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Functional Specification

TCDS DILUTER TO PROTECT MSD SEPTUM MAGNETS

Abstract

The LHC beam dumping system (LBDS) consists of a set of fast-pulsed kicker magnets (MKD), horizontally deflecting the beam to 15 modules of 3 different types of Lambertson septum magnet (MSD), which deflect the beam vertically to the TDE dump absorber block. A fixed diluter block (TCDS) will be installed immediately upstream of the MSD magnets in order to protect these from destruction in the event of an asynchronous firing of MKD kickers which would cause the beam to sweep over the septum. The TCDS is not part of the collimation system.

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History of Changes

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	2003-07-02	All	Submission for check
0.2	2003-07-23	All	Submission for approval
1.0	2003-11-20	All	Released version
1.1	2004-06-23	5	Vacuum requirements for the LHC collimators, paragraph 4.2.
		6, 7, 8	Modified Configuration of TCDS diluter blocks, paragraph 5.1, 5.2, 5.3, 5.4
		11	Dimension of vacuum chambers for circulating beams in the MSD septa, paragraph 6.3.
		12	Reference list updated
	2004-07-09	All	New released version
	2004-10-15	4, 11	Update of TCDS length and position, reference 16 added.
		7	Remark on C-C composite density.
1.2	2004-10-20	All	Released version
1.3	2006-03-30	6	Modified Configuration of TCDS diluter blocks, paragraph 5.1.
		7	New Figure 2
		11	New Figure 5
	2006-04-05	All	Submission for approval

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1. SCOPE

This engineering specification is focussed on the TCDS (Target Collimator Dump Septum) absorber block. The performance objectives and operating conditions in relation to the LHC ultimate beam intensity and energy will be presented. We describe the functional requirements and technological constraints for the conceptual design and report on the manufacture, installation and interface requirements of the mechanical design. Finally a summary of all the specification data will be given in Appendix 1.

2. INTRODUCTION

The LHC beam dumping system consists of a set of fast-pulsed kicker magnets (MKD), horizontally deflecting the beam to a Lambertson septum magnet (MSD), which deflects the beam vertically, via a set of dilution kickers (MKB), to the TDE dump absorber block. A fixed collimator block (TCDS) shall be installed immediately upstream of the MSD magnets in order to protect them from destruction in the event of an asynchronous firing of MKD kickers which would cause the beam to sweep over the septum walls. Figure 1 shows a schematic presentation of the layout and function of the TCDS absorber system.

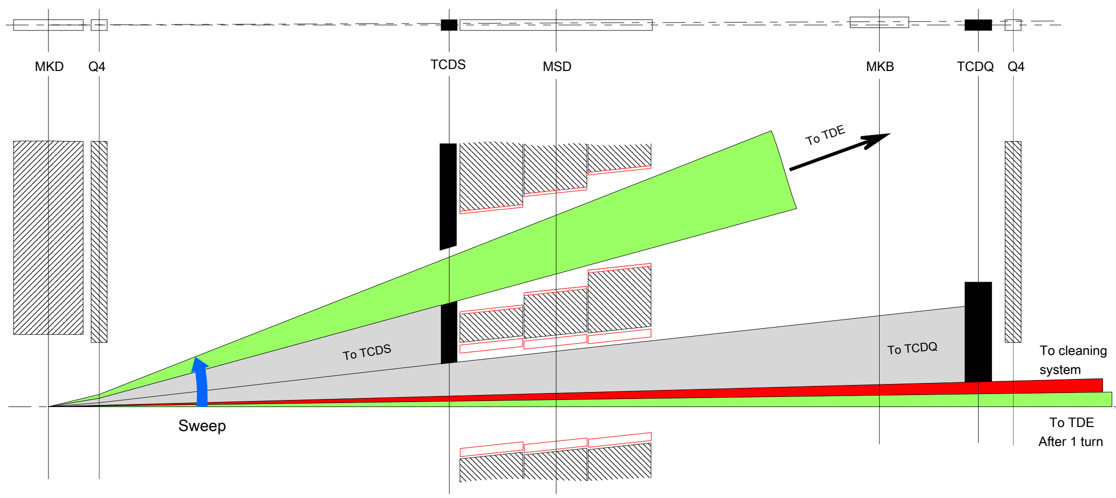

Figure 1 - Schematic and functional layout of TCDS absorber system.

