

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN – ACCELERATOR AND TECHNOLOGY SECTOR

CERN-ATS-2011-058

BEAM-INDUCED QUENCH TEST OF LHC MAIN QUADRUPOLE

Agnieszka Priebe*, Knud Dahlerup-Petersen, Bernd Dehning, Ewald Effinger, Jonathan Emery, Eva Barbara Holzer, Christoph Kurfuerst, Eduardo Nebot Del Busto, Annika Nordt, Mariusz Sapinski, Jens Steckert, Arjan Verweij, Christos Zamantzas, CERN, Geneva, Switzerland

Abstract

Unexpected beam loss might lead to a transition of the accelerator superconducting magnet to a normal conducting state. The LHC beam loss monitoring (BLM) system is designed to abort the beam before the energy deposited in the magnet coils reach a quench-provoking level. In order to verify the threshold settings generated by simulation, a series of beam-induced quench tests at various beam energies has been performed. The beam losses are generated by means of an orbital bump peaked in one of main quadrupole magnets (MQ). The analysis includes not only BLM data but also the quench protection system (QPS) and cryogenics data. The measurements are compared to Geant4 simulations of energy deposition inside the coils and corresponding BLM signal outside the cryostat.

CERN-ATS-2011-058
02/09/2011



BEAM-INDUCED QUENCH TEST OF LHC MAIN QUADRUPOLE

Agnieszka Priebe*, Knud Dahlerup-Petersen, Bernd Dehning, Ewald Effinger, Jonathan Emery, Eva Barbara Holzer, Christoph Kurfuerst, Eduardo Nebot Del Busto, Annika Nordt, Mariusz Sapinski, Jens Steckert, Arjan Verweij, Christos Zamantzas, CERN, Geneva, Switzerland

Abstract

Unexpected beam loss might lead to a transition of the accelerator superconducting magnet to a normal conducting state. The LHC beam loss monitoring (BLM) system is designed to abort the beam before the energy deposited in the magnet coils reach a quench-provoking level. In order to verify the threshold settings generated by simulation, a series of beam-induced quench tests at various beam energies has been performed. The beam losses are generated by means of an orbital bump peaked in one of main quadrupole magnets (MQ). The analysis includes not only BLM data but also the quench protection system (QPS) and cryogenics data. The measurements are compared to Geant4 simulations of energy deposition inside the coils and corresponding BLM signal outside the cryostat.

INTRODUCTION

The superconducting LHC magnets are protected from quenching (transition from superconducting state to a normal one) by two independent and complementary systems. The Beam Loss Monitoring system allows to measure particle shower generated by beam loss and dumps the beam before the quench occurs. The Quench Protection System measures the voltage generated on the magnet coil when part of it becomes normal-conducting and fires the quench heaters to dissipate the energy stored in the electric current over the whole volume of the coil.

The aims of the experiment were to understand the quench development and determine the quench level for beam losses in a 5-10 second timescale, and to correlate observables from various systems (mainly BLM and QPS) in order to create a consistent model of quenching magnet. The results of the experiment can also be used to validate QP3 heat transfer code [1].

EXPERIMENT

The quench test was performed in the LHC arc half-cell 14R2 (Fig. 1) on the October 17, 2010. The three-corrector orbital bump has been applied to diverge a proton beam from its initial orbit and hit the aperture within the MQ magnet, focusing in the bump plane.

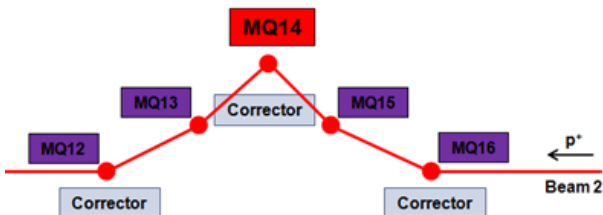


Figure 1: Layout of 3-corrector bump.

The beam energy was 3.5 TeV and the intensity was $1.85 \cdot 10^{10}$ protons. The circulating beam 2 was deflected in a vertical direction with an imposed bump set to reach maximum deflection of 15 mm. The beam-abort thresholds on BLMs have been increased by a factor of 3 in order not to dump the beam before the quench occurs.

