BEAM PHYSICS ISSUES FOR A POSSIBLE 2ND GENERATION LHC IR

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Abstract

We consider a possible 2nd generation IR for the LHC that would be designed to achieve at least a factor of two increase in luminosity beyond that reached with the original IRs. We discuss the optics issues, in particular those associated with larger bore quadrupoles with Nb3Sn superconductor, field quality issues, energy deposition issues and the limitations imposed on energy and luminosity reach.

1 INTRODUCTION

After several years of being exposed to high radiation doses in the LHC interaction regions (IRs), it is likely that the first generation of inner triplet quadrupoles will need to be replaced. The second generation of inner triplet quadrupoles must allow the LHC to extend both its luminosity and energy reach. In this paper we consider some of the beam physics issues of an interaction region design which is a simple extension of the present design.

2 OPTICS

The luminosity can be doubled by lowering β^* from 50cm to 25cm. There are two options in a simple extension of the present design, as discussed in a previous report [1]. In the first option we consider higher gradient quadrupoles with the same aperture of 70mm as at present. Increasing the gradient allows them to be shortened and moved closer to the IP. In the second option the gradients are the same as at present but the aperture is increased to 90mm. The positions and lengths of the quadrupoles are unchanged. Both options assume that the quadrupoles will be constructed with Nb_3Sn superconducting cable.

The conclusion reached in [1] was that the larger aperture option offers the superior path to higher luminosity. Figure 1 shows the optics in the IR with $\beta^* = 25$cm. As in the first generation optics, the quadrupoles Q4 to Q7 are used to lower the β^* during the beta squeeze. Table 1 shows the gradients of the quadrupoles in the 1st and 2nd generation optics

Larger β functions in the quadrupoles imply that the effects of the nonlinearities will be stronger in the 2nd generation quadrupoles. We assume that a local correction system as proposed for the 1st generation [2] will be necessary. This correction scheme which locally corrects the kick from each multipole scales with the β function. Lowering β^* from 0.5 m to 0.25 m doubles the beta functions everywhere in the triplets and their vicnity, if the gradients

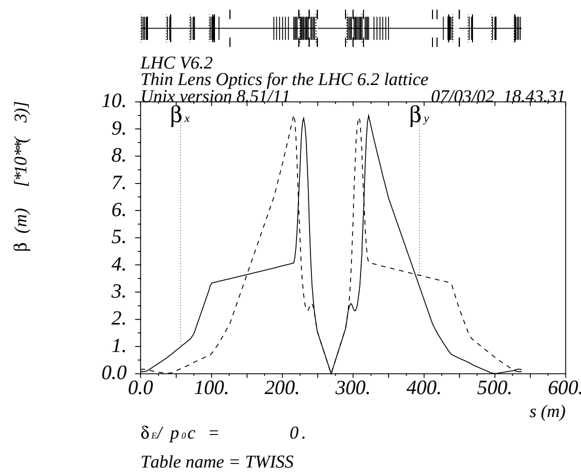

Figure 1: Optics solution at $\beta^* = 0.25$ m

Table 1: Gradients of quadrupoles in the IR. The 2nd generation quadrupoles have an aperture of 90mm.

	1st generation β^* =0.5 m	2nd generation β^* =0.25 m
Q1	200	200
Q2a	200	200
Q2b	200	200
Q3	200	200
Q4	81	88
Q5	70	59
Q6	66	32
Q7	186	212

are left unchanged. If all the beta functions are scaled by the same factor, then the corrector strengths are unchanged.

However this does not imply that the same corrector strengths will suffice. Due to the larger crossing angle, the feed-down from higher order multipoles will be more important. Figure 2 shows the tune footprints with local correction of the same multipoles at $\beta^* = 0.5$m and $\beta^* = 0.25$m. The footprint at $\beta^* = 0.25$m is significantly larger implying that more multipole correctors will be required.

3 MAGNET DESIGN

The 90-mm quadrupole optimized for the best field quality with minimal number of wedges is shown in Figure 3. The coil has 36 turns/octant grouped in 3 blocks. The

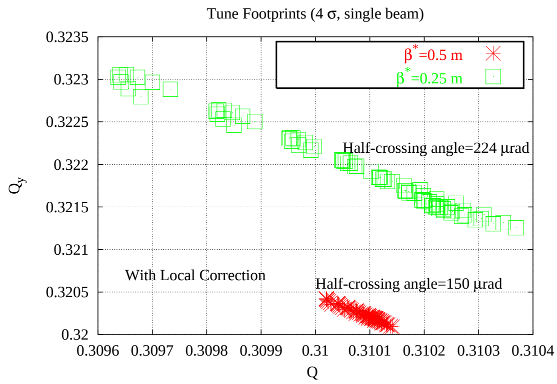

Figure 2: Tune footprints with local correction using the same multipole layers at $\beta^* = 0.5$m and $\beta^* = 0.25$m. The crossing angle is larger at lower β^*.

