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CONCEPTUAL DESIGN OF THE LHC BEAM DUMPING PROTECTION ELEMENTS TCDS AND TCDQ

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The Beam Dumping System for the Large Hadron Collider, presently under construction at CERN, consists, per ring, of a set of horizontally deflecting extraction kicker magnets, vertically deflecting steel septa, dilution kickers and finally, a couple of hundred metres further downstream, an absorber block. A fixed diluter (TCDS) will protect the septa in the event of a beam dump that is not synchronised with the particle free gap or a spontaneous firing of the extraction kickers which will cause the beam to sweep over the septum. Another, mobile, diluter block (TCDQ) will protect the superconducting quadrupole immediate downstream of the extraction as well as the arc at injection energy and the triplet aperture at top energy from bunches with small impact parameters. This paper describes the conceptual design of the protection elements.

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The Beam Dumping System for the Large Hadron Collider, presently under construction at CERN, consists, per ring, of a set of horizontally deflecting extraction kicker magnets, vertically deflecting steel septa, dilution kickers and finally, a couple of hundred metres further downstream, an absorber block. A fixed diluter (TCDS) will protect the septa in the event of a beam dump that is not synchronised with the particle free gap or a spontaneous firing of the extraction kickers which will cause the beam to sweep over the septum. Another, mobile, diluter block (TCDQ) will protect the superconducting quadrupole immediate downstream of the extraction as well as the arc at injection energy and the triplet aperture at top energy from bunches with small impact parameters. This paper describes the conceptual design of the protection elements.

INTRODUCTION

The LHC beam dumping system (LBDS) includes an extraction kicker magnet system (MKD), which deflects the beam horizontally into to a set of Lambertson septum magnets (MSD). The MSD deflect the beam vertically out of the LHC machine towards the dump absorber block (TDE). A fixed diluter block (TCDS) [1] will be installed immediately upstream of the MSD magnets in order to protect these from destruction in the event of an asynchronous firing of the MKD which would cause the beam to sweep over the septa. Part of the swept beam could also impact on the Q4 magnets or on other aperture limits in the LHC. In order to protect these elements against damage, a mobile diluter block (TCDQ) [2] will be installed immediately upstream of the Q4 magnets. Fig. 1 shows a schematic presentation of the layout and function of the TCDS and TCDQ diluter elements.

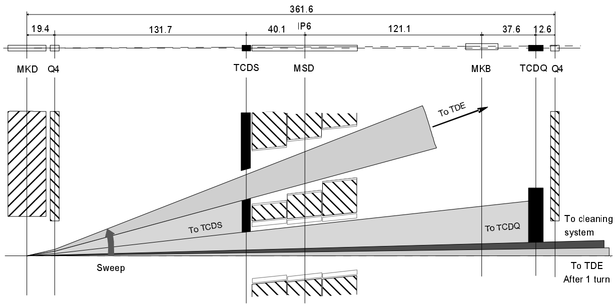

Figure 1: Schematic and functional layout of TCDS and TCDQ diluter elements.

The TCDQ also has to protect the LHC arc aperture at 450 GeV, and the low-beta triplet aperture at 7TeV, from swept bunches. In addition, the TCDQ serves to reduce the number of bunches deposited on the collimator jaws in the event of an asynchronous dump.

OPERATING CONDITIONS

The main beam parameters for ultimate LHC proton intensity are given in Table 1. Each circulating 7 TeV proton beam will be composed of 2808 bunches containing $1.67 \cdot 10^{11}$ protons, containing 525 MJ of energy [3].

Table 1: Main beam and extraction parameters for TCDS-TCDQ performance at ultimate LHC proton intensity.

Proton energy	7	TeV
Stored energy per beam	525	MJ
Number of bunches	2808	
Bunch spacing	24.95	ns
Protons per bunch	$1.67 \cdot 10^{11}$	
Extraction rise time	2.76	µs
Retriggering delay	1.2	µs
Intercepted bunches	27	

TCDS

Performance Objectives

The performance objective of the TCDS collimator, in the event of an unsynchronised beam abort of the MKD, is to prevent damage to the downstream MSD septa and MSD vacuum chambers, by diluting about 9.4 MJ of energy, 1.8% of the LHC beam energy, assuming a pessimistic 1.2 µs MKD retriggering delay after a single kicker module pre-fire [4].

Conceptual Design

The main constraints taken into account for the conceptual design are the maximum allowed temperatures of the MSD and TCDS components after beam impact. Any of the layers of the MSD vacuum chambers should not exceed 300°C and a maximum temperature of only 100°C in the MSD is allowed, above which the MSD steel would loose its magnetic properties. Several [5] scenarios have been studied for the TCDS and a 6 meter-long configuration gives optimal results.

