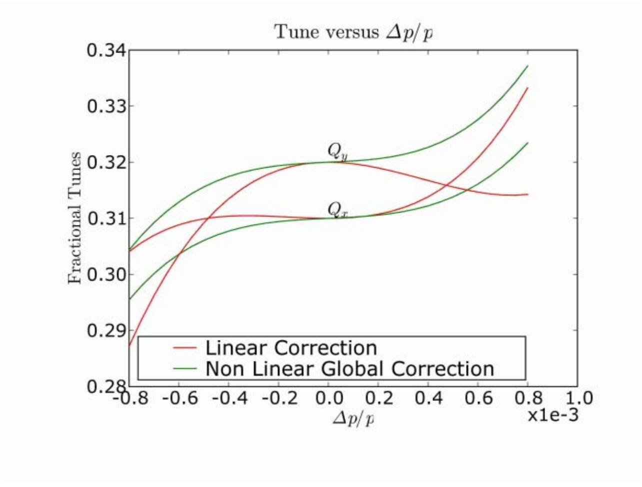

Figure 5: Horizontal and vertical chromaticity for Beam 2 after several correction options.

Table 2 and 3 show the required sextupole strengths.

Table 2: Required strengths of the arc sextupoles for the correction of the linear part of the chromaticity. All focusing and defocusing families respectively equally powered.

Family	k_2 max	Strength
MS Defoc.	0.380m^{-2}	68%
MS Foc.	0.380m^{-2}	76%
MCS	0.130m^{-2}	70%

Table 3: Required strengths of the arc sextupoles for the correction of the linear and second order part of the chromaticity. The MS families are individually powered.

Family	Average Str.	Max Str.
MS Defoc.	69%	102%
MS Foc.	76%	110%
MCS	70%	70%

The results shows that the arcs are still able to compensate the chromaticity generated by the high β region with margin left for off-momentum beta-beat correction.

DYNAMIC APERTURE

The dynamic aperture (DA) of the LHC at collision is dominated by the field quality in the high beta region, that is triplet and separation recombination magnets.

The tracking studies are performed with SIXTRACK using 60 seeds and 10 10^5 turns, the target DA for collision is 10σ ([3]).

In the LHC the triplet is equipped with a corrector package used to minimize the Hamiltonian driving terms which are close to the working point.

Tracking studies for the nominal configuration shows that the minimum DA of LHC without triplet correction is about 13σ.

The new layout, because of the high beta values, requires a careful definition of the field quality allowed in the triplet and the implementation of a correction scheme.

Tracking studies are on going in order to explore the parameter space (multipole errors) for the definition of the required field quality for this design.

A preliminary study using an ideal machine and the field quality of the present LHC triplet magnets (Figure 6) for the new ones shows that the minimum DA over 60 seeds is about 2.3σ. Scaling by a factor of 10 the triplet errors shows an increase of the minimum dynamic aperture to 7.3σ.

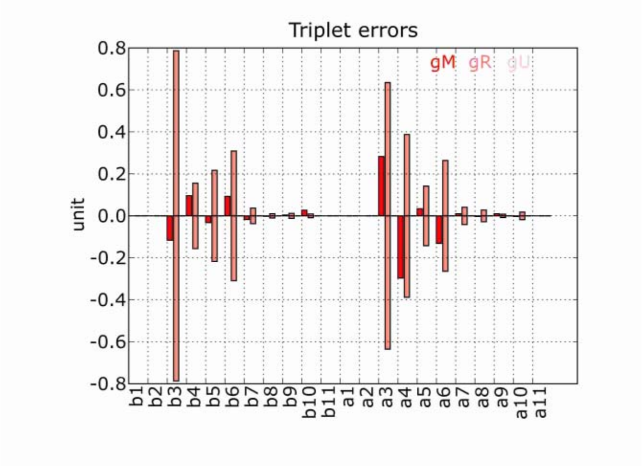

Figure 6: Triplet error used for DA studies."gM gR gU" stays respectively for mean, random, uncertainty of the geometric component of the multipole errors.

An efficient correction scheme or a better field quality is required to meet the specification of 10σ.

CONCLUSION

The present layout shows that the NbTi can be still a viable technology for the IR upgrade. The chromaticity generated by the high beta values can be compensated by the existing sextupoles circuit with margin left for off-momentum beta-beat correction.

The low value for the dynamic aperture may probably be restored to the LHC requirements by a corrector package or a further improvement of the field quality. A tracking campaign for their definitions is on going.

The radiation issues should be solved by the huge margin in aperture that can still be provided by NbTi quadrupoles. The peak field at the coil gives a margin of 50mm in radius to the minimum required aperture. The margin can be used for a shielding layer (which may positively contribute to the final field quality) or for a further optimization of the layout in the direction of lowering the beta function and reducing the magnetic length by increasing the gradient.

Studies for the radiation protection of the magnets, still missing, should give the last confirm for the feasibility of this layout.

REFERENCES

[1] Francesco Ruggiero. LHC Accelerator R&D and Upgrade Scenarios. Technical Report LHC-Project-Report-666, CERN, August 2003.

[2] O. Bruning, P. Collier, P. Lebrun, S. Myers, R. Ostojic, J. Poole, and P. Proudlock. LHC Design Report. Technical Report CERN-2004-003, CERN, 2004.

[3] Olivier Sim Bruening, Roberto Cappi, R. Garoby, O. Gröbner, W. Herr, T. Linnecar, R. Ostojic, K. Potter, L. Rossi, F. Ruggiero, Karlheinz Schindl, Graham Roger Stevenson, L. Tavian, T. Taylor, Emmanuel Tsesmelis, E. Weisse, and Frank Zimmermann. LHC Luminosity and energy upgrade : A Feasibility Study. Technical Report LHC-Project-Report-626, CERN, dec 2002.