BEAM COMMISSIONING PLAN FOR LHC COLLIMATION

C. Bracco, R.W. Assmann, S. Redaelli, T. Weiler, CERN, Geneva, Switzerland

Abstract

The Large Hadron Collider extends the present state-of-the-art in stored beam energy by 2-3 orders of magnitude. A sophisticated system of collimators is implemented along the 27 km ring and mainly in two dedicated cleaning insertions, to intercept and absorb unavoidable beam losses which could induce quenches in the superconducting (sc) magnets. 88 collimators for the two beams are initially installed for the so called Phase 1. An optimized strategy for the commissioning of this considerable number of collimators has been defined. This optimized strategy maximizes cleaning efficiency and tolerances available for operation, while minimizing the required beam time for collimator setup and ensuring at all times the required passive machine protection. It is shown that operational tolerances from collimation can initially be significantly relaxed.

INTRODUCTION

The LHC beam intensity and luminosity can be limited by the efficiency of the collimation system in providing beam cleaning and passive machine protection. This requires a specific setup of the full system for each operational scenario.

Phase 1 collimation system [1] includes 88 movable ring collimators, for the two beams, which are set to different openings to implement a multi-stage cleaning system. Primary (TCP) and secondary (TCSG) collimators plus absorbers (TCLA) build up the two cleaning insertions of the LHC ring: momentum (IR3) and betatron (IR7) cleaning. Tertiary (TCT) collimators and special absorbers (TCLP) are placed closed to the interaction points (IP) to protect the triplet magnets and catch the physics debris coming out from the collisions at the experiments. Additional collimators are used to intercept mis-kicked beams during injection (TDI, TCLI) and extraction (TCDQ, TCS).

LHC collimators consist of two parallel, fully movable jaws which define a gap for the passage of the beam. In total one needs to control more than 340 independent degrees of freedom [2] (two stepping motors per each collimator jaw).

The setup of the collimation system is one of the most delicate phases for the commissioning of the LHC with beam. In addition, performance optimization and machine protection require to respect setting tolerances which become more demanding when increasing beam energy and intensity. An optimized commissioning strategy for the Phase 1 collimation system is described in this paper. The required complements of collimators are defined for various steps in beam commissioning. Moreover the tolerances for machine and collimator setup are specified.

GOALS AND ASSUMPTIONS

The LHC collimation system is the most elaborate system of this kind built to date. Setup and beam tolerances are more demanding than in previous colliders. A learning period for setting up the system and for optimum performance will be necessary and, ideally, it should be as short as possible. It is therefore important to define an optimized commissioning strategy which is matched to the beam commissioning plan of the LHC and has the following overall goals:

- Maintain at all times the required passive machine protection for the given beam intensity.
- Minimize the number of collimators required for each step in beam commissioning, such reducing the beam time required for collimation.
- Maximize the performance for each commissioning step by defining the most efficient set of collimators to be used.
- Maximize the tolerance budget available for collimator setup errors or machine imperfections for each step of commissioning.

The collimation cleaning efficiency and induced losses in sc magnets depend strongly on imperfections [3]. Local losses are expected to be up to a factor of 11 higher when realistic imperfections are assumed, this safety margin has been considered when determining the achievable performance of the system during commissioning. Besides, conservative assumptions are made (i.e. 0.1 h beam lifetime τ during the energy ramp) to take into account further safety margins and uncertainties (e.g. on the quench limit). All the estimates presented here are related to these assumptions. Should beam lifetime and quench limit vary, than the maximum achievable beam intensity would have to be reevaluated.

TOLERANCE BUDGET

The tolerance budget T_b for collimator positioning is defined as:

$$T_b = n_2 - n_1 \tag{1}$$

where n_1 is the half-gap of the primary collimators and n_2 is the half-gap of the second closest collimator to the beam (nominally secondary collimators). T_b is attributed to the following contributions:

- Collimator setup and imperfections (40% of T_b)

- Transient orbit at collimator (30% of T_b)
- Transient beta-beat at collimator (30% of T_b)

The nominal retraction between TCP and TCSG is equal to $1\sigma_\beta$, where $\sigma_\beta = \sqrt{\varepsilon\beta}$ gives the normalized beam size. The beam is adiabatically damped during the acceleration and σ_β (at the location of primary collimators) is reduced from 1 mm at 450 GeV to 250 μm at 7 TeV. The optimum cleaning efficiency is obtained when all collimators are closed following the beam size reduction (scaled with energy setting). Gaps and tolerances decrease when increasing the beam energy (see Fig. 1) and collimator operation becomes therefore more demanding. During the first stages of the

