IMPROVED ROBUSTNESS OF THE LHC COLLIMATION SYSTEM BY OPERATING WITH A JAW-BEAM ANGLE*

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Abstract

The robustness of the Phase I collimation system could be improved playing with the angular orientation of each single jaw.

A preliminary study on the asymmetric misalignment of the collimator jaws, scanning through different jaw angles and varying beam sizes and energy, have been carried out, aiming at minimizing the energy deposited on metallic collimators, following an asynchronous dump.

INTRODUCTION

The present LHC Phase I collimation system [1] is composed of 108 collimators and absorbers installed on both beam lines, out of which 97 are precision movable devices (i.e. collimators). 38 of these 97 collimators are featured by tungsten-based jaws, for absorbing particle showers at the end of the two cleaning regions (i.e. the so-called TCLAs) or to protect the triplet magnets in the interaction points (i.e. the so-called TCT). Using a tungsten-based material (i.e. INERMET 180 composed by tungsten at 95%, nickel at 3.5% and copper at 1.5%, mass fractions), these collimators enhance their efficiency, while being sensitive to beam damage. Thus, the effects of the most probable accident have to be carefully evaluated in order to minimize the damage on these collimators and on the other elements downstream.

In order to improve the robustness of these devices against the direct impact of one full intensity bunch as consequence of an asynchronous dump accident, different jaw-beam angles have been considered for different beam energies. The scope of this preliminary study is to evaluate the effectiveness of operating with tilted jaws. The energy deposited in the jaw, resulting in temperature peak in the tungsten-based part as well as the amount of high energetic protons escaping from the tilted jaw are outputs that have to be evaluated before moving to more complex calculations.

METHODOLOGY

The probability that an asynchronous dump accident happens was estimated to be once per year [2]. On the other hand, the probability that a collimator is hit directly by a full intensity bunch is lower, since it comes as result of other error combinations. In principle only the first bunch could escape before the MKD is re-triggered in a time of about 0.9μs. In such a situation, the retraction of all the protecting devices in Point 6 (i.e. the two diluter blocks (TCDQs) and one secondary collimator (TCSG)) has to be taken also into account before the bunch could reach one of the collimators with still a dangerous intensity level. However, if it happens during physics or collimation beam-based alignment runs, it could have catastrophic consequences, in particular if a tungsten-based collimator jaw is hit. Indeed, tungsten absorbs particle cascades started by the inelastic scattering of protons at TeV energies better than a carbon based material (carbon radiation length = 24.12 cm; tungsten radiation length = 0.35 cm).

A transverse Gaussian bunch profile of 0.3x0.3 mm RMS beam size and an impact parameter of 0.5 mm has been chosen as reference values for a jaw-beam angle scanning study. With reference to Fig.1, one jaw was moved starting from a jaw-beam angle of δ=+5mrad (see Fig.1 – case 1) until δ=-5mrad (see Fig.1 – case 3), considering also the case of the jaw parallel to the beam (see Fig.1 – case 2). It should be kept in mind that for negative angles, the bunch hits the jaw on the inner surface, thus being more spread out, while for positive angles, the impact occurs on the front face of the jaw, perpendicular to the beam direction.

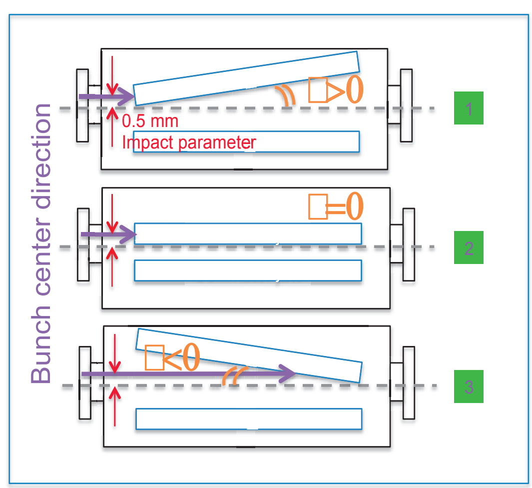

Figure 1: Schematic layout of the collimator jaw tilt. The impact parameter considered and the sign of the scanning angle are shown. Dotted gray line refers to the collimator position in design orbit.

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The FLUKA Monte Carlo code [3,4] was used to evaluate the instantaneous increase of the temperature due to the proton interactions with the jaw material. Steps of 1mrad were considered at the beginning for a fast scan; at a later stage more accurate evaluations were based on steps of 0.1mrad for angle ranges selected from the results of the fast scan. It has to be pointed out that angles of few mrad are already big when dealing with collimators.

The FLUKA model of the tungsten-based insert of TCT collimators jaw alone (see Fig.2) was considered in this preliminary evaluation, being it the most exposed region in case of asynchronous dump, with temperatures that could possibly reach the melting point at its surface. This volume is also representative of the TCLA collimators. A scoring mesh stepped by 0.01x0.01x0.5 cm was used and about 200000 primary particles were run.

