Verena Kain, 2003-07-14

28$^{\text{th}}$ Meeting of the LHC Collimation Working Group, July 11, 2003

Present: Ralph Assmann (chairman), Hans Braun, Brennan Goddard, Jean-Bernard Jeanneret, Verena Kain (scientific secretary), Barbara Holzer, Helmut Burkhardt, Gianluca Guaglio, Peter Sievers, Jan Uythoven, Wim Weterings, Markus Brugger, Oliver Aberle

1 Outcome of the LTC (R. Assmann)

R. Assmann (RA) conveyed the positive feedback from Lyn Evans and Steve Myers and their congratulations to the CWG and Collimator Project Team for their good work. The proposal was fully accepted.

It was suggested in the LTC (P. Collier) to build two prototypes – one to be tested at RHIC as already foreseen, another one for the SPS. Besides robustness tests with the LHC beam in the SPS, the RF heating could be used as a measure for the impedance. The development of electron clouds under beam impact might possibly also be studied.

Installation of the collimator prototype in the SPS could be foreseen in September next year during an 8 hour installation period. J.B. Jeanneret (JBJ) asked whether the collimator should be put into the transfer-line or rather in the ring. RA answered that due to the fact that there is no fast extraction, the installation would be in the ring. J. Uythoven (JU) added that if RF heating was an issue, the collimators had to be in the ring anyway.

B. Goddard (BG) pointed out that the shutdown of the SPS might already be scheduled. A. Spinks has to be contacted as soon as possible for the preparation of the shutdown.

2 Present Status of the TCDQ (B. Goddard)

See slides at http://www.cern.ch/lhc-collimation/files/BGoddard_a_11Jul03.pdf.

BG presented the status of the TCDQ concept. The TCDQ, a massive absorber in IR6, protects Q4, a superconducting magnet right after the TCDQ, the arcs at injection and the low β insertions in case of dump failures. The three stage collimation system with metallic hybrid collimators would possibly be in need of the TCDQ to protect the metallic horizontal collimators. Another absorber in IR6 is the TCDS to avoid damage to the MSD septum magnet.

The TCDQ concept is based on a number of simulations, calculations and discussion with various people. The TCDQ loading during a pre-fire of one of the MKD modules and re-triggering of the remaining modules were obtained for the old re-triggering time of minimum 1.2μs and are thus pessimistic. The required thickness of the TCDQ resulting from these numbers is 40 mm. RA wondered whether this is enough as for the collimators an impact at 0 - 5mm needs a thickness of 25mm of material due to propagation of heat (at least 15mm in addition to the impact parameter).

The TCDQ's nominal setting at injection and collision is $10 \pm 0.5\sigma$, it therefore must be movable. It must be long enough to sufficiently dilute irregularly dumped beam to prevent damage downstream. The dilution of residual abort gap population to avoid quenching Q4 might have become less important due to new results of simulations by E. Shaposhnikova, JBJ said. Data on instantaneous dose is also available.

All nuclear simulations were done by Nikolai Mokhov and Igor Rakhno from Fermilab. Their simulation's input is based on a total length of the object of 9.5m; 8m C (1.8g/cm^3) and 1.5m Al. They provided numbers on heat load and temperature rise during dump failures. A single jaw should fulfill the TCDQ's protection objective. For machine protection issues (and orbit control) a two-sided short collimator-like object could be considered in addition.

H. Braun asked whether the impedance was not problematic for an object of such a length. BG and RA replied that because of its transverse setting at 10σ and the large beta function at the TCDQ it should not be an issue. Coating might still be considered. H. Braun also wanted to know whether a single-sided object did not make the situation worse. BG quoted L. Vos saying that 1 jaw gives half the impedance. RA pointed out that it was important to have a full 3D simulation for the impedance at the TCDQ.

The location of the TCDQ is more or less fixed now, its position is at a phase advance of 87° from the MKD (dump kicker magnets). The question of additional downstream masks to further avoid IP6 quenches for dump failures were also investigated. Two masks by Q5 could limit the quench region to one dipole instead of 5 magnets. (They should be closed to 20σ at 7 TeV and must therefore be movable. For the moment they are not considered as part of the baseline.) Space for masks is available.

