LONGITUDINAL LOSS DISTRIBUTION ALONG THE LHC

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Abstract

For the design and calibration of the LHC beam loss monitoring (BLM) system it is essential to have good predictions of the expected longitudinal loss distributions. For this purpose, a complete and detailed aperture model of the LHC arc and dispersion suppressor (DS) was compiled and applied to the tracking of halo particles originating from the betatron cleaning insertion for proton and ion beams. The positions of all beam pipe bellows are included in the model as well. Therefore, it is possible to investigate the loss pattern due to misalignment effects, in addition to steady beam losses (beam halo, beam-beam and beam-rest gas interactions) and orbit errors. For proton beams the model was applied within the tracking code MAD-X [1]. Resulting loss maps are presented in this paper. The simulation for the ion beam halo is presented in [8]. The model served to identify critical loss positions. The implication of both simulations for the BLM design are discussed.

INTRODUCTION

At the Large Hadron Collider (LHC) a beam loss monitoring system will be installed in the arcs, dispersion suppressors and the straight sections for a continuous surveillance of particle losses. These beam particles deposit their energy in the machine components including the super-conducting magnets. The resulting temperature increase could lead to magnet quenches or damages as well as the destruction of other machine components. One of the purposes of the BLM system is to prevent quenches and damages by triggering a beam dump via the beam interlock system, whenever the detected beam losses are above defined threshold values. At the position of super-conducting magnets the thresholds are calculated according to their respective quench levels. Other functions of the BLM system include the identification of the loss mechanisms by measuring the loss pattern and beam diagnostic during setup and machine studies. A special set of detectors will be used for the setup and control of the collimators. A full description of the design of the BLM system for the LHC can be found in these proceedings [2].

Quench Levels

The quench and damage levels of the super-conducting magnet coils expressed in protons per meter per second lost at the beam screen inside the magnet strongly depend on the beam energy and on the duration of the loss. The quench levels decrease by two to three orders of magnitude from injection (450 GeV) to collision energy (7 TeV). The different mechanisms involved in carrying away the locally deposited heat in the coils act on very different time scales. This leads to quench level reductions of three to four orders of magnitude for long loss durations of 10s and more as compared to losses in the order of 1 LHC turn (89 μs). A detailed description of the different processes of heat flow as well as the calculation of the corresponding quench levels can be found in [3] and [4].

Detector Design

Cylindrically shaped ionization chambers will be used as beam loss monitors. They will be filled with N_2 or Ar at one to two bar pressure. The diameter of the chambers is 9 cm and they are 50 to 150 cm long. Inside there is either a stack of parallel plate electrodes or a coaxial electrode design. The bias voltage will be 1500 V. These chambers will be mounted on the outside of the magnet cryostat in the plane of the beam pipes, where the signal is maximum. The beam particles lost at the beam screen inside the magnets form a strongly forward directed particle shower through the magnet coils and the cryostat. The BLM detectors sit in the transverse tail of this shower where the average particle energy is below the energy of minimum ionization.

Calibration and Dimensioning of the BLM System

The signal from the BLM detectors has to be related to the temperature inside the super-conducting coils in order to protect them from overheating. This is done by combining two simulations. One links the beam particles loss rate per meter to the temperature increase in the coil (as described above). The second simulation describes the signal in the ionization chamber due to secondary shower particles caused by lost beam particles. Results of this simulation for the arc and the dispersion suppressor have already been presented [6] and [5]. These two simulations together with the simulations of longitudinal loss distributions determine the positioning of the loss monitors, the longitudinal distance one detector has to cover to achieve the required resolution as well as all calibration factors for the individual detectors.

LOSS LOCATIONS IN THE DS AND ARC

Primary and secondary collimators in the momentum and betatron cleaning insertions define the aperture limitations in the ring. The primary and most of the secondary halo of the beam is absorbed by the collimation system. Escaping from these collimators is the tertiary halo and a fraction of the secondary halo which is then lost along the LHC ring.

The design and positioning of the BLM system depends critically on the predictions of the longitudinal loss distribution. Previously, proton losses have been assumed to mainly take place at the following positions: Firstly, at the magnet interconnect positions before and after the quadrupole misalignment (coupled with a large beta function) can cause losses.

