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LHC COLLIMATION EFFICIENCY DURING COMMISSIONING

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Abstract

The design of the LHC collimation system requires understanding and maximizing the ultimate performance with all collimators. However, for the commissioning of the LHC it is important to analyze the collimation efficiency with certain subsets of collimators, with increased collimator gaps and relaxed set-up tolerances. Special studies on halo tracking and energy deposition have been performed in order to address this question. The expected cleaning performance and intensity limits are discussed for various collimation scenarios which might be used during commissioning of the LHC.

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Abstract

The design of the LHC collimation system requires understanding and maximizing the ultimate performance with all collimators. However, for the commissioning of the LHC it is important to analyze the collimation efficiency with certain subsets of collimators, with increased collimator gaps and relaxed set-up tolerances. Special studies on halo tracking and energy deposition have been performed in order to address this question. The expected cleaning performance and intensity limits are discussed for various collimation scenarios which might be used during commissioning of the LHC.

INTRODUCTION

The Large Hadron Collider (LHC) will accelerate 2 beams of 3.2×10^{14} protons to an energy of 7 TeV with an energy density of up to 1 GJ/mm^2 at the collimators. This high energy density makes the beams strongly destructive and dangerous particularly for the superconducting (SC) magnets which have a quench threshold of about 5 mW/cm^3 [1]. The energetic LHC particles experience diffusion due to different effects like RF noise, beam-beam scattering, intra-beam scattering, etc.

The allowed peak loss rate is specified to be 1% of beam lost in 10 s (beam life time of 0.2 h). Such losses are occasionally unavoidable and if, not controlled, may happen everywhere along the ring of the LHC. The aim of the collimation system is to ensure that these beam losses occur at collimators in dedicated (warm) sections of the LHC with only small leakage into the cold magnets. Two insertions are dedicated to momentum (IR3) and betatron (IR7) cleaning [2]. In addition, collimators protect the machine against irregular and unpredictable abnormal beam losses and minimize the collimation related background at the experiments.

The collimation in the LHC is relying on a multi stage cleaning system per beam with primary (TCP) and secondary (TCS) collimators intercepting the beam halos, plus absorbers and supplementary collimators to protect the mechanical aperture of the machine:

- Tertiary tungsten collimators (TCT) are placed upstream of the low beta insertions to protect the SC triplets against incoming beam halo plus irregular beam impacts.
- Tungsten absorbers (TCLA) absorb the energy of the particles generated in the electromagnetic showers from collimators.
- Diluter elements (TCDQ, TDI, TCLI) protect the machine from mis-kicked beams during delicate processes as injection or beam dumping.

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Table 1: Half gaps **a** at 7 TeV for different collimator families in nominal σ.

a **TCP** **[σ]**	**a** **TCS** **[σ]**	**a** **TCLA** **[σ]**	**a** **TCT** **[σ]**	**a** **TCS@TCDQ** **[σ]**
6.0	7.0	10.0	8.3	7.5

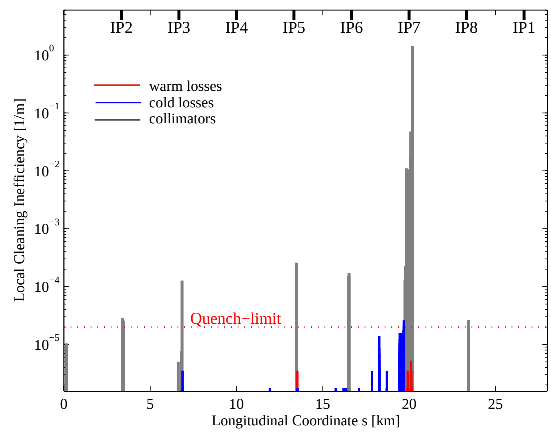

Figure 1: Proton loss map for Beam 2 betatron cleaning at 7 TeV (horizontal halo). The full phase 1 collimation system is simulated with collision optics. Blue bars correspond to losses on SC elements, red bars to losses in warm elements and grey bars to inelastic interactions in collimators. The beam moves from the right to the left. The estimated quench limit refers to nominal intensity (3.2×10^{14} protons) and 0.2 hours beam lifetime.

