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IMPACT OF THE LHC BEAM ABORT KICKER PREFIRE ON HIGH LUMINOSITY INSERTION AND CMS DETECTOR PERFORMANCE*

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Abstract

The effect of possible accidental beam loss in LHC on the IP5 insertion elements and CMS detector is studied via realistic Monte Carlo simulations. Such beam loss could be the consequence of an unsynchronized abort or – in worst case – an accidental prefire of one of the abort kicker modules. Simulations with the STRUCT code show that this beam losses would take place in the IP5 inner and outer triplets. MARS simulations of the hadronic and electromagnetic cascades induced in such an event indicate severe heating of the inner triplet quadrupoles. In order to protect the IP5 elements, two methods are proposed: a set of shadow collimators in the outer triplet and a prefired module compensation using a special module charged with an opposite voltage (antikicker). The remnants of the accidental beam loss entering the experimental hall have been used as input for FLUKA simulations in the CMS detector. It is shown that it is vital to take measures to reliably protect the expensive CMS tracker components.

1 INTRODUCTION

At nominal operation parameters each of the 7 TeV circulating beams of the LHC contains approximately 334 MJ of energy[1], which is enough to cause severe damage to the expensive machine and detector equipment. It must be dealt with by a reliable abort system which uses fast extraction to divert the beam to an external graphite absorber at the end of a normal fill or in case of a detected anomaly in beam behaviour. The LHC abort kicker system consists of 14 pulsed magnets having a rise time of about 3μs. Normally this system is triggered during the 3 μs abort gap in the circulating beam. An accidental prefire of one of the abort kicker modules induces coherent oscillations of the circulating bunches. As a result, the beam may not reach the absorber, being lost instead on the machine limiting apertures. With the abort system at IP6, the high-luminosity insertion at IP5 is the first limiting aperture for the counterclockwise beam, where about 10% of the misbehaved beam is lost. The detailed analysis of such a phenomenon and possible protective measures has been performed in [2, 3] for the SSC. Without protection, accidental beam loss consequences in LHC would range from superconducting magnet quenches, to overheating of some components or even total destruction of some units through their explosion. In this paper, the problem is studied–as in[4]–via realistic Monte Carlo simulations with the STRUCT[5], MARS[6] and FLUKA[7] codes.

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2 FAST ACCIDENTAL BEAM LOSS

2.1 Parameters and Assumptions

The simulations were done for a $\pm 150\mu$rad horizontal crossing angle, which is chosen for IP5. Calculations verified that a horizontal crossing is the favourable choice, since a vertical crossing would result in significantly higher accidental beam loss level. Only the worst case is investigated: closed orbit deviation in the Q2B is 4 mm, mechanical error is 0.6 mm and alignment accuracy is 1 mm. These are simulated by a bump with Δx_{max}=Δy_{max}=5.6 mm in the inner quadrupole triplet in the horizontal and vertical planes. Every bunch is affected by the abort kicker with a gradually increased strength. The counterclockwise beam direction is studied. It turns out that for the injection optics, all losses would take place at the beam cleaning insertions only.

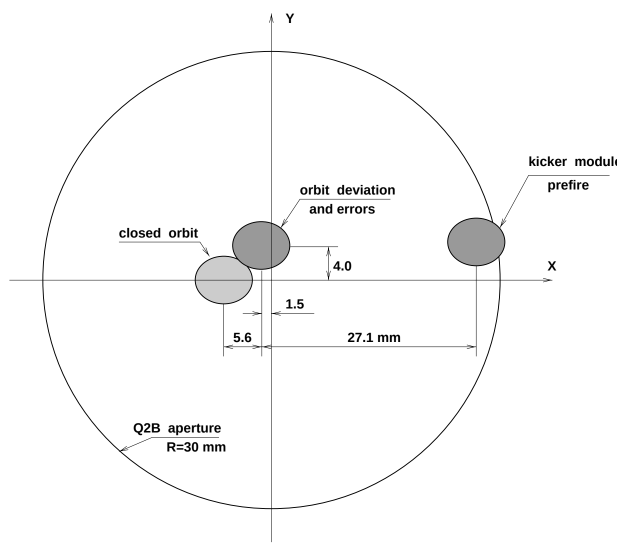

Figure 1: Beam positions in the Q2B quadrupole at the kicker module prefire with a horizontal crossing at IP5.

2.2 Kicker Module Prefire

The assumption is that one of the abort kicker modules accidentally prefires. A prefired kicker module induces coherent oscillations of the beam with an amplitude equal to 21σ of the beam at collisions. Starting from 80% of the kicker strength, the disturbed protons hit the aperture of the IP5 elements, if the kicker module prefires at collisions. The disturbed and undisturbed beam positions in the Q2B quadrupole are shown in Fig. 1. The beam is lost at the first limiting aperture–Q2B.R5 quadrupole–where β-function reaches its maximum. One module kick and 3 σ beam size for the counterclockwise direction are shown in Fig. 2 for the collision optics. Energy deposition density in the Q2B.R5 quadrupole coil reaches several kJ/g with the peak temperature rise exceeding the melting point.