Data on activation of the area and a check whether the TCDQ concept is sufficient for ions still have to be done. The TCDQ sandwich (C,Al) might be redefined. Because of the small temperature rises in the Al part during failures, 8m of C seem to be excessive.

ATB pointed out that further Monte Carlo (MC) analysis is needed to perform the structural design of the TCDQ. These additional calculations would be complementary to the MARS results and should focus on the absorber only. The aim of the new studies is mainly to optimize (reduce) the length of the TCDQ's core and to investigate its mechanical resistance to the beam load. The TCDQ design requires iterations between the MC code and a structural finite element code. This iterative design process should be managed inside ATB in order to avoid relevant delays. ATB-TD has set up and validated interfaces between the MC code FLUKA and ANSYS on the one hand and a dedicated proprietary code to analyze fast mechanical transients on the other hand. For the very same reason of avoiding delays, L. Bruno (LB) recommended to profit from the already existing tools. JBJ added that writing an interface would be an useful investment and discouraged from redoing MARS calculations.

It is still not clear what the really required orbit tolerances at the TCDQ are or how a transverse setting of $10 \pm 0.5\sigma$ can be guaranteed. JBJ commented that the BPMs in IP6 could do the job. BG replied that there is a 4mm-orbit interlock on them while an interlock to 0.5σ ($\sim$0.3mm) is needed for the so far required TCDQ setting. RA mentioned that there might be time for learning during collimation phase 1, where the TCDQ could sit a 13σ leading to a 1-2σ tolerance.

If the TCDQ acts as a secondary collimator in phase 2 of the LHC collimation system too high loss rates at the TCDQ might lead to further complications such as quenches of the Q4 and higher activation at and around the TCDQ. If quenching of magnets downstream is a problem, additional TCL collimators could be considered, JBJ said. The first load estimate based on a 0.2h lifetime ($2 \cdot 10^9$p/s) resulting in 10^{16}p/y is unrealistic as average loss rate. Loads corresponding to lifetimes of 20h, giving approximately 10^{14}p/y give a more realistic impact scenario. Tracking studies have to be performed.

The TCDQ will have to be cooled. A TCDQ cooling system could be based on the one of the TCDS.

3 TCDS Diluter to protect MSD Septum Magnets

See slides at http://www.cern.ch/lhc-collimation/files/WWeterings_11Jul03.pdf.

W. Weterings presented the TCDS functional specification. The concept was defined under the performance objective of being able to dilute 1.7% of the LHC beam energy ($\sim$ 6.1MJ) during an unsynchronised beam abort at baseline luminosity and 1.2μs retrigger time for a prefire of the MKD. For the choice of material thermal, mechanical, impedance, vacuum, radiological and environmental constraints were taken into account.

In order to guarantee temperatures below 300°C in the MSD vacuum chamber and below 100°C in the MSD steel yoke on the one hand and compatibility with an in-situ bake-out at least at 250°C for 24 hours on the other hand the baseline solution for the TCDS is: **1m C, 2m C-C, 1.5m C, 1m AlN and 1m Ti**. Despite the ideal TCDS layout being wedge-shaped it was agreed on an absorber block with increasing thickness to facilitate manufacturing, assembly and alignment. A second jaw is planned to define a 30mm-diameter aperture. The design took thermal expansion of TCDS elements due to bake-out and beam impact into account.

Simulations for radiological issues after an unsynchronized beam abort gave acceptable dose rates of $\sim$ 0.035mSv/h after a cooling time of 30 days and a distance of 30cm from the object. After a cooling time of 1 day it is $\sim$ 3mSv/h, 1 minute of cooling results in a dose rate of $\sim 10^4$mSv/h.

The RF heating due to circulating beam results in a power deposition of 40W/m. A 500W cooling system is foreseen to absorb this power.

