ENERGY DEPOSITION IN ADJACENT LHC SUPERCONDUCTING MAGNETS FROM BEAM LOSS AT LHC TRANSFER LINE COLLIMATORS

V. Kain, S. Beavan, Y. Kadi, CERN, Geneva, Switzerland

Abstract

Injection intensities for the LHC are over an order of magnitude above the damage threshold. The collimation system in the two transfer lines is designed to dilute the beam sufficiently to avoid damage in case of accidental beam loss or mis-steered beam. To maximise the protection for the LHC most of the collimators are located in the last 300 m upstream of the injection point where the transfer lines approach the LHC machine. To study the issue of possible quenches following beam loss at the collimators part of the collimation section in one of the lines, TI 8, together with the adjacent part of the LHC has been modeled in FLUKA. The simulated energy deposition in the LHC for worst-case accidental losses and as well as for losses expected during a normal filling is presented.

INTRODUCTION

The LHC beams will be injected from the SPS via the two transfer lines TI 2 and TI 8, see Fig. 1. The momentum of the proton beams after the acceleration in the SPS is 450 GeV/c and a full nominal batch extracted from the SPS consists of 3.2×10^{13} protons, which is about a factor of 20 above the estimated damage limit of accelerator equipment [1] at 450 GeV. The main parameters of the extracted beam are summarised in Table 1.

The collimation system in the transfer lines is designed to provide protection of the LHC up to ultimate intensities (4.9×10^{13} protons).

To protect the small LHC aperture at injection energy (7.5 σ [2]) a set of transfer line collimators (TCDI) will be placed at three phase locations in the horizontal and vertical plane with $\mu_{\rm x,y} = \rm n \times 180 + 60°$ (n = 0,1,2,...) between two adjacent collimators. The collimation sections are in the last 300 m of the transfer lines.

To provide enough attenuation of mis-steered beam while remaining sufficiently robust, the TCDI collimators are equipped with 1.2 m long graphite jaws. The required setting of these jaws is 4.5 σ (R.M.S beam size) from the beam axis.

The normal-conducting magnets downstream of the TCDI collimators have to be protected against the showers generated in the jaws during beam impact with fixed stainless steel masks mounted in front of these magnets [3]. With the LHC magnets close to the transfer line collimators energy deposition in the superconducting magnets from collimator showers might also be an issue for quenches. This paper presents the results of expected energy deposition in the LHC magnets adjacent to the collimation section of the transfer line TI 8 in the event of beam loss on a collimator jaw.

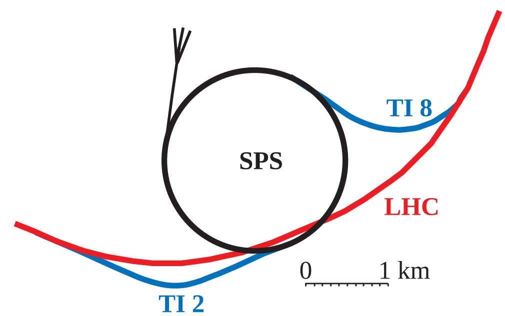

Figure 1: Schematic view of LHC injection from the SPS.

Table 1: Beam parameters for LHC injection.

Proton energy	450 GeV/c
Normalized emittance	$\epsilon_N = 3.5\,\mu$m
Nominal:	
Protons per injected batch	3.2×10^{13}
Ultimate:	
Protons per injected batch	4.9×10^{13}

SIMULATION OF BEAM LOSS AT TCDI COLLIMATORS

The existing model of the collimation section in TI 8 [3] for the simulation code FLUKA [4] was extended to also include a simplified model of the adjacent superconducting LHC dispersion suppressor magnets MB.B9R8 to MQM.B7R8. A top view of the resulting FLUKA geometry can be seen in Fig. 2, corresponding to about 70 m of transfer line plus LHC. From Fig. 2 it can also be seen that in this region the transfer line aperture can be as close as about 1 m to the LHC cold mass. The two most critical locations out of six collimators in TI 8 were studied, TCDIV.87804 and TCDIH.87904. Whereas the FLUKA geometry for the transfer line includes every relevant detail of magnets, collimators, beam pipes, vacuum equipment, beam instrumentation etc., we restricted ourselves to simplified models of the main dipoles and quadrupoles for the LHC part. Magnetic fields were included in the FLUKA geometry in the form of field maps. In the case of the LHC dipoles and quadrupoles MQML and MQM realistic field

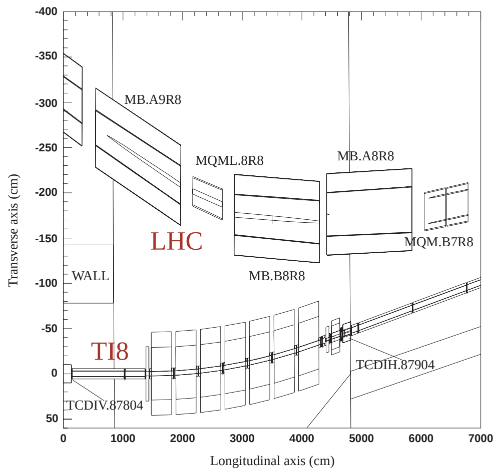

Figure 2: FLUKA geometry used for simulations.

maps had been obtained with ROXIE [5]. The resulting cross-section in FLUKA with the field map for one of the superconducting twin aperture quadrupoles, MQML.8R8, can be seen in Fig. 3.