The second area of concern is in the middle (or distributed over the first half) of the quadrupole, where losses occur due to the maximum beta function. Accordingly, it is foreseen to place 6 BLM detectors on and around each quadrupole to detect these losses [6]. A coverage of the dipole magnets (apart from a certain number of mobile detectors) is not included in the current BLM design.

Proton loss processes can be divided into normal losses due to beam dynamics effects or operational conditions and the abnormal losses which result from equipment failure. Simulations for the main loss scenarios are needed to validate or possibly improve the BLM design.

APERTURE MODEL

In order to yield a sufficient precision in the simulation of the secondary particle fluence and hence the signal in the detectors, the precision and granularity of the aperture model has to stay below the detector length of 0.5 m. From considerations of the maximum possible closed orbit excursion in the arc it is assumed that lost beam particles hit the beam screen under an angle of typically 0.25 mrad. Under this angle of incidence a difference of 1 mm in beam aperture will lead to a displacement of the impact point by 4 m. The longitudinal granularity of the model should be around 20 cm. Therefore the transverse precision should be as high as possible to achieve the desired longitudinal precision.

The proton beam loss simulations were performed with MAD-X, the LHC sequence V6.4 and the corresponding collimator layout. In a first analysis a longitudinal granularity of 1 m was used. At a second step some regions were zoomed in closer with a variable granularity. The model itself describes all changes in aperture, so that the precision can be chosen according to the needs of the simulation. In particular it comprises all vacuum chamber bellows as points of possible misalignment (offset or angle). The aperture model covers the standard LHC arc and dispersion suppressor including the region after the quadrupole magnet Q6 right of the betatron cleaning insertion IP7. For all magnetic elements the aperture from MAD-X V6.4 was used.

RESULTS

The loss scenario presented is the tertiary and secondary halo escaping from the betatron cleaning insertion (collimation layout of optics version 6.4) with an ideal machine, no orbit or alignment error. The halo of the proton beam 1 at injection energy (450 GeV) was tracked from the last collimator through the dispersion suppressor and the arc right of IP7. The number of particles lost per meter per beam particle hitting the primary collimator is calculated.

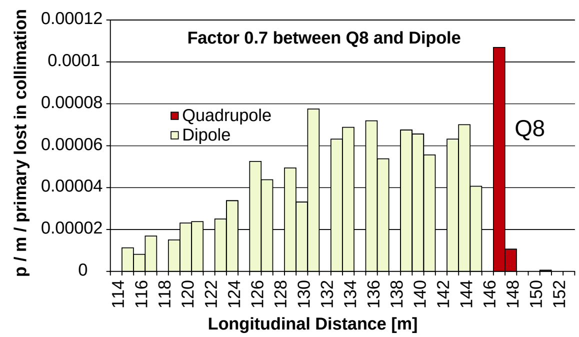

Figure 1: Typical loss distribution in the DS, bin size is 1 m. Losses are concentrated in the first two meters (the length of Q8 is 6 m).

The result confirms the BLM system design assumption that losses occur mainly at the quadrupoles. Nevertheless, losses in the dipoles of the dispersion suppressor and the beginning of the arc are not negligible, see fig. 1. Within any of those dipoles the losses follow the same pattern. They increase over the first half of the dipole and stay approximately constant over the second half. They are apparently caused by off momentum halo particles. Dipoles not being surveyed by their own monitors rely on the surveillance of the downstream quadrupoles. For this protection mechanism to be effective dipole losses have to stay safely below quadrupole losses. The highest ratio of dipole loss to quadrupole loss per meter seen was 0.7 (dipole before Q8 as compared to Q8) in the dispersion section. This value should still guarantee the protection of the dipole, but is high enough to raise concerns. Further simulations are needed.

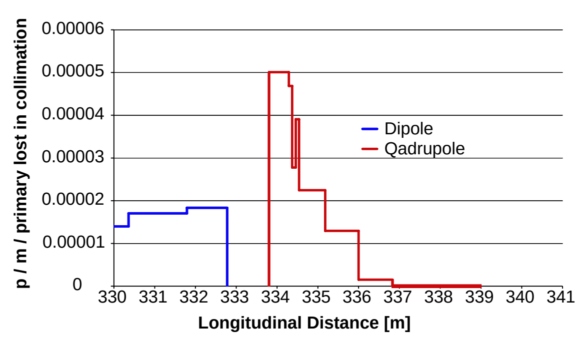

Figure 2: First quadrupole in the arc (Q12) with higher resolution and variable bin size.