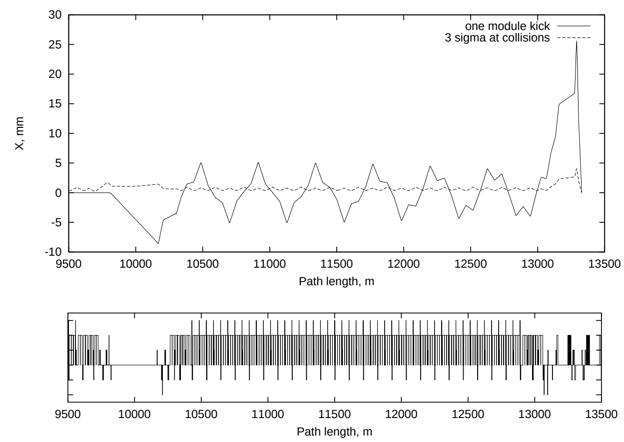

Figure 2: 1-module kick and a 3σ beam size at collisions.

2.3 *Unsynchronized Abort*

An unsynchronized abort could be the consequence of a control system or timing failure but it could also result from an immediate firing of the rest of the kicker modules in an attempt to cure a kicker prefire. At an unsynchronized abort, the kicker front does not necessarily come into the longitudinal abort gap. This causes coherent oscillations of some bunches and corresponding beam loss until the kicker reaches the needed strength. Calculated beam losses are presented in Fig. 3. Peak energy deposition in the low-β quadrupoles are lowered by about a factor of 300 compared to the prefire case. The irradiation pulse duration is 0.26 μs.

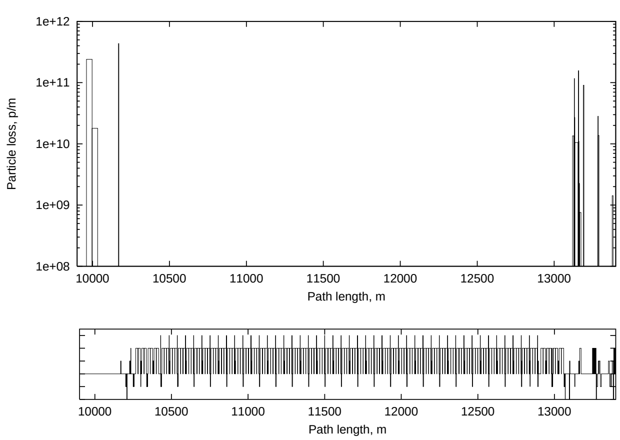

Figure 3: Beam loss at unsynchronized abort at collisions.

3 SHADOW COLLIMATORS

A possible way to protect the collider and detector components is a set of shadow collimators in IP6 or in the IP5 matching quadrupole triplet. The first location is attractive because it allows in principle to intercept most of the losses in the warm IP6 section downstream of the abort system. It assumes very tight movable jaws which have to follow the beam over the cycle. The system efficiency, jaw survivability and design have to be studied yet.

In this paper, detailed simulations have been performed for stationary collimators in the IP5 outer triplet (Fig. 4). At the top energy with low-β optics the beam can be efficiently intercepted by these shadows. The first shadow is positioned at $21\sigma_{collis}$=$10.3\sigma_{inject}$=10 mm from the beam orbit (11.8 mm from the beam pipe center). Second and third collimators are used to protect magnets from secondary particles emitted from the first shadow. The collimator configuration, materials and dimensions have been carefully optimized to provide reliable protection of the inner triplet and to ensure collimator survivability. Combined with an unsynchronized abort, such a system reduces peak energy deposition in the IP5 inner triplet quadrupoles by almost six orders of magnitude compared to the disastrous case of a 1-module prefire.

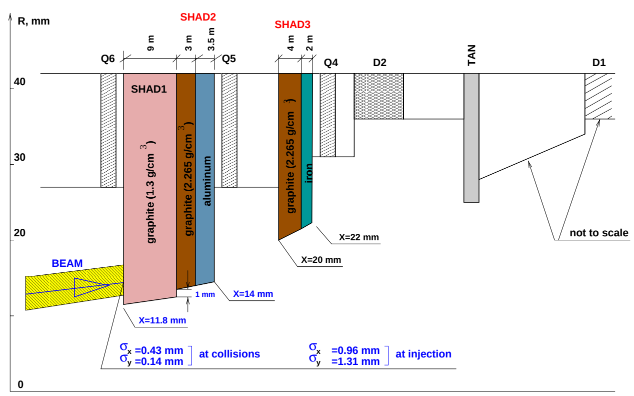

Figure 4: Shadow collimators in the IP5 outer triplet.