Simulations of an all-graphite diluter showed high energy densities and associated high peak temperatures (>1100°C) in the graphite. An optimised TCDS core design was chosen, consisting of blocks of graphite, C-C composite, aluminium nitride and titanium, giving acceptable peak temperatures with sufficient beam dilution.

A study of the thermal behaviour of the TCDS [6] resulted in a change of the longitudinal distribution of the carbon in the TCDS core. Furthermore, since the titanium section was not very loaded, the aluminium nitride section was shortened, the titanium section moved upstream and a stainless steel section was added, resulting in the following TCDS baseline design:

- 0.5m Graphite (density 1.77 g/cm^3)
- 0.5m C-C composite (density 1.9 g/cm^3)
- 2.0m C-C composite (density 1.4 g/cm^3)
- 0.5m C-C composite (density 1.9 g/cm^3)
- 1.0m Graphite (density 1.77 g/cm^3)
- 0.75m Aluminium nitride (density 3.31 g/cm^3)
- 0.5m Titanium (density 4.5 g/cm^3)
- 0.25m Stainless Steel (density 7.8 g/cm^3)

In order to optimise the nominal aperture requirements while maximising the protected area of the MSD magnets, the ideal TCDS configuration is wedge-shaped and positioned as close as possible to the circulating beam axis [7]. With mechanical and alignment tolerances of ±1 mm this results in a wedge shape of 23.6 mm to 24.1 mm, with a minimal height of 40 mm, positioned at 16.3 mm (upstream) and 17.2 mm (downstream) from the beam axis, see Fig. 2..

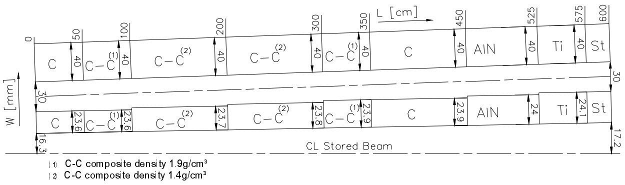

Figure 2: Schematical presentation of dimensions and position of TCDS diluter blocks.

In order to protect the MSD magnets in the event of an over-kicked beam, an outer parallel row of diluter blocks are included (the so-called 2nd jaw), giving a clear aperture of 30 mm.

To avoid impedance problems and charging of the insulating aluminium nitride segment, a Cu coating of 5 µm thickness will be applied. The estimated [8] power deposited by the circulating beam in the TCDS will be about 30 W/m, or 185 W in total.

Radiological and Environmental Issues

The TCDS will be subject to irradiation by protons or heavy ions during unsynchronised beam dumps, and also from spurious particles in the beam abort gap. The estimated remnant radiation dose rates at 30 cm from the beam axis have been calculated [9] for 1 failure and 3 different cooling times. (The number of protons hitting the TCDS in this case was $4.4{\cdot}10^{12}$, 40 bunches x 1.1 10^{11}). As can be seen in Fig. 3, the activated vacuum vessel dominates the doses at large cooling times and intervention after a few hours cooling would require detailed dose planning.

TCDQ

Performance Objectives

The TCDQ should prevent damage to the downstream Q4 superconducting magnets, of which the damage limit is 87 J/cm^3 [10], by intercepting 27 proton bunches, at 7 TeV and at ultimate intensity of $1.67{\cdot}10^{11}$ protons per bunch. It should also attenuate sufficiently the primary beam at low impact parameters, so as to avoid damage to elements far downstream in the LHC.

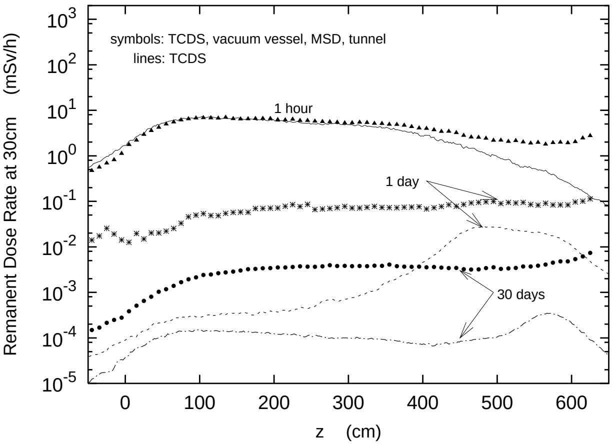

Figure 3: TCDS remnant dose rate for 3 different cooling times after 1 failure at 30cm from the beam axis.

At 450 GeV the LHC arc has a transverse aperture of about 7.5σ, which means that the TCDQ will need to have a slightly smaller transverse setting, of the order of 7σ, or ~15 mm, depending on the orbit precision and the object tolerance.