Contrary to the design assumption that the losses would peak in the middle of the quadrupoles or be distributed evenly over its first half, the simulation yields losses strongly peaked in the first meter of the quadrupoles for the dispersion suppressor and the arc alike, see fig. 2 and 3. In the arcs, the middle part of the quadrupoles is mostly free of losses. However, this distribution of losses is still

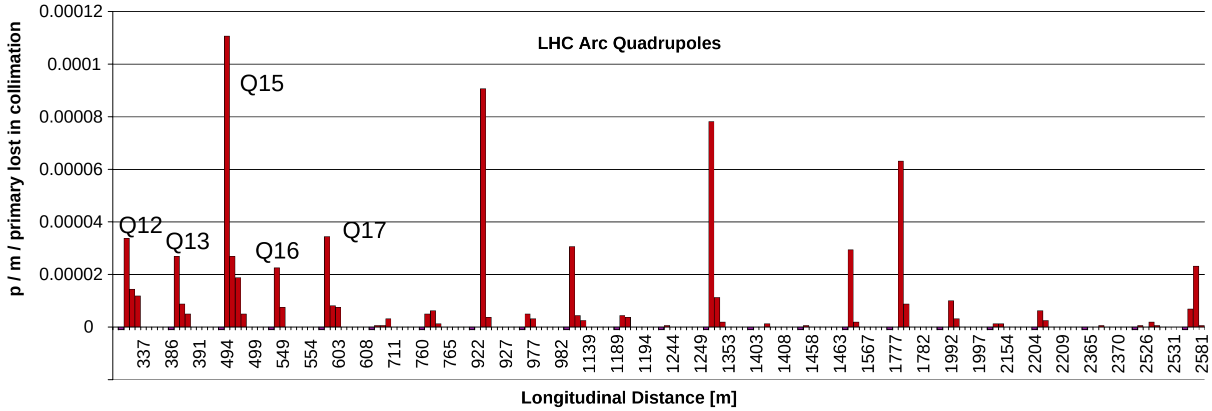

Figure 3: Quadrupoles in the arc where losses occur. x-axis not to scale. No losses outside of quadrupoles.

compatible with the positioning foreseen for the BLM detectors. These detectors will monitor misalignment losses between the magnets and will also catch losses at the beginning of the quadrupoles.

The interconnect regions in the arc are free of losses (fig. 2). The apertures in these regions are typically a few mm larger than in the magnets and all interconnect regions are between 0.5 and 0.9 m long. This enlarged aperture prevents losses at the interconnect regions and concentrates them at the beginning of the magnets instead. The local loss peaks at the beginning of the quadrupoles, however, can not be explained by the 0.9 m long loss free distance before the quadrupole.

Ions

The same aperture model has been employed in simulations covering the nominal LHC ion beam at collision energy (7 TeV). This work is presented in [8]. It revealed that the local heat load in dispersion suppressor dipoles exceeds the quench levels by a factor of two. New ways for protecting the magnets from the varieties of ion species exiting the collimation region have to be found. The highest peaks occurred in the dipole magnets between Q10 and Q11. Additional loss monitors will be installed at peak loss positions of these dipoles.

SUMMARY AND OUTLOOK

A complete aperture model for one section of the LHC was compiled. It allowed for the first time the production of realistic longitudinal loss maps. The example of the betatron collimation halo losses in the following dispersion suppressor and arc is presented. The resulting proton loss map is compatible with the envisaged positioning of the BLM detectors. The corresponding loss map for ions showed losses above the quench level in the dispersion suppressor for nominal running conditions and lead to the request of the installation of additional BLMs at positions not previously foreseen.

Recently a new aperture model for the current optics version 6.5 and the final collimator layout has been compiled. It comprises the whole LHC ring including all long straight sections. Details are described in [9]. It will be used in the near future to produce loss maps for dominant loss scenarios. The loss maps will allow us to validate and finalize the positioning of the beam loss monitors along the LHC.

ACKNOWLEDGMENT

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