The nominal 7 TeV values for the LHC collimation half gaps **a** are listed in Table 1 in units of nominal sigma (nominal emittance at 7 TeV is $\varepsilon = 0.5$ nm). All collimators are two-sided and jaws sit at ± **a**. An exception is the the TCDQ, which is a one-sided object but complemented by a two-sided TCS collimator (TCS@TCDQ).

The performance of the collimation system is described by the local cleaning inefficiency η_c:

$$\eta_c = \frac{N_{losses}}{N_{absorptions} \cdot \Delta s} \quad . \qquad (1)$$

Here, N_{losses} is the number of particles lost in individual aperture bins of length Δs and $N_{absorptions}$ is the total number of lost particles. Losses along the machine are investigated using a detailed aperture model with a longitudinal resolution of 0.1 m [2, 3].

In Fig.1 a loss map is shown for the LHC with all 88 phase 1 collimators [4]. From this map it is visible that losses on collimators (grey bars) are higher than losses on the aperture: blue bars for SC elements and red bars for machine elements at room temperature.

The peak losses in SC magnets are above the assumed quench limit in the SC magnets of IR7. Due limited cleaning efficiency and impedance limitations the intensity in collimation phase 1 will be limited to less than 40% of the nominal intensity. A collimation upgrade will allow reaching higher intensities.

For the commissioning of the LHC different increasing steps of intensity are planned [5]. This allows using initially a minimal set of collimators. This set should be adequate to work at lower intensity, has more relaxed tolerances and therefore is less affected by imperfections.

EARLY COMMISSIONING SCENARIOS

Before first LHC commissioning 74, out of the 88 phase1 collimators will be installed along the 2 rings. Various commissioning scenarios were studied and are summarized in Table 2.

During commissioning the intensity of the beams is reduced and the β* values are relaxed: 2 m at IR1 (ATLAS), IR5 (CMS) (nominal β*=0.55 m) and IR8 (LHC-b) (nominal β*=10 m). The scenarios listed in Table 2 were used to perform halo simulations for 5×10^6 protons and for the two beams. The loss maps shown in the next paragraphs refer to Beam 2. The considerations are mostly equivalent for Beam 1.

Scenario 0: This scenario is similar to the nominal collimation introduced before and refers to nominal values of β*. The resulting loss map is shown in Fig. 2 and is similar to Fig. 1. The only differences are due to the fact that we are using less collimators: a few collimators for injection protection, absorbers for the showers from p-p collision and two vertical tertiary collimators in IR2 and IR8 are missing. The performance is limited by losses in SC magnets downstream of IR7 to 95.2% of the nominal intensity. This is the reference case after full commissioning.

Scenario 1: A basic one stage collimation system in IR3 and IR7 is established. The simulated loss map for Beam 2 (not included into this paper) predicts a maximum intensity lower than 1.2% of nominal.

Scenario 2a: The secondary collimators in IR7 are kept open and the tungsten absorbers act as de facto secondary collimators. Considering the opening of the TCDQ (8 σ) and comparing the loss map for this case (in Fig. 3) with the full reference case (in Fig. 2), it is evident that the TCS@TCDQ collimator now starts acting as a secondary collimator. It intercepts a factor 100 more particles than in the nominal case. The small gaps at the TCDQ are required in order to protect the tungsten absorbers against beam-induced damage. The high beam load on the TCDQ can be a problem since showers escape the TCDQ and its associated collimator. This situation is more critical for Beam 2 because the TCDQ is in the next insertion downstream the betatron cleaning insertion and losses are higher than for Beam 1 [6].