3. OPERATION CONDITIONS

3.1 LHC BEAM INTENSITY AND ENERGY

The beam parameters for extraction during the nominal LHC operation in proton mode are given in Appendix 1. Both nominal circulating 7 TeV proton beams of the LHC will be composed of 2808 bunches, one every 24.95 ns, each containing 1.1 10^{11} protons at nominal intensity and 1.67 10^{11} protons at ultimate intensity. Each beam contains a nominal energy of 350 MJ [1].

The performance objective of the TCDS collimator, in the event of an unsynchronised beam abort of the MKD kickers at nominal intensity and 1.2 μs retriggering delay, is to dilute about 6.1 MJ of energy, about 1.7% of the energy contained in the LHC beam [2], preventing damage to the downstream MSD septum and MSD vacuum chamber.

3.2 EXTRACTION PARAMETERS

For the calculation of the energy deposition in the TCDS, every bunch is deflected proportionally to the kicker strength. The kicker waveform is assumed to consist of a linear ramp with a rise time of 2.76 μs and a bunch separation time of 25ns. The distance between bunch hits is calculated from the extreme orbit trajectories at the TCDS position, the dimensions and position of the TCDS in the IP6 line, the kicker strength and the above mentioned kicker parameters.

4. DESIGN REQUIREMENTS AND CONSTRAINTS

4.1 MATERIALS

The choice of all materials for the mechanical design must fulfil the constraints of thermal, mechanical, impedance, vacuum, radiological and environmental specifications described below.

4.2 VACUUM SYSTEM

The design of the beam vacuum must be compatible with an ultra high vacuum system as described in the functional specification of room temperature beam vacuum system for the LHC Long Straight Sections [3] and vacuum Requirements for the LHC Collimators [4].

The equipment is to operate at a nominal pressure of $<10^{-8}$ Pa and tested to have no measurable leaks with a calibrated leak detector with a sensitivity of $1\cdot10^{-11}$ Pa.m^3/s.

To ensure vacuum stability, the vacuum system and TCDS components must be compatible with an *in-situ* bake-out to at least 250°C for 24 hours.

4.3 IMPEDANCE

The vacuum system must have a low electrical resistivity in order to have low transverse machine impedance. The surface resistance R_s of the material used for the beam shielding (see section 6.3) and absorber materials surrounding the LHC circulating beam should be smaller than $3.906\ 10^{-11}\bullet d^3\ \Omega$, where d (mm) is the chamber inner diameter [3]. A good electrical contact between the absorber blocks shall be envisaged. The surface resistance of a vacuum chamber depends on its resistivity ρ, and thickness t, according to $R_s = \rho/t$ [5].

4.4 APERTURE AND POSITIONING

The apertures of the MSD septa and TCDS diluter are critical for the circulating and extracted beams and the calculations are described in [6] presenting the TCDS element position and aperture limits as shown in Table 1.

The TCDS is positioned as close as possible to the circulating beam axis giving maximum protection to the MSD vacuum chamber, yet allowing the nominal aperture requirements. Assuming mechanical and alignment tolerances of ±1mm, the nominal TCDS position from the stored beam axis is set to 16.3mm upstream and 17.2mm downstream. In order to offer sufficient shielding to the chamber of the extracted beam at this position, the position of the TCDS outside edge at the upstream end is determined to be 39.86mm and 41.29mm at the downstream end. This results in a TCDS width fixed at 23.6mm and 24.1mm for the upstream and downstream ends respectively.

	Position [m]	X (Inside) [mm]	X (Outside) [mm]
Nominal Physical Element Position			
TCDS Upstream	165.10	16.30	39.86
TCDS Downstream	171.10	17.23	41.29
Clear Aperture Limits (assuming a total of ±1mm tolerance)			
TCDS Upstream	165.10	15.30	40.86
TCDS Downstream	171.10	16.23	42.29

Table 1 - Nominal physical element position and clear aperture limits of TCDS diluter.

