UPGRADE OF THE TCDQ DILUTERS FOR THE LHC BEAM DUMP SYSTEM

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Abstract

The TCDQ diluters are installed as part of the LHC beam dump system to protect the Q4 quadrupole and other downstream elements during a beam dump that is not synchronised with the abort gap, or in case of erratic firing of the extraction kickers. These diluter elements installed during Run 1 were compatible with beam up to 60 % of the nominal intensity, which was insufficient for the second run of the LHC. This paper describes the requirements for the upgrade done during the First Long Shutdown (LS1), to make the TCDQ compatible with the full 7 TeV LHC beam at intensities that are required for the future runs of the machine. Subsequently the mechanical design changes, implementation and commissioning of the TCDQ are reported.

INTRODUCTION

The need to upgrade the single jaw moveable diluter elements Target Collimator Dump Quadrupole (TCDQ) was already apparent during the first run of the LHC. Whereas the initial design was sufficient for operating at the lower intensity adopted for the first physics run of the machine, simulations have shown that the system would not survive the impact of the LHC beam at ultimate intensity and beyond [1]. The proposed upgrade required the absorber material to be changed from 1.77 g/m^3 graphite to a sandwich of lower density carbon fibre-reinforced carbon (C/C) and graphite, and the total absorber length to be increased from 6 to 9 m [2]. The displacement system would also have to accommodate for a ±1 mrad radial displacement with respect to the longitudinal centre of the diluter [3] [4].

CONSTRUCTION OF THE ABSORBER

The upgrade of the diluter required the dismantling of the four tanks from the tunnel and the two spares for the replacement of the graphite absorber blocks with the C/C and graphite sandwich, and the refurbishment of the cooling circuit fittings. The old graphite blocks have been removed and stored in a radioactive storage bunker. The estimated dose rate during the dismantling was 1 μSv/h at 10 cm.

Absorber Blocks

The new absorber blocks measure 250 mm in length and 72 mm in height. The width is 40 mm for the C/C and 35 mm for the graphite. The C/C blocks of densities 1.4 and 1.75 g/m^3 are produced from carbon fibre preforms (or pre-pregs) using the Rapid Chemical Vapour

Infiltration (R-CVI) technique. The first axis of maximum strength is the vertical y axis as seen by the beam. The fibre orientation in adjacent layers is 0º/90º/0º/90º. The graphite is of type R4550 with a density of 1.8 g/m^3. Figure 1 shows one of the C/C blocks during the quality assurance.

Figure 1: C/C absorber block.

In order to condition the new blocks for the Ultra-High Vacuum (UHV) of the LHC both material types were pre-cleaned with small amounts of alcohol and acetone. The final cleaning was done by CO_2 jet blasting. To reduce the outgassing rates, the blocks were subsequently heat-treated under vacuum in two two-hour stages at 600 ºC and 1000 ºC with several stabilization plateaux. Beam impedance considerations require the face of the C/C blocks adjacent to the beam to be copper coated by means of magnetron sputtering with a first layer of titanium providing better adherence for the 5 μm layer of copper. Furthermore as the figure shows the blocks at the extremities of each vacuum tank are tapered for a smooth transition between the racetrack endplate and the interior of the absorber structure.

Vacuum

After assembly the vacuum tanks were baked-out in an oven at 300 ºC for 24 hours with a temperature ramp of 13 ºC/h and a stabilization plateau at 150 ºC and subsequently aligned in a clean room. The tanks are equipped with heating jackets for bake-out in the LHC tunnel during commissioning of the vacuum sectors. The vacuum levels achieved during the validation in the assembly and test lab were in the order of 1·10^{-10} mbar. The newly constructed spares are reaching the 10^{-11} mbar

range due to better cleanliness, and the installation of brand new ion pumps and fully refurbished sublimators. During the bake-out in the tunnel several leaks occurred that were traced to non-uniform heating, fast temperature ramp rates and short stabilization plateaux. The leaks were localised and repaired and currently experts from CERN's vacuum group are working on developing a more reliable procedure for future bake-outs in the tunnel. Figure 2 shows one of the assembled diluters during insertion in its vacuum tank.

Figure 2: TCDQ diluter.