Table 2: Geometrical harmonics at 17 mm radius units of 10^{-4}. The random components are calculated assuming random $\pm 50\mu$m block displacement.

n	Systematic b_n		Random σ_{an}/σ_{bn}	
	Nb_3Sn	MQXB	Nb_3Sn	MQXB
3	-	-	1.114	0.28/0.26
4	-	-	0.456	0.37/0.08
5	-	-	0.172	0.15/0.07
6	0.0002	-0.013	0.069	0.05/0.17
7	-	-	0.025	0.03/0.03
8	-	-	0.009	0.01/0.00
9	-	-	0.003	0.01/0.00
10	0.0005	-0.001	0.001	0.00/0.01

design utilizes the Rutherford cables made of 42 Nb_3Sn strands 0.7 mm in diameter and insulated with ~0.18 mm thick insulation. The iron yoke was designed with additional constraints including the yoke outer radius of 200 mm as for MQXB and longitudinal heat transfer inside the cold mass sufficient for the quadrupole operation at luminosity up to 10^{35}cm^{-2}s^{-1}. Eight holes with total cross-section of 400 cm^2, used for that purpose and four rectangular holes for electrical buses and instrumentation are shown in Fig.3. The holes occupy significant fraction of iron cross-section excluding usage of the iron yoke as an element of coil mechanical support structure. Thus, the full mechanical support will be provided by the 30-mm thick stainless steel collars.

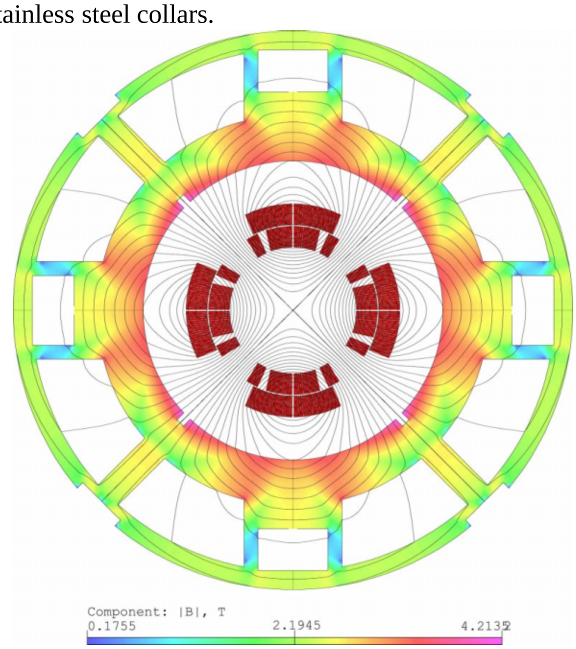

Figure 3: 90-mm quadrupole cross-sections.

The nominal field gradient of 205 T/m is reached at the nominal currents of 14.1 kA. In order to provide a 15% critical current margin at nominal gradient, the critical current density of superconducting strands at 12 T and 4.2 K has to be 2400-2500 A/mm2 for operation at 1.95 K or 2800-3000 A/mm2 for operation at 4.5 K (including 10% critical current degradation during cabling).

3.1 *Field quality*

The systematic and random (due to $\pm 50\mu$m block displacement) geometrical harmonics are presented in Table 2. The systematic geometrical harmonics are an order of magnitude better than in present 70-mm MQXB design. For the assumed large random block displacements, the calculated harmonics RMS spread is close or better (except few low order harmonics) than for MQXB where block displacement was within $\pm 15\mu$m. The yoke saturation effect is suppressed to the level of 10^{-4}. The iron strips placed on top of the wedge in the inner layer reduce large coil magnetization effect in Nb_3Sn quadrupoles to the level less than in MQXB. If necessary the coil magnetization effect could be also reduced using more expensive PIT Nb_3Sn strands with effective filament diameter ~20-30μm.

4 ENERGY DEPOSITION IN IP5 INNER TRIPLET

4.1 *Calculation Model*

Longitudinal structure of the second generation IP5 inner triplet [1] is assumed the same as before [3]. The updates consist of replacing quadrupoles based on NbTi superconductor with larger bore ones based on Nb_3Sn [1]. The four magnets in the region, *i.e.* Q1, Q2A, Q2B, and Q3 differ only in length. According to manufacturer's specifications, the cold cable contains 50% bronze and 50% Nb_3Sn with a specific density of 5.4 g/cm^3. A nominal field gradient of 200 T/m is used. A cross section of the MARS [4] model for such a quadrupole and longitudinal view of the inner triplet are shown in Figs. 4 and 5, respectively.