5. CONCEPTUAL DESIGN

5.1 CONFIGURATION

Besides the operation conditions and extraction parameters described in paragraph 3, the main constraints to take into account for the conceptual design are the maximum allowed temperatures of the TCDS components after impact of the beam. The protection of the TCDS shall be such that the temperature in any of the layers of the MSD vacuum chambers should not exceed 300°C and only a maximum temperature of 100°C in the MSD is reached, above which the MSD steel would loose its magnetic properties. The main values are presented in Appendix 1.

Considering the ultimate LHC beam intensity and the total number of bunches in case of a MKD sweep, several [7] scenarios have been studied for the configuration of the TCDS. Following the results of two [8, 9] studies on the thermal behaviour of the TCDS, the modified baseline solution was chosen to be as follows:

- 0.5m Graphite (density 1.77 g/cm3)
- 0.5m C-C composite (density > 1.75 g/cm3)
- 2.0m C-C composite (density 1.4 g/cm3)
- 1.5m C-C composite (density > 1.75 g/cm3)
- 1.0m Graphite (density 1.77 g/cm3)
- 0.5m Titanium (density 4.5 g/cm3)

Impact on an all graphite absorber would result in high energy densities, thus relative high peak temperatures (>1100°C) in the graphite. Furthermore, the rate of temperature increase will result in high stress values. Therefore the 2nd and 3rd meter is composed of a lower density C-C composite followed by another 1.5m of high density C-C composite, resulting in a peak temperature of <800°C in both the graphite and the C-C composite and acceptable stress limits. In order to keep the temperature in the MSD lower than 100°C, the final part of the TCDS is composed of 50cm titanium resulting in temperatures around 400°C for the titanium part, giving high stresses, but we have to consider that titanium alloys are ductile materials and hence may yield to bear the thermal stress but not necessarily break.

In order to avoid impedance problems and charging of the material by the beam, a Cu coating of a few microns thickness has to be applied to the all graphite and C-C composite part.

5.2 DIMENSIONS

In order to optimise the aperture for the extracted beam yet to maximise the protected area of the MSD magnets, the ideal TCDS configuration is wedge-shaped (see section 4.4). Since a perfect wedge-shape would imply manufacture, assembly and alignment difficulties with associated higher costs, an approximate configuration with increasing thickness of the absorber blocks, as shown in Figure 2, is proposed.

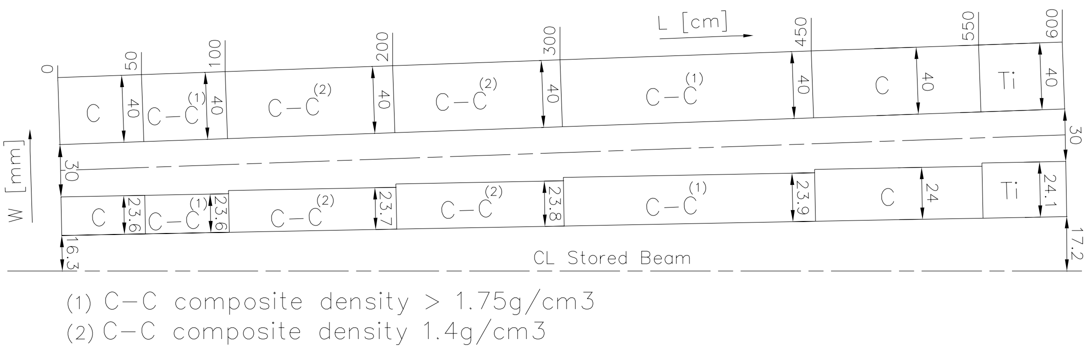

Figure 2 - Dimensions and position of TCDS diluter blocks.

In order to protect the MSD magnets in the event of extraction of the particles to the TDE after 1 turn (see Figure 1) a parallel row of diluter blocks, so-called 2nd jaws, giving a clear aperture of 30mm, are envisaged.

5.3 THERMO MECHANICAL STRESSES AND DILATATION

The subject of thermal mechanical stresses is treated in a separate technical specification for study of the thermal behaviour of the TCDS absorber block [10] and the results are published in [8]. Nevertheless, the design of the TCDS system must take into account the estimated thermal expansion of the TCDS absorber elements due to bake-out and beam impact as shown in Table 2.