Table 2: Half gaps **a** of the collimators for different early 7 TeV commissioning scenarios (betatron collimation). The openings are given in units of nominal sigma.

scenario	**a TCP [σ]**	**a TCS [σ]**	**a TCLA [σ]**	**a TCT [σ]**	**a TCS@ TCDQ [σ]**
Scenario 0	6.0	7.0	10.0	17.0	8.0
Scenario 1	10.0	-	-	17.0	13.5
Scenario 2a	6.0	-	10.0	17.0	8.0
Scenario 2b	6.0	-	10.0	17.0	9.0
Scenario 3a	6.0	9.5	10.0	17.0	8.0
Scenario 3b	6.0	9.5	10.0	17.0	9.0

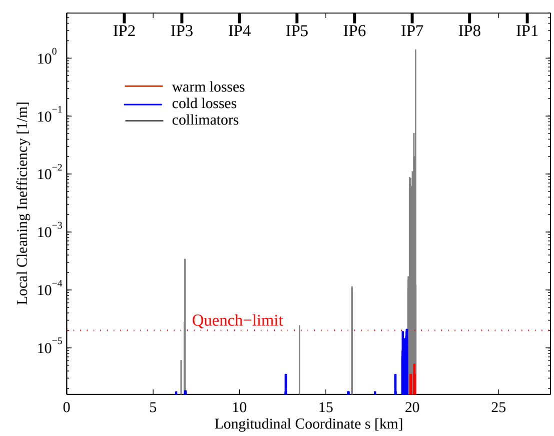

Figure 2: Loss map for *scenario 0* and Beam 2.

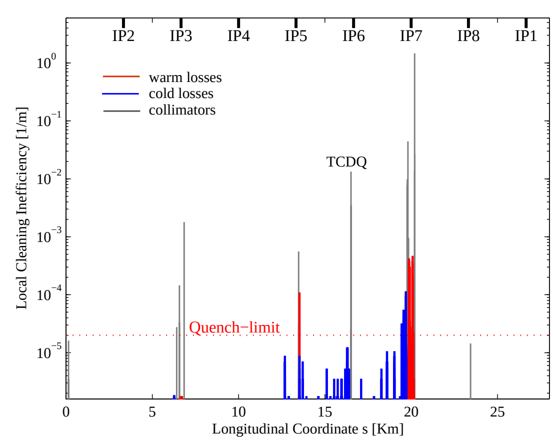

Figure 3: Loss map for *scenario 2a* and for Beam 2. The bar corresponding to particles absorbed on TCS@TCDQ is a factor 100 higher than for the nominal case (see Fig. 1). Losses in SC magnets (cold) appear immediately after the TCDQ but are below the quench limit.

Table 3: Summary results for various commissioning scenarios. The assumed quench levels correspond to $\eta_{peak}^{cold} = 2\times10^{-5}$ m^{-1} and $\eta_{peak}^{TCDQ} = 2.55\times10^{-4}$ m^{-1}. The inefficiency values printed in bold were found to limit performance (I_{limit}: intensity limit).

Scenario (hor. halo)	η_{peak}^{cold} [1/m]	η_{peak}^{TCDQ} [1/m]	I_{nom}/I_{limit} [%]
Nom. phase1	$\mathbf{2.61\times10^{-5}}$	1.53×10^{-4}	76.6±19.7
Scenario 0	$\mathbf{2.10\times10^{-5}}$	1.16×10^{-4}	95.2±27.5
Scenario 1	1.08×10^{-3}	$\mathbf{2.20\times10^{-2}}$	1.159±0.003
Scenario 2a	1.14×10^{-4}	$\mathbf{1.33\times10^{-2}}$	1.917±0.007
Scenario 2b	9.14×10^{-5}	$\mathbf{7.91\times10^{-3}}$	3.224±0.016
Scenario 3a	3.87×10^{-5}	$\mathbf{6.24\times10^{-3}}$	4.086±0.021
Scenario 3b	5.09×10^{-5}	$\mathbf{1.52\times10^{-3}}$	16.78±0.17