RESULTS

During the quench test about 58% of the initial beam intensity has been deposited on the MQ (Figure 2) within approximately 6 s. Figure 3 shows QPS and BLM signals during the last second before the quench. The QPS registered a voltage drop on MQ (U_{QS0_EXT} signal) of approximately 160 mV before the firing of the quench heaters. The BLM detector signal also increased with time. A moment of the beam dump has been estimated as regards to a sudden drop of quench heaters voltage and steep decrease of the BLM signal.

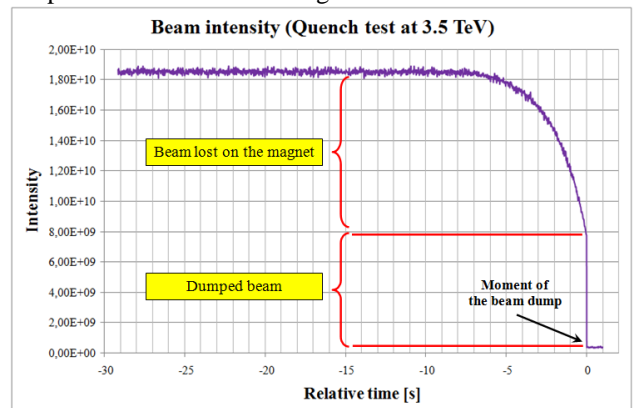


Figure 2: Beam intensity of 3.5 TeV proton beam provided by BCT (Beam Current Transformer).

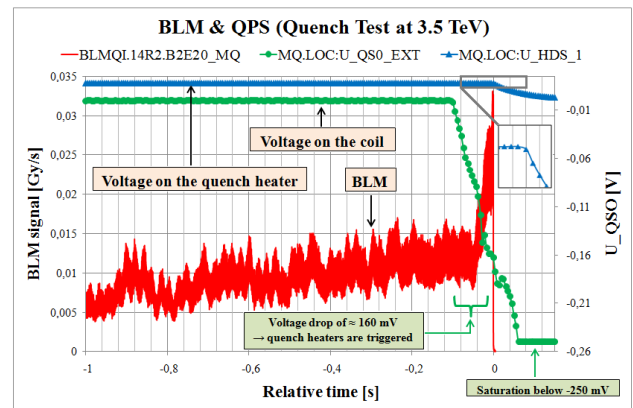


Figure 3: Comparison of signals. Red line – BLM, green line – voltage difference between apertures, blue line – voltage on quench heaters.

The data registered by Beam Position Monitors (BPMs) indicate that the beam had been dumped before it reached the imposed bump amplitude of 15 mm (at around 14.65 mm).

The BLM signals along the LHC ring are presented on Figure 4. Almost all beam losses have appeared in cell 14R2 and they were around eight times higher than those observed on collimators. The loss registered by the beam dump monitors is not shown on the plot.

SIMULATIONS

A simplified Geant4 simulation of the quench test was performed. A detailed representation of the LHC half-cell was implemented. It includes the main accelerator components: three downstream MBs and MQ, interconnections, corrector magnets – MSCBB and MQT. In the simulation the loss location was chosen to be at the beam screen in the center of the main quadrupole. An impacting angle of 202 μrad (vertical direction), calculated from the settings of the orbital bump, was applied. The location of BLMs is presented in Figure 5.

The simulation provides estimates of the energy deposition inside the superconducting coils, E_{dep} and the signal from the BLMs mounted on the cryostat. The energy deposition in the coil is measured in cylindrical bins with size $\Delta\rho = 5.13$ mm, $\Delta\phi = 4^\circ$, $\Delta z = 9.83$ mm. It is important to note that the value of E_{dep} cannot be derived directly from the experiment.

The BLM detectors were represented as long tubes along the cryostat to study the fluence of secondary particles, not only at position of the installed monitors but also in the region of dipoles locations.

The peak of energy deposition inside the coil occurs at about 40 cm from the loss location while the highest number of secondary particles, therefore the highest potential BLM signal, is registered by BLMs at around 2 m from the loss location (Figure 6). The radial distribution of energy density in the most exposed azimuthal and longitudinal position was fitted by a power law function [2]

$$E_{dep} = p_0(r - p_1)^{p_2} \quad (1)$$

where r is the distance from the coil centre and p_0 , p_1 , p_2 are the fit parameters (Figure 7).