Material	Coefficient α [K-1]	**Impact** [°C]	Δh [mm]	Δw [mm]	ΔL [mm]	**Bake-out** [°C]	Δh [mm]	Δw [mm]	ΔL [mm]
Graphite	2-3.8 x 1E-6	80	0.02	0.01	0.2	250	0.07	0.02	0.9
C-C Composite	0.5-1.8 x 1E-6	190	0.02	0.01	0.6	250	0.03	0.01	0.8
Graphite	2-3.8 x 1E-6	185	0.05	0.01	0.9	250	0.07	0.02	1.3
Aluminium Nitride	4.4-5.3 x 1E-6	130	0.05	0.01	0.6	250	0.10	0.03	1.2
Titanium	8-10 x 1E-6	50	0.02	0.01	0.2	250	0.18	0.05	1.2
Stainless Steel	1.5-2 x 1E-6	50	0.04	0.01	0.1	250	0.31	0.09	1.0

Table 2 - Estimated thermal expansion due to bake-out and beam impact at ultimate intensity.

5.4 COOLING REQUIREMENTS

The estimated [11] power deposited by the circulating beam in the TCDS will be about 40W/m, or ~260W in total. In order to allow for sufficient margin, a cooling system with a capacity of about 1000W will be needed.

5.5 RADIOLOGICAL AND ENVIRONMENTAL ISSUES

The system will be subject to irradiation by protons or heavy ions due to losses arising from secondary particles or p-p collisions and scattering from the collimator. The estimated remanent radiation dose rates at 30cm from the beam axis have been calculated [12] for 1 failure and 3 cooling times (the number of protons hitting the TCDS in this case was $4.4\cdot10^{12}$, 40 bunches x 1.1 10^{11}). The result is shown in Figure 3, for each cooling time the dose rates are given for the TCDS alone (lines) and for a simulation which includes the vacuum vessel, the downstream magnet and the tunnel wall. As can be seen, in the latter case the activated vacuum vessel dominates the doses at large cooling times. An intervention after a few hours cooling would therefore require detailed dose planning as dose rates are within a few mSv/h. Later interventions (>1day cooling) can possibly be performed with less precautions, depending on the duration and other related factors (time for passage to reach the location, number of people, etc.). Figure 4 shows the specific and total activity for the different scoring regions as a function of the cooling time.

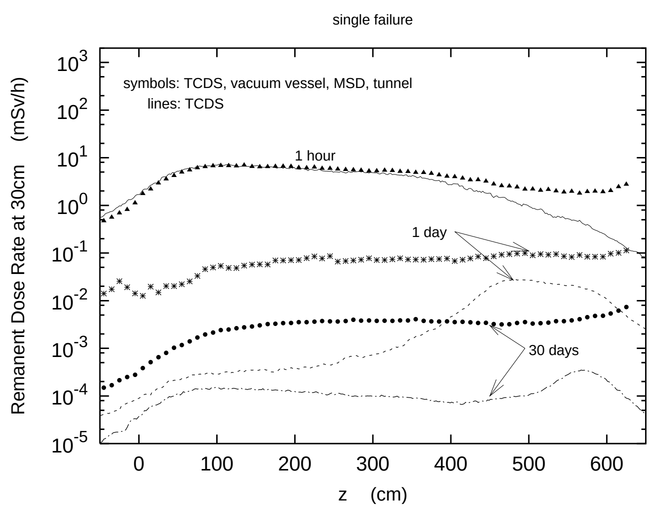

Figure 3 - Remanent dose rate at 30cm from the beam axis for 3 cooling times simulated for the TCDS absorber element (lines) as well as for the TCDS and surroundings (dotted lines).