The IP5 shadow system alone, gives a factor of 300-1000 reduction in peak energy deposition in the low-β quadrupoles. Instantaneous peak temperature rise for all the considered cases is shown in Fig. 5 and 6 for the inner and outer triplet elements. Horizontal position of the first shadow collimator depends on the accelerator tune, closed orbit displacement at the shadow location and beam crossing scenario. This shadow at the specific horizontal position (determined by tune) protects the elements of the IP5 insertion at any accelerator tune in the range of ν=$Q_o \pm 2$.

4 ANTIKICKER

Another way proposed in [2, 3] is to compensate the prefired module by an additional module charged with an opposite voltage (antikicker). The antikicker should be fired with a delay less than 1 μs after the kicker prefire to eliminate

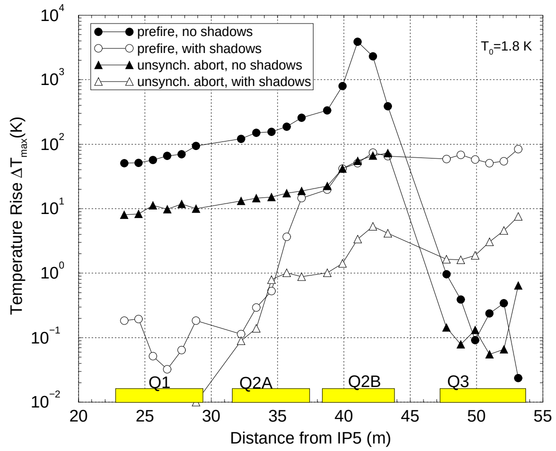

Figure 5: Peak temperature rise in the IP5 inner triplet superconducting coils.

losses in the IP5. After this, the beam can be safely aborted using the abort gap. This method seems to be rather attractive because it does not depend on the accelerator tune, closed orbit deviation, beam crossing scenario, and protects the entire accelerator from losses at kicker prefire.

5 DETECTOR PERFORMANCE

Our simulations show that even the most severe accidental beam loss (prefire) is equivalent less than 50 hours of normal operation. Thus no significant contribution from beam accidents is expected to integral damage of detectors. The main worry seems to be, however, that large instantaneous ionization over all the detector volume could cause irreversible damage by creating breakdown in some components. For the worst case (prefire), we observe a dose rate of 20 MGy/s at the inner pixels (R=4.3 cm) which is 9 orders of magnitude above the normal conditions. At the MSGC (R=75 cm), which are likely to be the most sensitive detectors with respect to such accidents, the corresponding worst case dose rate is 6 kGy/s which still is more than 7 orders of magnitude above nominal. Although, the unsynchronized abort significantly decreases the total dose, it lowers the dose rate during the pulse by less than a factor of 2. The shadow collimators reduce the dose rate at the inner pixels by a factor of 10^4, but by only a factor of 40 at the MSGC detectors. This 'best protected' dose of 150 Gy/s at the MSGC is still a factor of 10^6 above nominal conditions and there is a fear that it could have severe consequences on the rather sensitive detectors. This observation has the more general implication that any fast losses close to IP5 could lead to extremely high dose rates in the detectors. While all possible measures to mitigate such losses close to IP5 should be taken, detectors still should be prepared to survive fast pulses with several orders of magnitudes higher particle rates than in nominal conditions.

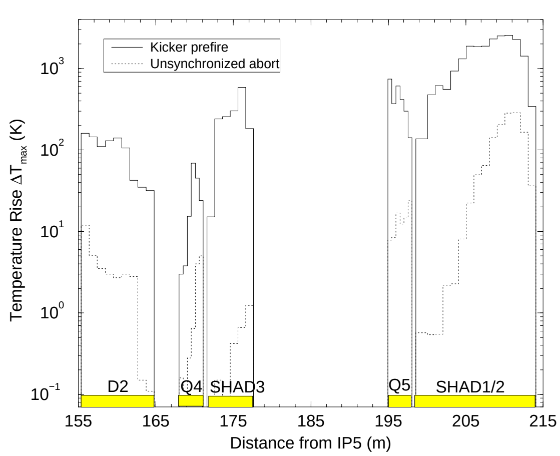

Figure 6: Peak temperature rise in the IP5 outer triplet.

6 CONCLUSION

Abort kicker prefire, which happened twice at Tevatron over a 20 month collider run and which would be disastrous at LHC parameters, should be suppressed by the more modern LHC beam abort system. Unsynchronized abort in combination with the shadow collimators in IP5 or IP6 are sufficient to protect the LHC machine against irreversible consequences of the fast beam loss. The proposed antikicker scheme looks rather attractive, but even with this system, the shadow collimators should be installed as a last line of defense. A major concern might be that the dose and particle rates (but not integrated values) in experiments are very high in all cases where a fast beam loss takes place in the interaction region, no matter if on magnets or protective elements.

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