Calculated maximal energy occurred on the inner surface of the coil, $3.9 \cdot 10^{-6}$ mJ/cm³ per proton while the average energy per superconductor cable is approximately $6 \cdot 10^{-7}$ mJ/cm³ per proton.

Fluences F of secondary particles have been convoluted with response functions R given by [3] to provide variables comparable with the LHC data. The convolution is expressed by the following equation

$$Q = \sum_{i=1}^5 \left(w_i \cdot \sum_j \sum_k R_{i,j,k} F_{j,k} \right) \quad (2)$$

where index i corresponds to an angle of incoming secondary particle (15°, 30°, 45°, 60°, 90°) and w is a weight related to a number of particles in an angular bin

$$w_i = \frac{I_i}{I_{total}} \quad (3)$$

I_i is an integrated area assigned to a peculiar angle and I_{total} is an integral of the angular distribution (Figure 8). The index j iterates over the particle types (p^+ , e^- , e^+ , π^- , π^+ , n , γ) and k -index iterates over secondary particles

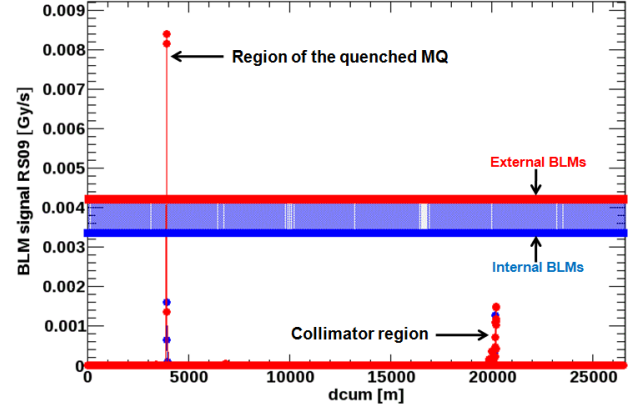


Figure 4: Beam losses along the LHC ring.

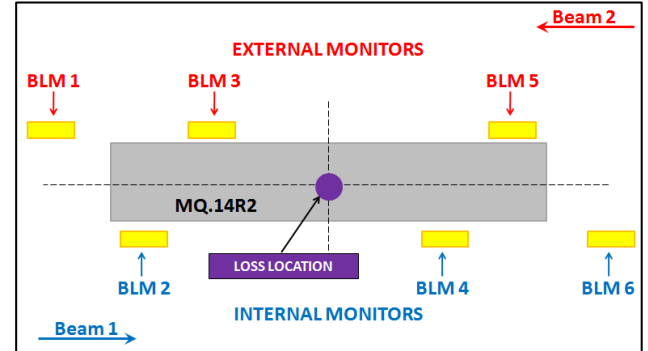


Figure 5: Each MQ is equipped in six monitors. Three external (with respect to LHC ring centre) BLMs survey the beam 2 and three internal detectors observe beam 1.

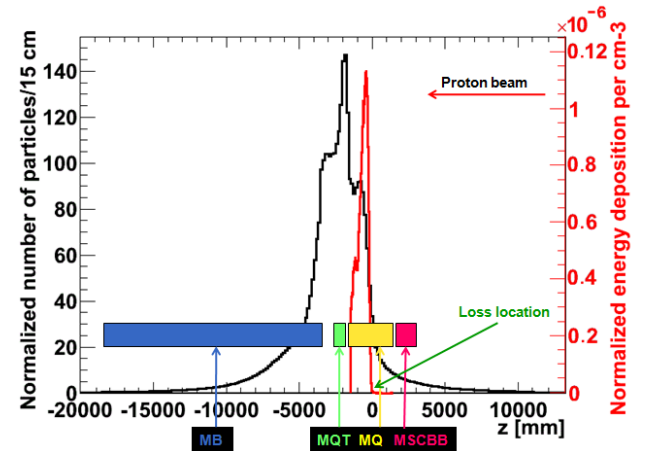


Figure 6: Energy deposition along a coil cable (for a region where E_{dep} reaches maximum) and number of particles registered outside the cryostat. Main magnets have been marked.

Table 2: Revision of Geant4 simulation results and comparison with the quench test. Data of 1.3 integration time.