The design of the TCDS system must take into account the limits of radiation exposure of personnel during replacement, repair or maintenance of the activated equipment. All components related to the equipment placed in the tunnel will be classed as radioactive. It will be possible to return it for repair only if the manufacturer has a license to work with radioactive materials. [13]

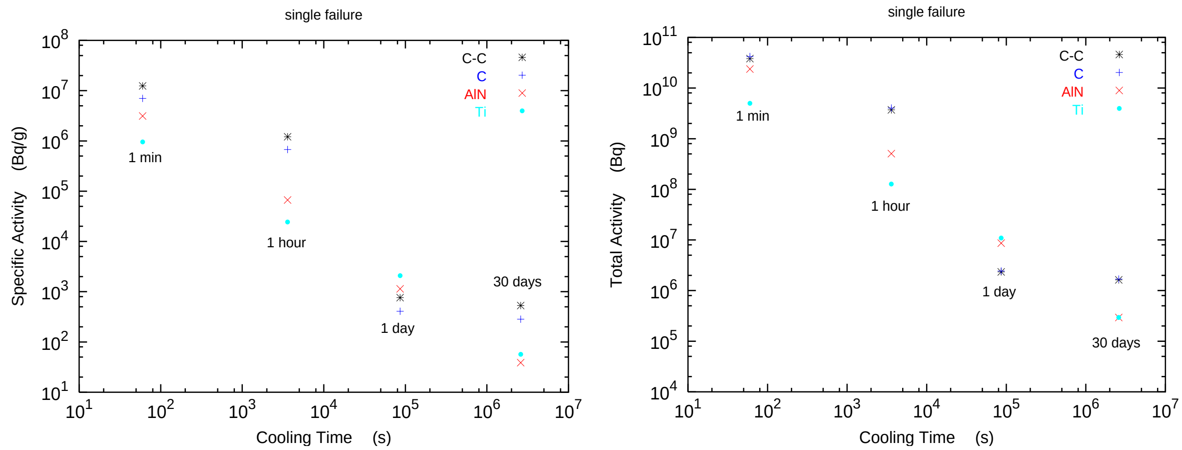

Figure 4 - Specific and total activity for C-C composite, second Graphite part, Aluminium nitride, and Titanium.

6. MECHANICAL DESIGN

6.1 VACUUM VESSEL

In order to avoid interference with the adjacent LHC vacuum tube of the circulating beam, the outside diameter of the TCDS shall be maximum Ø350mm. Therefore, the use of a CERN standard stainless steel circular vacuum chamber of a dimension of Ø254mm using a DN250 (OD Ø306mm) flange, as shown in Appendix 2, is recommended.

The vessel can be supported either directly on the floor or on an intermediate alignment girder allowing an accumulated alignment precision of ±1mm, this including allowances for tolerances during manufacture and assembly.

The beam vacuum components shall be of all metal construction and UHV compatible. Aluminium and its alloys, without an anti-electron multipacting coating, are not suitable materials [3]. It is recommended that the TCDS tank is made out of stainless steel 316 L (N) in order to allow external bake out at 300°C.

The maximum unit length of the vacuum chamber shall be limited to 7.18 m, compatible with the existing cleaning baths at CERN and the use of halogen containing brazing flux is excluded for reasons of corrosion. For practical reasons a unit length of 2-3 m is recommended.

In-situ welding of the vacuum system in the tunnel must be avoided since post-welding cleaning will be difficult and, moreover, any pre-conditioning of the vacuum system will be lost.

Interconnection bellows shall accommodate the thermal expansion and contraction of the vacuum chambers during bake-out. The interconnection bellows shall permit a transverse radial off-set between the two centres at the extremity of the interconnection bellows by up to 4 mm. The interconnections shall assure the continuity of the electrical conductivity of the vacuum chambers (see section 6.3).

6.2 VACUUM EQUIPMENT

The active part of the TCDS is composed mainly of graphite and C-C which are known to outgas CO and CH families when heated up. The required vacuum shall be obtained by using ion-pumps attached to the TCDS since sublimation and NEG pumping of these gases will not be possible. To cope with the non-negligible total out-gassing and expected gas load during the 15 years of operation, two manifolds with two 400 l/s ion-pumps each shall be installed under the total TCDS tank and two manifolds with two sublimators each shall be installed on top of the tank. If possible in the available space, re-using of the existing LEP ZL manifolds could be an easy and cheep solution which will allow also pressure reading since, Bayard Alpert gauges are also attached to these manifolds [14].

The TCDS will not be sectorised, i.e. not isolated from the other equipment by special sector valves. A sector valve will be installed in the standard vacuum pumping units opposite to the MSD magnets.