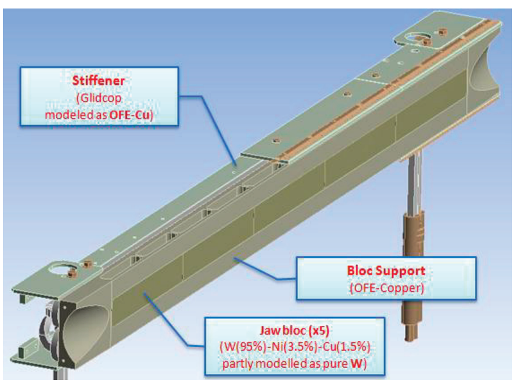

Figure 2: Mechanical layout of a tertiary TCT collimator jaw [5]. The main component i.e. the tungsten-based insert, composed by five jaw blocks, the copper block support and the copper based stiffener are shown.

RESULTS

Figure 3 and 4 show the temperature peak calculated in adiabatic conditions for a bunch with 1.3e11 protons at 7TeV and 3.5TeV respectively. These curves have little physical meaning, since, once above the melting temperature, the material changes its state and the heat capacity at constant pressure cannot be considered constant. However, these temperature profiles give indications about the position of the melted regions and the effect of the tilted jaw. For example, if the jaw is tilted towards the entrance of the beam, the melted part will be located at the beginning of the jaw, whereas in case the jaw is tilted towards the beam exit, the end of the jaw will be damaged. It should be noted that the worst scenario is at no tilt of the jaw (red curves in Fig.3, 4 and 5).

Figure 5 shows that with an angle of about -1 mrad (see Fig.1 for the meaning of the angle sign), a homogeneous energy distribution close to the insert surface is found, with a consequent flat temperature profile.

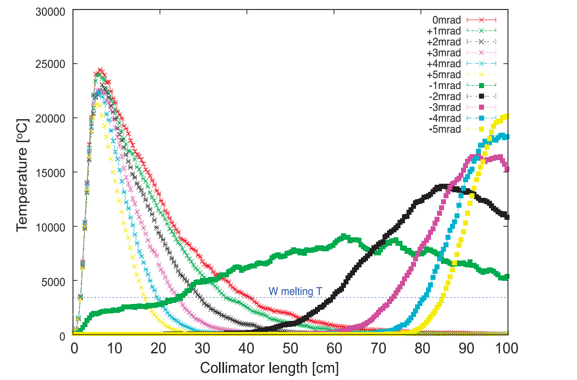

Figure 3: Temperature peaks on the tungsten insert surface for a bunch at 7TeV. The scan is performed using steps of 1mrad in the whole angle range.

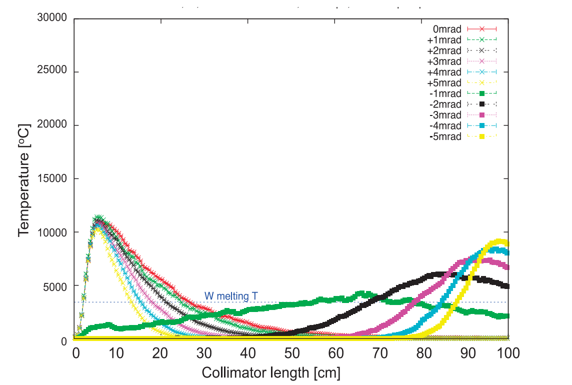

Figure 4: Temperature peaks on the tungsten insert surface for a bunch at 3.5TeV. The scan is performed using steps of 1mrad in the whole angle range.

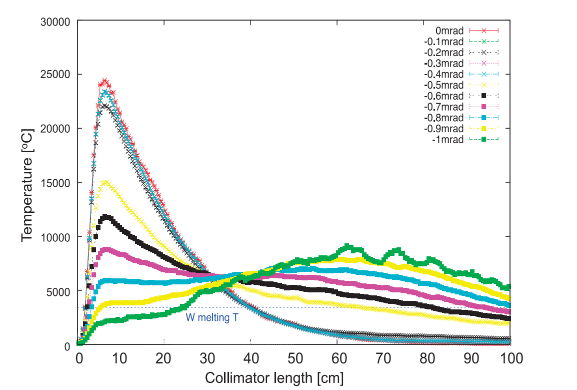

Figure 5: Temperature peaks on the tungsten insert surface for a bunch at 7TeV. The scan is performed using steps of 0.1mrad in the angle range of [0:-1] mrad.

The amount of the escaping high energetic protons has also been estimated for the given scenarios. These particles can be potentially lost in the first strong superconducting magnets downstream of the impacted collimator. In the particular case of TCTs, the power deposited on the coils of the triplet magnets must be carefully evaluated, to avoid quenches, before implementing any jaw-beam angle.