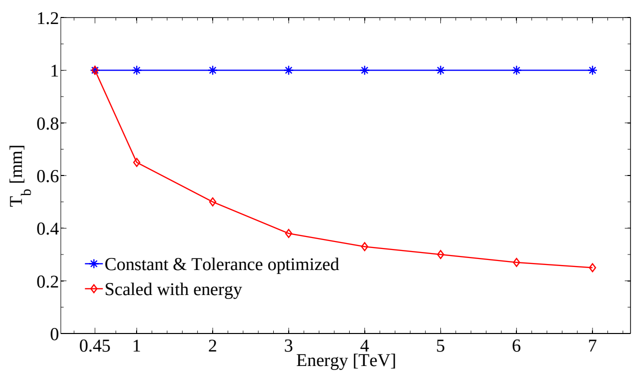

Figure 1: Tolerance budget T_b as a function of beam energy for different collimator settings.

commissioning, the reduced beam intensity allows to use more relaxed collimator settings and tolerances. Two alternative setups are proposed:

- Constant setting: collimators are not moved during the ramp
- Tolerance optimized setting: TCP follow the acceleration beam damping. Remaining collimators are closed by keeping the retraction (in mm) with respect to the TCP unchanged.

These options make operation easier (see Fig. 1) with the price of a lower cleaning efficiency [4].

The proposed commissioning strategy is base on the most favorable trade off between machine performance and operation.

COMMISSIONING STRATEGY

The commissioning plan has been defined based on experimental results and a large number of simulations for different optics configurations. Optimum Collimator settings have been worked out for four reference beam intensities [5] as presented in the following.

Pilot Bunch

A pilot bunch (up to $5 \cdot 10^9$ protons) will be used for initial commissioning of the LHC. Such a low intensity beam can be handled with a minimal set of collimators that implements a one-stage cleaning system. Only 15 collimators per beam are needed: primary collimators in the cleaning insertions and protection collimators (installed for 2008 run [4]).

Experimental tests showed that, on average, 20 minutes have to be taken into account for the manual alignment of each collimator with respect to the beam. A minimum time of 5 h is therefore expected for aligning the one-stage system.

The maximum achievable beam intensity I_{max} is defined as [6]:

$$I_{max} = \frac{\tau \cdot R_q}{\eta_c} \quad (2)$$

where R_q is the quench limit of the sc magnets [4] and η_c is the local cleaning inefficiency of the collimation system (number of particles locally lost with respect to particles absorbed by the collimators [3]). I_{max} is presented in Fig. 2 as a function of beam energy for the settings defined above. Lines referring to the beam intensities as foreseen

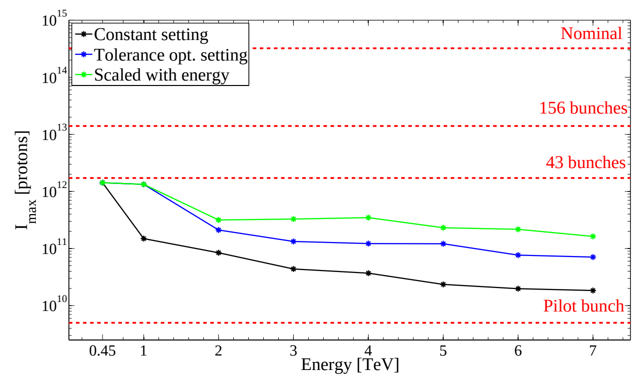

Figure 2: Maximum beam intensity reach for a minimal one-stage cleaning system. A 0.1 h beam lifetime is considered.

for commissioning and nominal operation are also shown. The one-stage system can withstand the pilot beam up to 7 TeV with constant gap (see.Fig. 2 and Table 1). This facilitates the first energy ramps, as collimator settings do not need to be changed and tolerances are kept constant.

43 Bunches

The beam with 43 bunches corresponds to about 0.5% of the nominal beam intensity but it can easily quench sc magnets and also induce damage on accelerator equipment. The stored energy of the beam at 7 TeV can reach the present state-of-the-art at the TEVATRON collider.
In this case a two-stage collimation system is required. Shower absorbers (TCLA) are added to the previous complement of collimators, in total 24 collimators per beam are used (8 h for alignment).
This configuration allows to reach 5 TeV (nominal top energy for the first years of operation) without beam intensity limitations, by scaling collimator gaps with the energy

Table 1: The collimator complements proposed for several beam target intensities foreseen for the LHC commissioning are shown. An estimate of the time needed for the manual setup and of the maximum reachable intensity (for a 0.1 h beam lifetime) at reference top energies are also presented. The best performance is obtained by setting the collimators with the tightest tolerances.