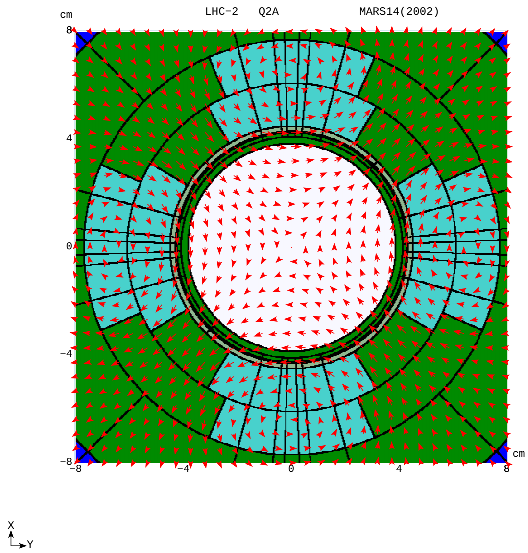

Figure 4: A cross section of the MARS model of a 90-mm Nb_3Sn quadrupole.

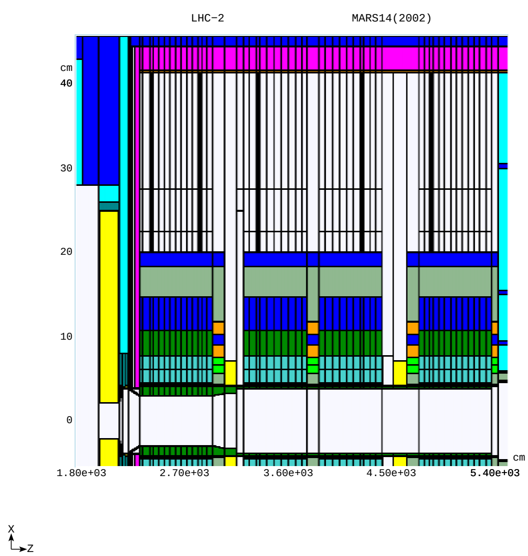

Figure 5: Longitudinal view of the inner triplet.

4.2 *Results and Discussion*

We assume a half crossing angle of 212 μrad and 21-mm aperture in Figs. 6 and 7. The calculated peak power density in the coils is below the quench limit for the Nb_3Sn quadrupoles which is a factor of few as large as that for present NbTi IR quadrupoles [5]. At the same time, dynamic heat load is significantly higher than the 10 W/m in the current design with the baseline luminosity and scales to almost 120 W/m if one goes further up to the 10^{35} $cm^{-2}s^{-1}$ luminosity. Analysis revealed that about 90% of total energy deposition in the hottest Q1 quadrupole is due to electromagnetic showers initiated by protons and charged mesons. The TAS1 collimator, which is upstream of the inner triplet, performs efficient radiation protection:

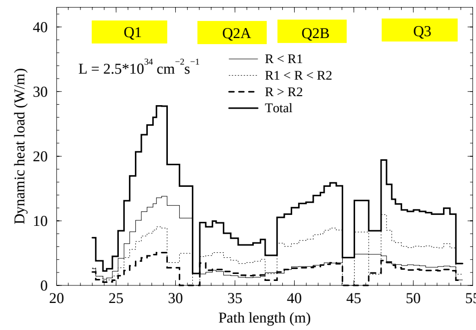

Figure 6: Dynamic heat load distribution in the inner triplet. The values of R1(R2) are equal to 45(77) and 56.2(75) mm for the quadrupoles and correctors, respectively.

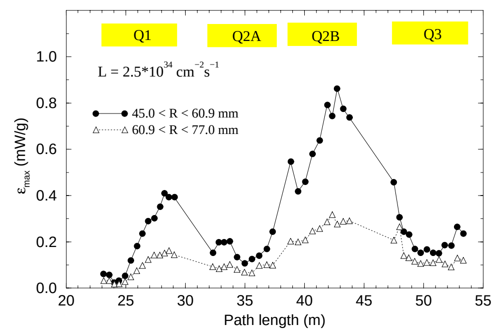

Figure 7: Peak power density distribution in the inner triplet.

only 5% of the incoming energy (outside TAS1 aperture) penetrates through the TAS1 body and is emitted downstream. The most realistic way to reduce energy deposition in Q1 is to reduce TAS1 aperture or field strength in Q1. It follows also from calculations performed to check several options for TAS1. If the aperture and/or magnetic field strength reduction is not possible another alternative is a separate cooling system for the beam screen of Q1 quadrupole.

5 REFERENCES

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