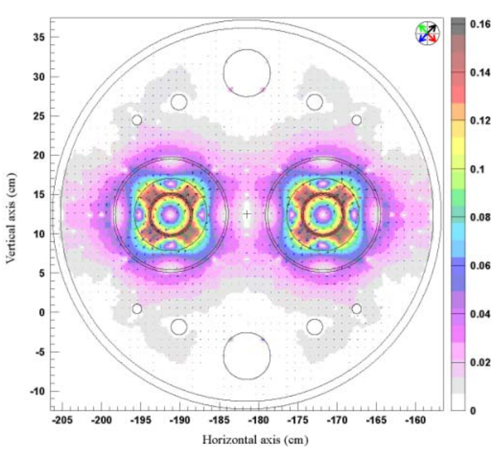

Figure 3: FLUKA field map in T/cm for MQML at 450 GeV.

Impact scenarios on the collimators with ultimate intensity of a full extracted batch were studied for impact parameters from 0 σ to 30 σ assuming Gaussian beams. The simulation input parameters are summarised in Table 2.

Table 2: Simulation parameters

Beam energy	[GeV]	450
Protons extracted		4.9×10^{13}
Impact parameters	[σ]	0, 1, 10, 30
σ_x (TCDIH.87904)	[μm]	410
σ_y (TCDIV.87804)	[μm]	492

QUENCH LEVELS

The temperature rise in the superconducting coils caused by energy deposition from particle showers can lead to loss of superconductivity, a magnet quench. The quench levels for LHC magnets in terms of energy deposition have been simulated with SPQR [6]. For the magnet types used in these simulations the limit can be assumed to be 30 $\mathrm{mJ/cm^3}$.

SIMULATION RESULTS

The distance between the areas of interest, the coils of the superconducting magnets, and the actual beam impact locations is up to 30 m. The errors on the obtained maximum energy deposition in the LHC magnets are hence relatively large, of the order of 50 %. Simulation runs with higher statistics are planned.

With the large error margin on the results there is no significant difference for different impact parameters on the TCDIs. A detailed summary of the results is given in Table 3.

Results for Impact on TCDIV.87804

The area affected by particle showers after an impact on TCDIV.87804 can be seen in Fig. 4. A concrete wall between the transfer line and the LHC ring shields MB.A9R8, the maximum energy deposition is about 4 $\mathrm{mJ/cm^3}$, well below the quench limit, Fig. 5. The adjacent dipole, MB.B8R8, is no longer protected by the wall and the quench level is exceeded with a maximum energy deposition of about 96 $\mathrm{mJ/cm^3}$, Fig. 6. The quadrupole MQML.8R8 would also quench during impact at TCDIV.87804 with maximum energy deposition values of about 91 $\mathrm{mJ/cm^3}$ in its coils.

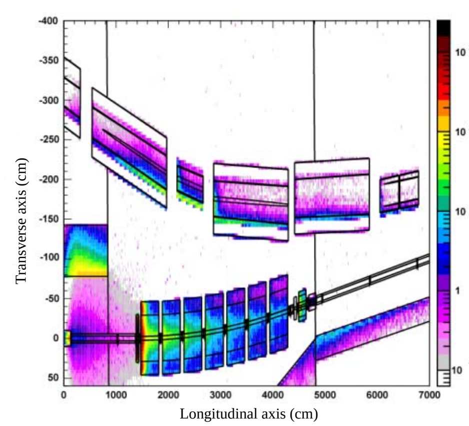

Figure 4: Top view of the simulated geometry after impact on TCDIV.87804. The values are in $\mathrm{mJ/cm^3}$.

Results for Impact on TCDIH.87904

Impact on TCDIH.87904 with different impact parameters gives a maximum energy deposition of 113 $\mathrm{mJ/cm^3}$ in the coil of MQM.B7R8 and leads hence to a quench of

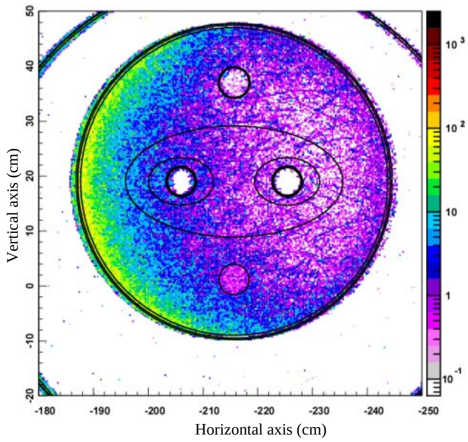

Figure 5: Cross-section of MB.A9R8 around the energy deposition maximum. The values are in $\mathrm{mJ/cm^3}$.