BLM	Name	G4 simulations BLM signal [Gy/s]	Quench test BLM signal [Gy/s]	Ratio [-]
1	BLMQI_14R2_B2E30_MQ	$1.72 \cdot 10^{-2}$	$1.79 \cdot 10^{-2}$	0.96
2	BLMQI_14R2_B1I10_MQ	$8.02 \cdot 10^{-3}$	$3.49 \cdot 10^{-3}$	2.30
3	BLMQI_14R2_B2E20_MQ	$2.55 \cdot 10^{-2}$	$1.47 \cdot 10^{-2}$	1.74
4	BLMQI_14R2_B1I20_MQ	$9.66 \cdot 10^{-4}$	$1.41 \cdot 10^{-3}$	0.69
5	BLMQI_14R2_B2E10_MQ	$4.97 \cdot 10^{-4}$	$2.74 \cdot 10^{-3}$	0.18
6	BLMQI_14R2_B1I30_MQ	$2.37 \cdot 10^{-4}$	$2.08 \cdot 10^{-4}$	1.14

energy ranges (from 10 keV to 10 TeV). In case of neutrons the lowest energy bound is 0.2 meV.

Table 2 summarizes a comparison between experimental data and Geant4 simulations. The differences observed could be attributed to the simplification of the loss scenario.

QP3

The Geant4 result of radial energy distribution has been combined with experimental data of the beam loss temporal distribution and used as an input to QP3 code. The preliminary results have shown that the simulations overestimate significantly the energy deposited inside the superconducting cable (factor of 11). E_{avg} obtained from QP3 is about 0.5 J/cm^3 while value based on the Geant4 simulation is about 6.06 J/cm^3 for considered lost protons.

CONCLUSIONS

The three-corrector bump technique has proved to be a successful method to induce the controlled quench of the magnet. The experiment has shown the correlation between losses detected by ionization chambers and the voltage on the superconducting coils.

Experimental data have been compared with Geant4 simulations. Although only a simplified loss scenario was simulated (point-like loss impacting the centre of the MQ) the agreement with experimental data is encouraging, although a difference with respect to QP3 predictions need further understanding.

Further investigations of the beam loss distribution are foreseen as well as an analysis of a similar quench test performed at beam energy of 450 GeV.

REFERENCES

- [1] A. Verweij, "QP3: Users Manual", CERN/EDMS 1150045
- [2] Jeanneret J.B., Leroy D., Oberli L., Trenkler T., *Quench levels and transient beam losses in LHC magnets*. LHC Project Report 44
- [3] Stocker M., CERN-THESIS-2008-099

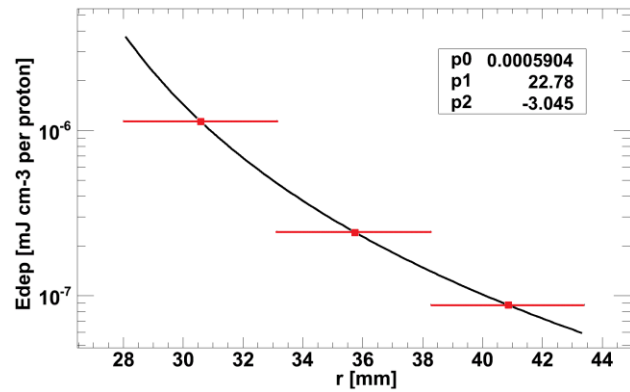


Figure 7: Radial distribution of the energy deposition.

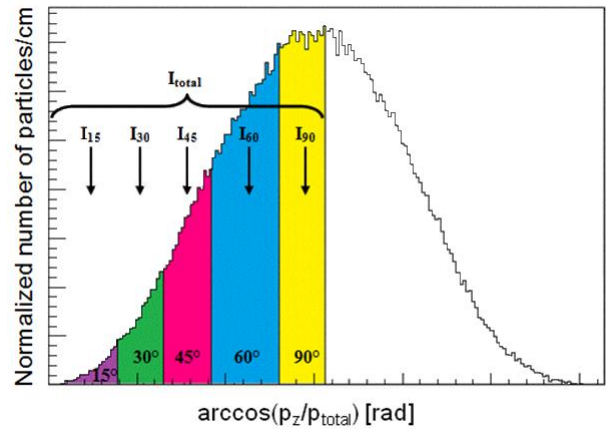


Figure 8: Angular distribution of secondary particles scored by the detectors. Scheme of weight calculations.