The low-beta triplets have a transverse aperture of about 10 σ for squeezed optics, and so during collision the TCDQ must be located sufficiently inside this setting to ensure protection.

During regular operation the TCDQ may intercept secondary halo particles and, during a regular beam abort, the TCDQ system will intercept any particles which are in the abort gap. These loads should not produce a quench in Q4.

During a regular abort, the maximum energy deposition in the superconducting coils should not exceed the quench limit for the maximum abort gap population, which is estimated to be $1.4{\cdot}10^{-4}$ of the ultimate beam intensity, or $0.3{\cdot}10^{7}$ p+/m.

The tight settings of the TCDQ mean that the system will intercept a significant continues beam load from the secondary halo. The maximum power deposition in the superconducting coils should not exceed the DC quench limit, for the maximum secondary halo load on the TCDQ.

Conceptual Design

Considering the ultimate LHC beam intensity and the total number of bunches in case of a MKD sweep, several scenarios have been studied [11] for the configuration of the TCDQ and a 6.0 m single-sided graphite absorber block (density 1.77 g/cm^3), positioned at ~12.5 meters in front of the Q4 magnet, followed by a 2.1 m iron mask (density 7.87 g/cm^3) positioned directly in front of the Q4 magnet has shown to give the most satisfying results. In this configuration, impact on the TCDQ results in a peak temperature of <550°C in the graphite, as illustrated in Fig. 4, and <45°C in the iron mask.

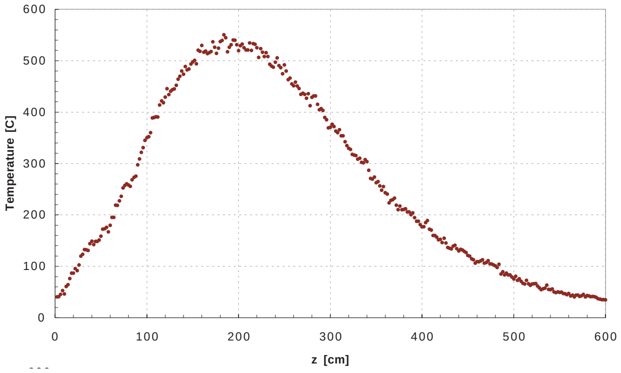

Figure 4: Temperature distribution in the TCDQ core for 27 bunches at ultimate LHC beam intensity.

The estimated power deposited by the circulating beam in the TCDQ [8] will be about 75W/m, or 450W in total and a cooling system will be required to evacuate this heat. To avoid impedance problems and reduce charging by the beam, a Cu coating of 5 µm thickness will to be applied to the graphite part.

To precisely define the position of the TCDQ with respect to the beam, and to intercept the secondary halo load, a short two-sided element based on the LHC secondary collimator design is proposed in addition to the single-sided TCDQ, set slightly closer to the beam than the TCDQ.

BEAM INSTRUMENTATION

A schematic representation of the required beam instrumentation in the IP6 region is given in Fig. 5. Beam position monitors (BPM) are placed to monitor the position of the extracted and circulating beams [12]. For the extracted beam, a first BPM will be installed downstream of the TCDS to adjust the steering (MKD kick strength). These BPMs will measure the position for both horizontal and vertical planes. In addition, loss monitors (BLMs) must be installed around the TCDS diluter blocks.

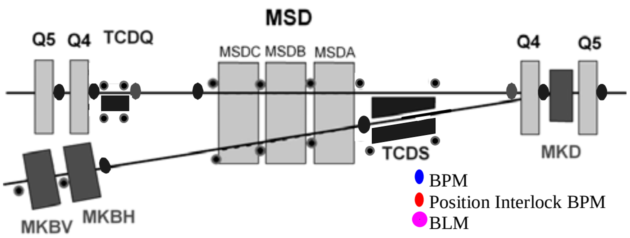

Figure 5: Schematic layout of the LHC Beam Dump line instrumentation

Further BPMs shall be placed to monitor the position of the circulating beam at the entrance and exit of the TCDQ and, in addition, BLMs are installed around the TCDQ collimator blocks.

Both TCDS and TCDQ will be equipped with temperature sensors to monitor the temperature profile of the collimator blocks. Furthermore, flow-meters and temperature gauges shall be installed to monitor the cooling system.

SUMMARY

A 6 m long fixed diluter block (TCDS), consisting of blocks of graphite, C-C composite, aluminium nitride, titanium and stainless steel will be installed immediately upstream of the MSD magnets in order to protect these from destruction in the event of an asynchronous firing of the MKD kickers. For the same reason and to attenuate the primary beam at low impact parameters, a 6 m long mobile graphite diluter block (TCDQ), in combination with a 1.2 m long iron mask, will be installed front of the Q4 magnet.

AKNOWLEDGMENT

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