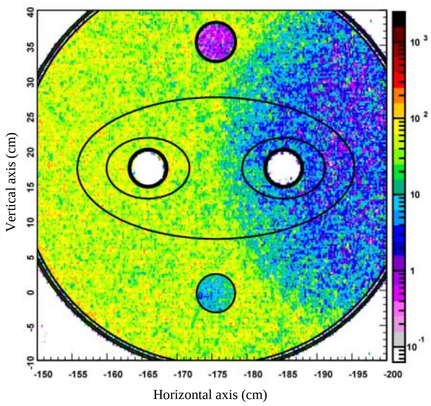

Figure 6: Cross-section of MB.B8R8 around the energy deposition maximum. The values are in $\mathrm{mJ/cm^3}$.

this quadrupole, Fig. 7. With errors of about 50 % on the maximum energy deposition values it cannot be excluded that MBA.8R8 also quenches, as the obtained maximum energy deposition of about 28 $\mathrm{mJ/cm^3}$ is near the quench threshold.

Table 3: Summary of Simulation Results. All values were obtained for ultimate intensity.

Collimator	Magnet	ΔE_{max}	Quench
		$[\mathrm{mJ/cm^3}]$	
TCDIV.87804	MB.A9R8	4	no
	MQML.8R8	76-91	yes
	MB.B8R8	90-96	yes
TCDIH.87904	MB.A8R8	18-28	(yes)
	MQM.B7R8	100-113	yes

ESTIMATES FOR NORMAL OPERATION

The results quoted above were obtained for beam loss scenarios with ultimate intensity, where the whole beam is lost at a collimator. The maximum particle loss fraction on the collimators due to random errors during normal operation was previously estimated to be in the order of 1 % of an extracted batch [3]. Scaling the numbers derived above for maximum energy deposition in the superconducting coils by a factor of 1/100 leads to an estimate of 1 $\mathrm{mJ/cm^3}$, which is well below the quench limit for impact at any collimator jaw.

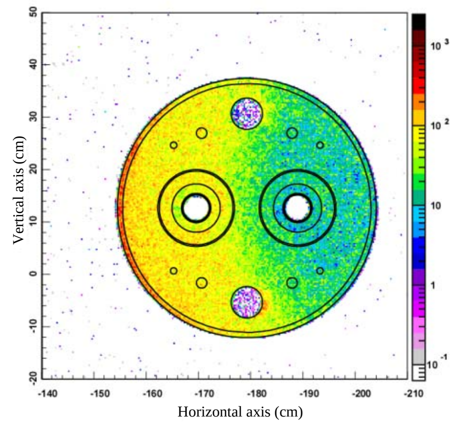

Figure 7: Cross-section of MQM.B7R8 around the energy deposition maximum. The values are in $\mathrm{mJ/cm^3}$.

CONCLUSIONS

The showers generated during beam loss at the LHC transfer line collimators can lead to quenches of adjacent LHC magnets. FLUKA simulations carried out to estimate the energy depositions from impact on the two most critical collimator locations, TCDIV.87804 and TCDIH.87904, in TI 8 for ultimate intensity show that for all simulated accidental impact scenarios quenches would occur in the LHC. The affected magnets have been identified. With the expected particle losses during normal operation in the order of 1 % of the extracted beam, the energy deposition in the adjacent LHC magnets is well below the estimated quench levels.

Issues associated with electronics in the LHC tunnel and material activation by beam impact on the TCDI still have to be addressed.

REFERENCES

[1] V.Kain et al., “Material Damage Test with 450 GeV LHC-Type Beam”, Proc. PAC 2005, Knoxville, Tennessee, USA.

[2] S. Redaelli et al., “LHC Aperture and Commissioning of the Collimation System”, Proc. Chamonix XIV, CERN-AB-2005-014, 2005.

[3] V. Kain, “Machine Protection and Beam Quality during the LHC Injection Process”, CERN-THESIS-2005-047, 2005.

[4] A. Fasso, et al. “The physics models of FLUKA: status and recent development”, CHEP 2003, L.A. Jolla, California.

[5] S. Russenschuck, “Electromagnetic Design and Mathematical Optimization Methods in Magnet Technology”, 3rd edition, http://cern.ch/russ, 2006.

[6] D. Bocian et al., “Enthalpy Limit Calculations for Transient Perturbations in LHC Magnets”, CERN-AT-MTM-IN-2006-021, 2006.