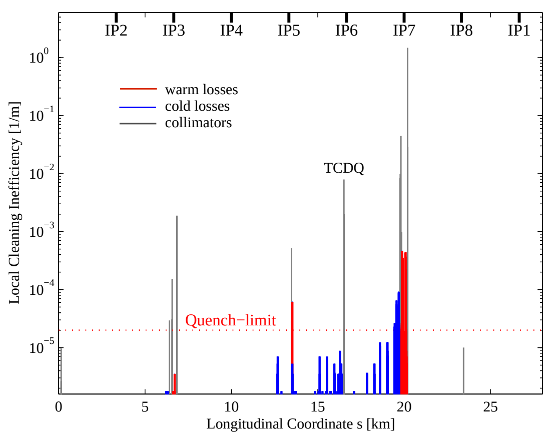

Figure 4: Loss map for *scenario 2b* and for Beam 2.

From the analysis of the proton loss map in Fig. 3 it is concluded that the system might work with up to 10% of the nominal intensity. However, since the proton loss maps do not include electromagnetic showers, it is necessary to evaluate in addition the energy deposition from showers in SC magnets.

The energy deposition is obtained by using the proton loss maps as starting point for FLUKA showering simulations. These studies are quite time-consuming and were so far only done for the nominal setting of the phase 1 collimation system and for nominal optics. The predicted maximum thermal load on SC magnets is 2.3 mW/cm^3 in IR7 (Beam 1), about half of the expected quench limit. This clearly reduces the performance reach of the collimation system. Downstream of the TCS@TCDQ element a maximum heat deposition of 3.1 mW/cm^3 was found for Beam 2 [6]. Scaling energy deposition with the beam load on the TCS@TCDQ we find a peak energy deposition in IR6 of about 270 mW/cm^3 for scenario 2a and full nominal intensity. This corresponds to 1.9 % of nominal intensity for an assumed IR6 Q4 quench limit at 5 mW/cm^3 [6].

Scenario2b: In this scenario secondary collimators are still completely open but now the half gap of the TCDQ collimator is 1 σ wider than for *scenario 2a*. The resulting loss map is shown in Fig. 4. The gain is less than a factor 2 and it can be expected to reach about 3.2 % of nominal intensity.

Scenario 3a: The secondary collimators are moved into an intermediate position. Losses in SC magnets are the same as for *scenario 0*. Losses on the TCDQ collimator are comparable to those of *scenario 2b*. A performance limitation at 4.1 % of nominal intensity is predicted.

Scenario 3b: The TCS@TCDQ collimator at is opened to 9 σ and the performance reach is increased to 16.9 %.

Table 3 summarizes the predicted performances for the different scenarios considered. For each scenario we list 1) the highest local cleaning inefficiency in SC elements, 2) the local cleaning inefficiency at the TCDQ collimators and 3) the relative intensity limit (I_{nom}/I_{limit}) from the most limiting parameter among η_{peak}^{cold} and η_{peak}^{TCDQ}.

CONCLUSIONS

Stages with increasing intensity are planned for the LHC commissioning. According to the different intensities a minimal system of collimators will be operated to protect the SC magnets against quenches from unavoidable beam losses. Different steps were simulated for collimator commissioning. Tracking and energy deposition studies show that the limitations arise in magnets downstream of IR7 and in the dump section of the machine in IR6. The gap of the TCDQ plays a crucial role.

Several early commissioning steps for the collimation system have been simulated in detail for the more critical Beam 2. The predicted reach in performance spans from about 1 % to about 17 % of nominal intensity. The collimator settings used during commissioning are less sensitive to imperfections and have relaxed tolerances. Future studies will look at further variations with larger gaps for the TCDQ and the TCLA.

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