PARAMETRIC STUDY OF HEAT DEPOSITION FROM COLLISION DEBRIS INTO THE INSERTION SUPERCONDUCTING MAGNETS FOR THE LHC LUMINOSITY UPGRADE

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Abstract

With a new geometry in a higher luminosity environment, the power deposition in the superconducting magnets becomes a critical aspect to analyze and to integrate in the insertion design. In this paper, we quantify the power deposited in magnets insertion at variable positions from the interaction point (IP). A fine characterization of the debris due to the proton-proton collisions at 7 TeV, shows that the energetic particles in the very forward direction give rise to non intuitive dependences of the impacting energy on the magnet front face and inner surface. The power deposition does not vary significantly with the distance to the interaction point, because of counterbalancing effects of different contributions to power deposition. We have found out that peak power density in the magnet insertion does not vary significantly with or without the Target Absorber Secondaries (TAS) protection.

INTRODUCTION

For developing the LHC Upgrade, a challenging issue concerns the expected increase of energy deposition due to the higher luminosity. The paper recalls the power deposition maps in the insertion region for the nominal luminosity, $10^{34}cm^{-2}s^{-1}$. An upgrade scheme could require some modification of the insertion layout. For a better understanding of the key factors of beam induced energy deposition, parametric studies have been performed with the Monte Carlo code FLUKA (version 2006.3) [1-2]. We have addressed the dependence of power deposition on the distance of the superconducting magnets from the interaction point. The effect of the Target Absorber Secondaries (TAS) is also detailed to characterize its efficiency in protecting the magnets.

INSERTION REGION

Proton-proton collisions products

The proton-proton collisions at 14 TeV in center of mass are treated by the event generator DPMJET III, integrated in FLUKA. The interaction point IP1 at nominal luminosity ($10^{34}cm^{-2}s^{-1}$) has been modelled with a vertical crossing angle of 285 µrad. The debris consist mostly of protons, charged pions, photons, and neutrons in the energy range of 1 to 10^3 GeV [3-4]. At the triplet location (pseudo rapidity η=6.7 to 7.4), both the number of particles received and their total energy varies rapidly with small changes of the geometry and longitudinal position [3].

*Work partially carried out in the framework of the FLUKA collaboration.

Geometry layout

The insertion region of IP1 has been described with up to date geometrical data for the nominal LHC version v6.5. It spans from the IP to the end of the triplet (56 meters) with a detailed description of the vacuum chambers, the absorbers (TAS and TASB), the insertion MQXA and MQXB quadrupoles and the corrector magnets (Figure 1).

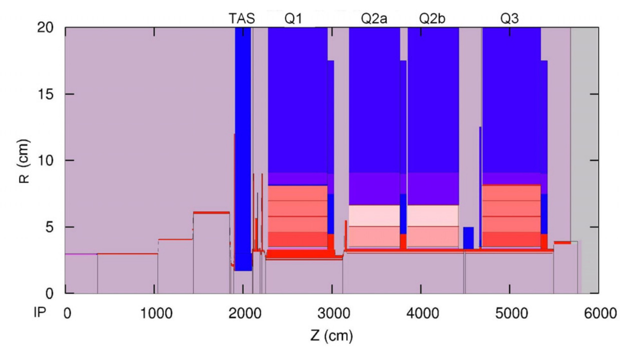

Figure 1: Geometry layout for IR1.

Magnetic field description

The 2D magnetic field maps have been used for each type of quadrupole. The nominal configuration is FDDF (F for focussing, D for defocusing in the horizontal plane for a positively charged particle) seen by the debris coming from the IP. An analytical description of the solenoid field of 2 T is also taken into account in the detector area.

Power deposition

Power deposition in the magnets results mainly from electromagnetic showers and in small parts from hadron and muon ionizations [4]. The dynamic heat loads in each quadrupole range between 20 to 30 Watts (Table 1).

Table 1: Steady state heat loads

Components	Dynamic loads	Statistical errors
TAS/ TAS B	151 / 3 W	1.6 / 4.6 %
Q1	29 W	1.6 %
Q2a	23 W	2.5 %
Q2b	22.5 W	2.5 %
Q3	28 W	2.6 %
Correctors	12 W	2.4 %

The peak power deposition distribution is presented in figure 2. The peak reaches 3.6 mW/cm^3 at the end of Q1, below the design value of 4 mW/cm^3 (with a safety factor

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of 3 w.r.t to the quench limit for Nb-Ti, 12 mW/cm^3). The values are in good agreement with the former calculations in [5].