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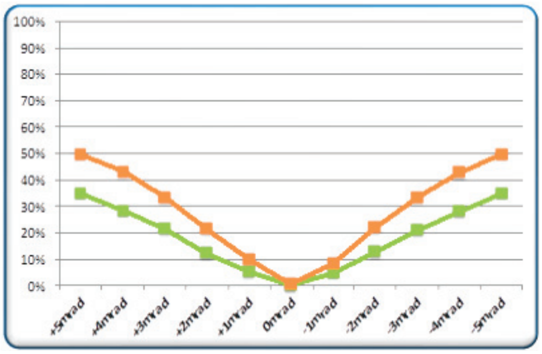

Figure 6: Fraction of escaping energetic protons (with respect to the impacting ones) for different jaw tilt angles. Orange line refers to escaping protons of energy between 1 and 7 TeV, while the green line refers to protons that have lost only 1% of the starting 7TeV energy, after impacting the jaw.

Figure 6 shows the amount of escaping protons as a function of the tilt angle, in case of a 7TeV bunch. Results refer to primary protons that after interacting with the collimator jaw have still energy of the order of TeV.

Scans over the beam size at 7TeV were evaluated in a second stage of the analysis. Figure 7 shows the longitudinal temperature peak profiles in case of parallel jaws, the worst jaw-beam angle scenario as presented above. The real RMS beam sizes for horizontal tungsten-based jaw located in the whole LHC are summarized in Table 1. These locations were taken into consideration since the asynchronous dump affects mainly the horizontal collimators, as the dump kickers act on the horizontal plane.

Table 1: RMS sizes of Beam 1 and Beam 2 at 7TeV for tungsten-based horizontal collimator jaws. Since the location of such collimators is symmetrical with respect to the Interaction Points (IP), the name refers in reality to 2 collimators, one located on the left side of the IP, and the other one located on the right.

Collimator	(x;y) RMS transverse beam size [mm]	
	Beam 1	Beam 2
TCTH.4 (@IP2)	(0.899; 0.55)	(0.578; 0.903)
TCLA.B5 (@IP3)	(0.276; 0.291)	(0.313; 0.277)
TCLA.6 (@IP3)	(0.255; 0.291)	(0.293; 0.253)
TCLA.7 (@IP3)	(0.182; 0.221)	(0.21; 0.184)
TCTH.4 (@IP5)	(0.89; 0.55)	(0.503; 0.889)
TCLA.B6 (@IP7)	(0.283; 0.196)	(0.193; 0.29)
TCLA.D6 (@IP7)	(0.181; 0.282)	(0.295; 0.185)
TCLA.A7 (@IP7)	(0.18; 0.272)	(0.286; 0.184)
TCTH.4 (@IP8)	(0.221; 0.256)	(0.237; 0.221)
TCTH.4 (@IP1)	(0.89; 0.55)	(0.578; 0.903)

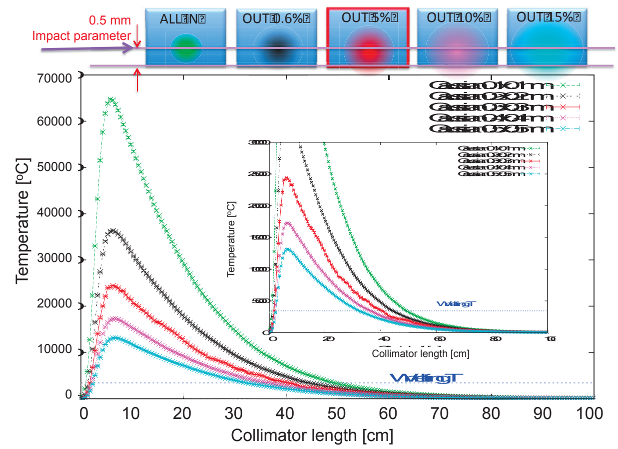

Figure 7: Temperature peaks in case of jaw-beam parallel orientation, scanning over 5 different beam sizes. In the zoomed area the temperature scale is the same as for the previous temperature graphs. Above the plot, 2D maps of the escaping protons that don't interact with the jaw due to the impact parameter chosen are shown.

CONCLUSIONS

The tungsten-based jaws used in the Phase I collimation system are exposed to high risks of damage in case of asynchronous dump. However operating with tilted jaws could mitigate the effects of such an accident. In particular, thanks to the 0.8mrad tilt of the jaw with respect to the design orbit, the melting temperature could be not reached on the TCT tungsten surface in the worst case of one bunch impact at full intensity. Indeed RMS beam sizes in these delicate locations but IP8 are above the 0.5x0.5 beam size dimension considered in this study. These promising results bring to investigate in detail more realistic scenarios [6]. In parallel, FEM analyses are on going in order to evaluate stresses on the collimator tungsten-based jaws [7,8].

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