The bake out is proposed to be obtained by heating the external part of the tank with special heating jackets. Tests will have to be done to define the exact temperature and duration of the bake out to ensure that the graphite, C-C and AlN are baked at least at 250°C.

As mentioned in paragraph 6.1, the TCDS vacuum vessel is recommended to be made out of stainless steel 316 L(N) in order to allow external bake out at 300°C. The internal supports for holding the graphite, C-C, AlN and Ti elements should be made according to the vacuum standard engineering requirements (welding, trapped volumes, …).

6.3 BEAM SHIELDING

The vacuum chamber or beam-shield geometry for the LHC circulating beam should be smooth to minimise beam–induced wakefields. The surface roughness R_t, or any topology on the inner surface of the vacuum chambers, such as a saw-tooth pattern to lower both the photo desorption yield and photoelectron yield, must be $\leq 200\ \mu m$. All cavities, however short, should be shielded whenever feasible and the angle of transition between different chamber cross-sections should not exceed 15º [5].

Pumping slots with a surface area of up to 20% of the pumping shields are acceptable in terms of longitudinal and transverse impedance provided the slots have rounded corners and their major axis is in the beam direction [15]. The beam shield is proposed to be made of 2mm thick copper and, in order not to limit the aperture, the minimum diameter of the beam shield should be at least identical to the MSDA vacuum chambers with a clear aperture of 52.4mm. The vacuum chambers used for the MSD magnets are described in [16]

Bellows, required for thermal expansion compensation and alignment, must be shielded with an impedance of $\leq 0.1 m\Omega$. The contact resistance between chambers should be $< 100\ \mu\Omega$ [3].

6.4 ABSORBER STRUCTURE

The TCDS absorber blocks shall have a cross-section as shown in Figure 2. The assembled TCDS and support system shall accommodate for the thermal expansion and contraction during the vacuum bake-out and thermal dilatation due to beam impact as mentioned in Table 2.

7. LAYOUT AND INTEGRATION

A schematic layout giving the position of the TCDS collimator with respect to the MSD magnets in IP6 is shown in Figure 5. The indicated length of the TCDS refers to the total reserved length. Exact length and position of the TCDS can be found in LHC-TCDS-EC-0001 [17].

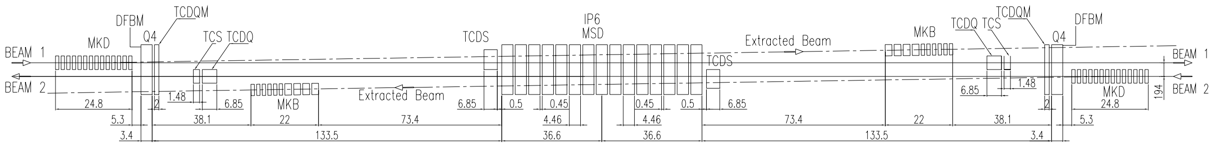

Figure 5 – Schematic layout of IP6 Beam Dump Insertion. (Dimensions and positions for information only).

On the beam entrance side, the LHC room temperature beam vacuum system consists of a 2mm thick, NEG-Coated copper pipe with an inner diameter of 80 mm and a maximum corresponding DN100 connection flange [18]. The TCDS collimator shall be connected to this by a transition chamber, allowing sufficient aperture for the extracted beam. On the beam exit (MSD) side the TCDS collimator shall be connected to the MSD pumping module. For this reason, the TCDS vacuum vessel will be fitted with DN250 conflat connection flanges at each end.

8. INSTRUMENTATION

8.1 EQUIPMENT SURVEILLANCE

The TCDS shall be equipped with temperature sensors in such a way that the temperature profile of the diluter blocks can be monitored with a maximum interval of 1000 mm. Furthermore, flow-meters and temperature gauges shall be installed in order to monitor the cooling system.

8.2 BEAM INSTRUMENTATION

A schematic representation of the required beam instrumentation in the IP6 region is given in Figure 6. The design of the TCDS equipment must take into account the integration of this equipment.