	Intensity [protons]	Number of collimators	Time [h]	Ramp setting	$I_{max}^{5\,TeV}$ [protons]	$T_b^{5\,TeV}$ [mm]	$I_{max}^{7\,TeV}$ [protons]	$T_b^{7\,TeV}$ [mm]
Pilot Bunch	$5.0 \cdot 10^{9}$	15	5	constant	$2.4 \cdot 10^{10}$	1.30	$2.0 \cdot 10^{10}$	1.30
43 Bunches	$1.7 \cdot 10^{12}$	24	8	scaled	$1.8 \cdot 10^{12}$	0.45	$1.4 \cdot 10^{12}$	0.38
		34	11	tol. opt.	$7.4 \cdot 10^{12}$	1.00	$1.7 \cdot 10^{12}$	1.00
156 Bunches	$1.4 \cdot 10^{13}$	34	11	scaled	$1.3 \cdot 10^{13}$	0.30	$4.1 \cdot 10^{12}$	0.25
Nominal	$3.2 \cdot 10^{14}$	44	15	scaled	$1.6 \cdot 10^{13}$	0.30	$5.0 \cdot 10^{12}$	0.25

(see Table 1). On the other hand at 7 TeV, either the intensity must be reduced or a third collimator family (e.g. secondary collimators, see next section) must be set up. Relaxed tolerances can then be adopted (see Table 1).

156 Bunches

Further stages of cleaning and protection are required for intensities above 43 bunches. Studies for this case were carried out considering the collimators which were installed in the LHC tunnel for the 2008 run. In particular, secondary collimators are implemented to the two-stage system described above. Only a reduced number of TCSG (6 out of 11 per beam) was installed in the betatron cleaning insertion at that time. Optimization studies allowed to define the collimators to be installed at first.
The foreseen operation up to 5 TeV is possible with this complement but with severe tolerances, as shown in Table 1. If these tight tolerances cannot be achieved, collimator gaps must be increased and the beam intensity should be reduced.

Nominal Intensity

The full Phase 1 collimation system will be installed for the 2009 run of the LHC. This system provides optimal performance which, however, is expected to be limited below nominal intensity (see Table 1). This relies on many assumptions, as outlined before. It is believed that it will be possible to increase the beam intensity once some experience of LHC operations is gained, leading to improved beam stability (longer lifetime) and reduced machine imperfections.
About 15 h are necessary for setting up the full Phase 1 system. An automized calibration procedure will be implemented to reduce setup time. A new beam based alignment will have to be performed after any substantial change in the beam parameters. If the machine is stable, collimators will be moved to reference positions from the last alignment. High reproducibility of the accelerator and beam parameters are therefore fundamental to avoide frequent collimator setup and obtain high efficiency of the accelerator for physics.

CONCLUSIONS

This paper summarizes the main features of a collimation commissioning plan optimized according to the intensities foreseen for the LHC beam commissioning. The proposed strategy starts with 30 collimators, for the two beams, and a tolerance budget that is relaxed by a factor of 5 (at 7 TeV) with respect to the nominal settings. The achievable performance is then improved in steps until a factor of 250 is gained with the full Phase 1 system and the achievement of tightest tolerances.
All the estimates presented here are related to given assumption on a peak beam lifetime. The performance reach is indeed improved when loss rates are smaller.

Beam commissioning might deviate from the foreseen procedure for various possible reasons. In this case, the appropriate collimator settings must be redefined in a short time. A master table has been worked out in order to allow fast reaction time without compromising safety aspects. It contains a large variety of collimator settings whose consistency and safety have been carefully checked. The cases described above were extracted from this table which is too detailed for the scope of this paper. The master table will be used as the reference for collimator setup and will be updated from the accelerator physics side as the knowledge and experience of LHC collimation will expand. A released version will be made available for accelerator operation after initial beam commissioning.

REFERENCES

[1] The LHC Design Report, Vol.1, Chapter 18. CERN-2004-003, pp. 467-498.

[2] S. Redaelli et al., “Implementation and Performance of the LHC Collimator Control System”, these proceedings.

[3] C. Bracco et al., “LHC Cleaning Efficiency with Imperfections”, these proceedings.

[4] C. Bracco, “Commissioning Scenarios and Tests for the LHC Collimation System”, CERN-THESIS-2009-031, EPFL, Lausanne, 2009.

[5] M. Lamont et al., “A Staged Approach to LHC Commissioning”, LHC-Project-Report 949, 2006.

[6] R. Assmann, “Collimators and Cleaning: Could That Limit the LHC Performance?”, proceedings of the Chamonix XII Workshop, 2003.