INTEGRATION AND INSTALLATION

An integration study was performed in order to allocate sufficient space and clearances for the increased length and stroke of the system. The two TCDQ systems (one per beam) are located symmetrically around the centre of Interaction Point (IP) 6 of the LHC. The existing TCDQ comprised of two vacuum tanks per beam mounted on a rigid two-segment moveable support girder. Figure 3 shows a section of the model of the vacuum tanks with the adjacent circulating and dumped beam lines.
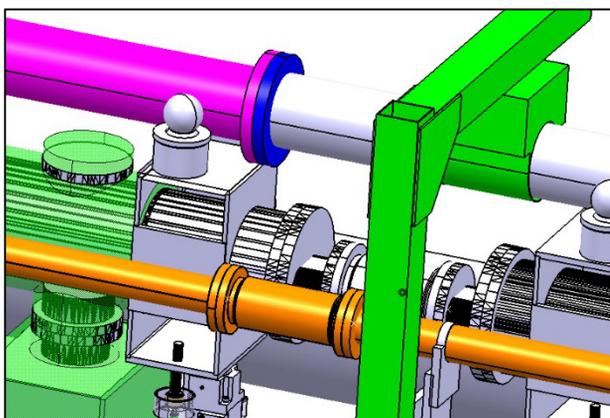

Figure 3: Integration study.

Two motorisation and measurement table systems are mounted on each extremity of the girder. For the extension a third intermediate girder segment was introduced between the two, displacing the upstream segment and its motorisation. In order to create the

necessary space, four beam position monitors per beam had to be displaced upstream towards IP 6. In parallel, the supports for the circulating beam line that lies adjacent to the TCDQ and is at the end of the stroke as close as 9 mm from the vacuum tank had to be redesigned as to accommodate the enlarged system. Lastly, the dumped beam line that runs above the TCDQ and whose diameter telescopically increases as it approaches the external dump block (TDE) was found to interfere with the alignment target supports on top of the tanks. Calculations showed that the diameter of the dump line could be increased after it clears the full length of the TCDQ, so that the larger diameter section sits downstream of the vacuum tanks. After installation the tanks were aligned by the LHC survey team. The misalignments caused by the tilt of the system at the extremities of the stroke are within the specified ±0.1 mm tolerance. Figure 4 shows the position of the TCDQ relative to the adjacent beam lines during injection and the mechanical limits.
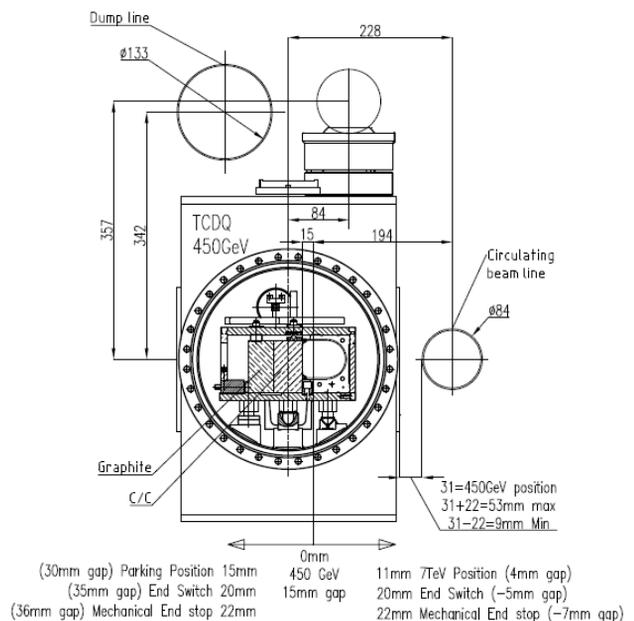

Figure 4: Mechanical limits of the system.

OPERATIONAL CONSIDERATIONS

The TCDQ is installed downstream of the extraction septa (MSD) and has to absorb the beam swept during an asynchronous beam dump in order to avoid the damage of the downstream elements. This absorber has to be precisely set up respecting a well-established hierarchy valid for the full LHC collimation system. It has to be in the shadow of the secondary collimators and at the same time shield and minimize the energy deposition on the tungsten tertiary collimators, which protect the triplet apertures at the experiments.

In order to provide the required protection, the TCDQ jaw has to be precisely centred and aligned with respect to the beam. A critical point is the angular adjustment with the beam: an accuracy of ~100 µrad is required. This corresponds to an offset of ~1 mm (10.4 m support

girder), which is ~0.5 σ at 450 GeV and ~2 σ at 6.5 TeV, between the two jaw ends. Any larger tilt would reduce significantly the amount of material crossed by the beam and thus the stopping power of the TCDQ in case of asynchronous beam dump. A well-established procedure exists for the angular alignment of long collimators and consists in applying a tilt and close the jaw in steps until the circulating beam is fully scraped. The beam centre is defined as the jaw position (average between up and downstream corner) corresponding to the beam losses at the collimator going to zero. The measurement has to be repeated for different tilts and the angle for which the jaw can be closed farthest into the beam (minimum beam centre) defines the real parallel position. The accuracy and reliability of these measurements strongly depends on the possibility of applying angles of up to ±1 mrad to the TCDQ jaw.