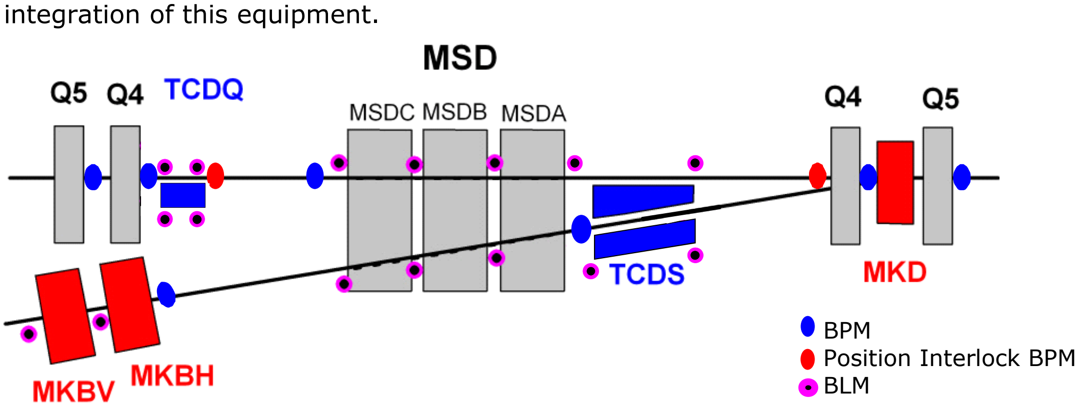

Figure 6 Schematic layout of the LHC Beam Dump Line Instrumentation.

Beam position monitors (BPM) shall be placed such as to monitor the position of the extracted and circulating beams as described in [19]. For the extracted beam, a first BPM must be installed downstream of the TCDS to adjust the steering (MKD kick strength). These BPM will measure the position for both horizontal and vertical planes. In addition, loss monitors (BLMs) must be installed around the TCDS diluter blocks.

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APPENDIX 1– TCDS SPECIFICATION DATA SHEET

<u>Operation Conditions</u>		
Beam parameters		
Proton energy	7	TeV
Stored energy per beam	350	MJ
Number of Bunches	2808	
Bunch spacing	24.95	ns
Protons per bunch (nominal)	$1.1 * 10^{11}$	
Protons per bunch (ultimate)	$1.7 * 10^{11}$	
Extraction parameters		
linear ramp rise time	2.76	µs
bunch separation time	24.95	ns
<u>Design Specification</u>		
Maximum allowed temperatures		
MSD vacuum chamber	300	°C
Graphite in TCDS	~800-1000	°C
Carbon Composite in TCDS	~1000-1200	°C
Aluminium Nitride in TCDS	~1000-1800	°C
Titanium in TCDS	~1000-1200	°C
MSD iron	100	°C
Main dimensions		
Diluter width	23.6-24.1	mm
2^{nd} Jaw width	40	mm
Position from circulating beam	16.3-17.2	mm
Aperture extracted beam	30	mm
Diluter length	6000	mm
Diameter vacuum vessel	250-350	Mm
Configuration		
1m Graphite	1.77	g/cm^3
2m C-C composite	1.4	g/cm^3
1.5m Graphite	1.77	g/cm^3
1m Aluminium nitride	3.31	g/cm^3
0.5m Titanium	4.5	g/cm^3

Impedance		
Surface resistance R_s (d=Ø beam screen)	< 3.906 10^{-11} d^3	Ω
Surface roughness R_t	≤ 200	μm
Beam screen thickness	2	mm
Pumping slots surface area	Max. 20	%
Pumping slots width	1.5	Mm
Pumping slots length	6-10	mm
Vacuum		
Nominal pressure	< 10^{-8}	Pa
Pumping speed	2 x 400	l/s
Leak tightness	$1 \cdot 10^{-11}$	$Pa.m^3/s$
Bake out	250-24hrs	°C
Radiological Doses After 1 failure at 30 cm of TCDS & surroundings		
Max. Radiation dose rate (1hour cool-down)	10	mSv/h
Max. Radiation dose rate (1day cool-down)	0.1	mSv/h
Max. Radiation dose rate (1month cool-down)	0.01	mSv/h
Layout parameters		
Distance MSD yoke – TCDS Diluter	0.5	m
Length TCDS diluter	6	m
TCDS Connection flanges	DN250	

APPENDIX 2- CROSS-SECTIONS OF MSD MAGNETS WITH PROPOSED TCDS DIMENSIONS.