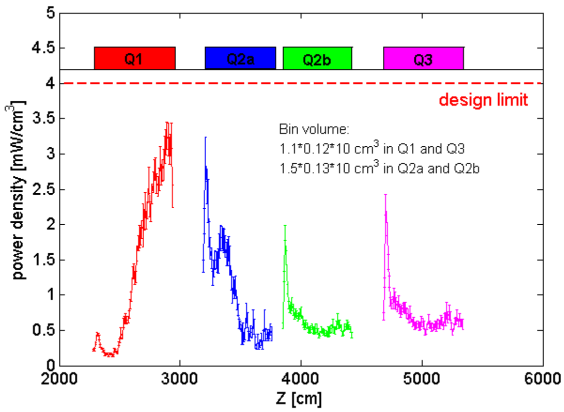

Figure 2: Longitudinal distribution of the peak deposition in the first layer coil. IR1 vertical crossing plane, FDDF magnets, L=10^{34}cm^{-2}s^{-1}.

PARAMETRIC STUDIES

First approach

Some preliminary studies [3-4] show that the body of a small magnet (no field) moving towards the IP is hit by particle debris with larger polar angle (smaller η) and therefore less energetic due to a peaked energy spectrum in the very forward direction. The main contributors are the particles impacting the front face. There are opposite variations of impinging power on the magnet front face and longitudinal inner surface, in the absence of magnetic field (Figure 3). These variations tends to saturate when the distance of the IP (l*) varies from 13 to 23 m.

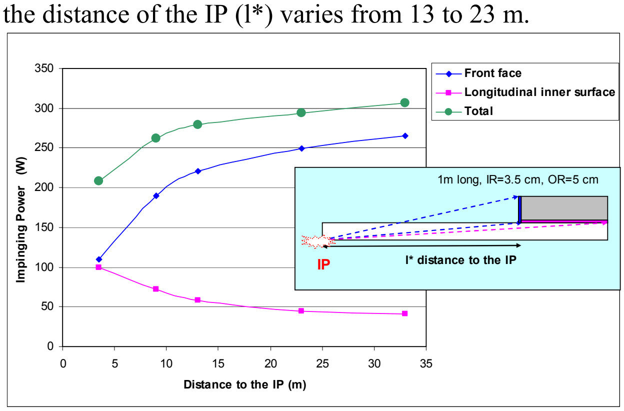

Figure 3: Variation of impinging energy with l*.

This non intuitive variation looks favourable for an upgrade scheme with magnets located closer to the interaction point. This investigation is further detailed with parametric studies applied to an insertion layout, with the implementation of the magnetic fields.

Distances l to the interaction point*

Four different values of l* were investigated by rigidly shifting the insertion elements from 23 m to 13 m (Table 2). The quadrupoles have an aperture diameter of 100 mm, with an average length of 6.3 m. The β* is assumed to be 0.25 m for an upgrade scheme allowing a higher luminosity (8.7*10^{34}cm^{-2}s^{-1}).

Table 2: Magnet and beam parameters

Cases	1	2	3	4
l* distance to the IP (m)	23	19	16	13
Gradient (T/m)	193	204	208	213
Crossing angle (μrad)	512	514	507	500
TAS opening (cm)	2.0	1.7	1.5	1.3

Target Absorber Secondaries (TAS) protection

First parametric studies were performed with a fixed TAS with a nominal aperture of 1.7 cm [6]. The main outcome was that power deposition does not show any significant increase when the insertion is moved closer to the IP. Only a linear increase of power deposition for the first quadrupole (Q1) could be observed.

Further simulations were performed without the TAS and with a TAS adapted to each l* (Table1). For the latter case, the TAS opening was calculated to take into account the beam envelope with the same constraints and rules [7].

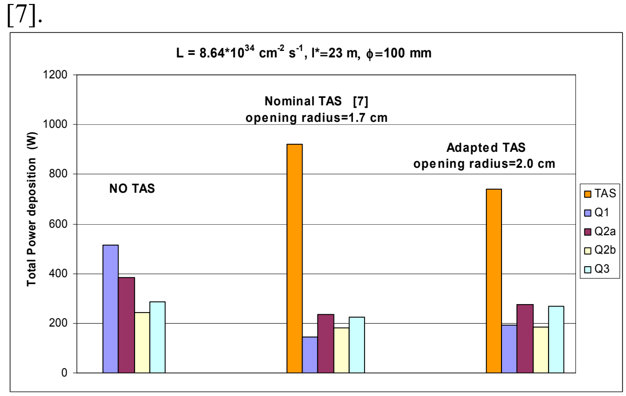

Figure 4: TAS effect at l*=23 m.