CONTROL SYSTEM

The upgrade of the TCDQ positioning system has consisted of the dissociation into two separate functional entities: the Motor Drive and Control (MDC) and the Position Readout and Survey (PRS). Each one is based on an independent PLC.

The MDC controls the positioning system. The position is acquired by a linear potentiometer used as feedback in the positioning regulation loops. A set of mechanical switches determines the operational limits of the jaws. A second set of switches is used for the protection of the mechanical limits.

The PRS is dedicated to the protection logic. The position is acquired by a second linear potentiometer used to survey the relative position of the jaw interlock limits defined by operational conditions and managed as Machine Critical Settings (MCS) [5]. The PRS is connected to the LHC Beam Interlock System (BIS) in order to dump the beam in case of an incorrect position. The PRS monitors also the jaw temperature.

The linear potentiometers are installed on the same axis in order to reduce the position readout discrepancies between the MDC and PRS.

Each TCDQ motorisation is equipped with a DC motor associated with a mechanical coupling and a reduction gear. The DC motors are controlled by PARVEX DC servomotor drives.

The TCDQ system upgrade has allowed to install a camera for the monitoring remotely the position on the dial gauges during the calibration sequences. This will limit exposure of technicians and engineers to radiation, in agreement with the As Low As Reasonably Achievable principle (ALARA).

Hardware

The MDC controller is a standard PLC with a PROFINET network interfacing a deported I/O station which supervises the servo motor drives and treats the functions of the motion control. The PRS controller is a Safety PLC with a PROFINET network interfacing with a deported I/O station which controls the Beam Interlock channel of the LHC and surveys the position of each TCDQ jaws during the displacement.

Integration within CERN Control Environment

The TCDQ is controlled and monitored from the CERN Control Centre (CCC) using the standard communication protocols developed at CERN, which are not available on SIEMENS hardware. So to interface the SIEMENS PLCs to the CERN Control Middleware (CMW), a 'proxy' computer was inserted which runs an implementation of a CERN standard Front-End Software Architecture (FESA) class. It communicates with the PLC on one side using SIEMENS proprietary protocols, and to the CERN control environment on the other side using CMW. This allows the remote control of the TCDQ by the 'central collimator application', the check of TCDQ references and limits against the values stored in the MCS database, the continuous publication of all the TCDQ data to the LHC Logging database, or the storage of the post operation data to the Post-Mortem Data Store after every beam dump, as shown in Figure 5.
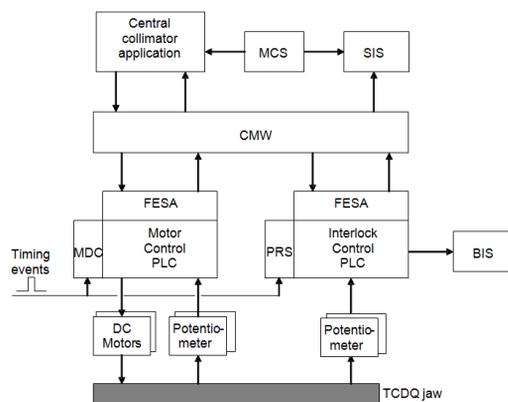

Figure 5: Architecture of MDC & PRS software.

CONCLUSION

During LS1 a total of six TCDQ diluters were reconstructed with new absorber blocks. In addition three spares were built and are currently going through qualification tests. An extended support girder was installed to allow angular displacement of the diluter jaw. The new TCDQ system has been fully commissioned and is currently being tested with pilot beams in preparation for the second physics run of the LHC.

REFERENCES

[1] R. Versaci, V. Vlachoudis, "Evaluation of the Energy Deposition in the Event of an Asynchronous Dump for a 7 TeV Beam on the New TCDQ Model Proposed for the LHC", CERN-ATS-2012-015-MD.

[2] W. Weterings et al., "Upgrade of the LHC Beam Dump Protection Elements", IPAC'12, New Orleans, May 2012, p. 556 (2012).

[3] J. Uythoven et al., "Changes to the LHC Beam Dumping System for LHC Run 2", IPAC'14, Dresden, June 2014, p. 134 (2014).

[4] W. Weterings, LHC-TCDQ-EC-0003 v. 1.0, EDMS 1167537, CERN (2012).

[5] C. Boucly et al., "Operational Experience with a PLC Based Positioning System for a LHC Extraction Protection Element", ICALEPCS'13, San Francisco, October 2013, p. 254 (2013).