Figure 4 sheds light on the effect of the TAS: it absorbs the energy that would impinge the front face of the triplet (-63% for Q1), but the protection decreases for quadrupoles located farther away (-7% for Q3). The TAS adapted for case 1 has a larger opening (2.0 cm) than the nominal TAS (1.7 cm) and therefore, the power deposition in the quadrupoles increases due to a larger acceptance for the debris (+31% for Q1).

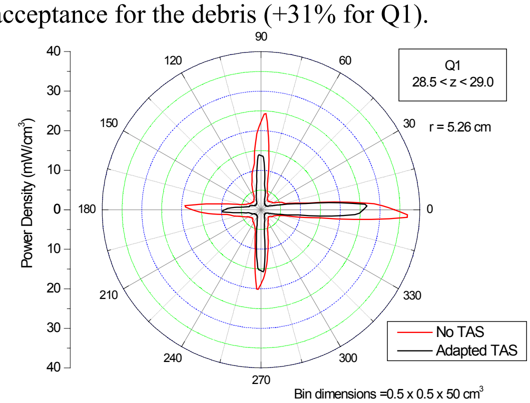

Figure 5: Azimuthal distribution of peak power in Q1.

An important result in figure 5 is the moderate increase of the peak power deposition without the TAS protection (+32%). It indicates that particles coming from the longitudinal inner surface are deviated by the magnetic field and are the main responsible for the local hot spots in the inner layer of the coils.

The variation of total power deposition in the triplet is addressed with different l*:

- without a TAS absorber (Figure 6)
- with an adapted TAS (Figure 7)

The first case aims at separating the possible effects of the TAS shielding and variation of l*, but the latter case is of main interest as the TAS is an active part of the insertion and shall be included in the model.

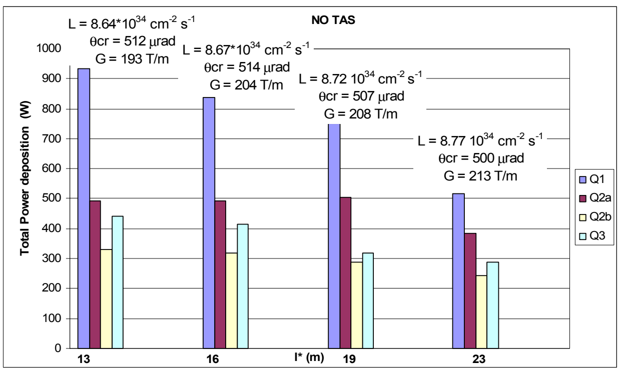

Figure 6: Parametric study without a TAS.

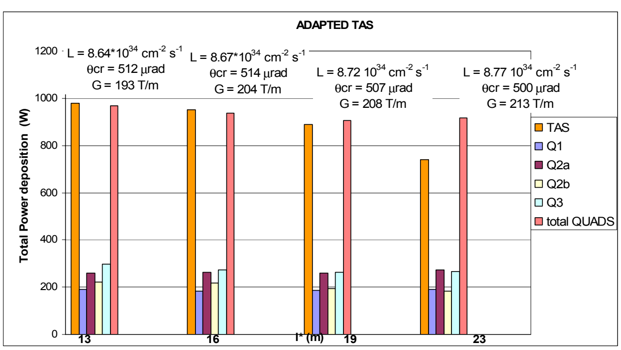

Figure 7: Parametric study with an adapted TAS.

Without a TAS absorber

The largest increase of power deposition is observed for Q1 (+80%). For the other quadrupoles, the increases are in between +30% to +50%. Q1 is affected by a supplementary contribution due to particles impinging the front face. However, this contribution was expected to decrease with l* according to the preliminary study. The magnetic field along the insertion becomes the most important parameter that more than counterbalances the geometrical dependence of the impinging energy on the front face magnet.

With an adapted TAS

The power absorbed by an adapted TAS shows an increase with decreasing l* (Figure 7). The effect of a smaller TAS opening takes over the effect of a larger solid angle intercepting the TAS: the impinging debris are less energetic particles but they are more numerous.

Q1 and Q2a are almost equally protected by the TAS for the 4 cases. The total power increases in Q2b and Q3 are less than +21%. These quadrupoles are mainly hit by debris impinging the longitudinal inner surface. The preliminary study shows that this longitudinal contribution increases slowly between 23 m to 13 m. The total heat load of the triplet magnets varies by +6%.

CONCLUSIONS

The variation of power deposition with decreasing l* has been addressed for different insertion layouts. These parametric studies stress the dominant contribution for both total heat loads and peak power depositions of the charged particles inside the vacuum chamber, deviated by the magnetic field and impacting the coils. The increase of power deposition remains moderate (+6% for the total power in the quadrupoles from l*=23 to l*=13 m) with decreasing l* and therefore does not represent a strong constraint on the distance of the insertion from the interaction point.

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