The mechanical design includes appropriate vacuum vessel and equipment as well as beam shielding (for detailed numbers see slides).

Temperature sensors to monitor the temperature profile, flow-meters and temperature gauges for the cooling system, beam position monitors (horizontal and vertical plane) for extracted and circulating beam and beam loss monitors around the TCDS are foreseen.

4 Maximum beam impact on TCL collimators (round-table)

H. Burkhardt has already circulated information on positions of collimators for TI8 as well as for TI2. He had also included the 45° and 135° position. Space problems lead to the consideration of the 225° position in TI2.

The impact assumption he uses for the combined TL-LHC-tracking studies is a full batch. He investigated a gracing impact on the TDI to look at the load at the TCL collimators. JBJ asked whether such a scenario can occur with the additional skew collimators in the transfer line. BG replied that a flash over in the injection kicker magnets could produce this. Under this constraint (full batch) copper TCL collimators are not possible, RA pointed out. Their length and material have to be redefined. RA stressed the importance of getting a realistic impact scenario for the TCL collimators.

5 Failures not covered by the TCDI collimators (B. Goddard)

See slides at http://www.cern.ch/lhc-collimation/files/BGoddard_b_11Jul03.pdf.

BG identified several families of magnets (in TI2 [similar in TI8]: septum magnets: MSIA, MSIB; quadrupoles: MQID295, MQIF294, MQID293, MQIF292; bends: MBIBH) where the tripping of the power supplies could be dangerous for LHC, as generated beam loss would not be caught by the transfer-line collimation. He calculated resulting orbit distortions in the horizontal plane (vertical plane for quads not checked).
The assumptions his calculations are based on:

- The power supplies are interlocked at a certain level
- In case of exceeding this level, the surveillance loop would react within 5ms
- The possible maximum error is given by the interlock level plus the exponential decay of the current over these 5ms

The orbit perturbations at chosen observation points in terms of offset and angle were derived by using the calculated errors in MAD (for the quadrupoles 4mm horizontal bumps were introduced).

The tripping of the dipoles and septa lead to orbit excursions between 5 and 6σ except of MBIBH of TI2. MBIBH could cause an offset of 14.57σ. RA asked whether such an oscillation fits through the narrow aperture of the septum. This has to be checked. The TCL collimators at in injection at IP2 and IP8 only collimate in the vertical plane. JBJ pointed out that there might be need of horizontal injection TCLs. The tripping of the quads is less severe.

For the rate of dangerous power supply trips BG assumed a power supply trip rate of (at most) 1/y, a length of the supply pulses of ∼300ms and a random distribution of trip time within these 300ms. For 6 families (3 dipole families per transfer-line) this gives 0.1 dangerous trips per year.

RA asked how many power supplies could trip during thunderstorms. JBJ proposed an interlock based on thunder storm predictions (no beam in the machine during thunderstorms).

BG will present his numbers at the MPWG on July 18. Questions whether the occurrence of a "dangerous trip" once in 10 years can be accepted or whether better surveillance (lower interlock levels, shorter loop,. . .) is needed, will be discussed.

6 Studies on a Different Optics and a Low Impedance Solution for Cleaning Insertion IR7 (R. Assmann, V. Kain)

See slides at http://www.cern.ch/lhc-collimation/files/RAssmann_11Jul03.pdf.

See slides at http://www.cern.ch/lhc-collimation/files/VKain_11Jul03.pdf.

6.1 Idea

The phase advance conditions for the full 2-dimensional 2 stage LHC collimation system are complicated. The phase advance conditions the LHC collimation system is based on are crucial for a small number of collimators. With more collimators it might become less important to stick to these conditions for a reasonable cleaning efficiency.

Observations with the present system in IR7 (V6.2):

- The impedance produced by a collimator depends on the beta functions at its location. Locations with rather unequal beta functions in the horizontal and vertical plane contribute most to the total impedance.

- The requirements for the collimation system in terms of robustness lead to the need of longer collimator jaws. Space problems might occur when matching the new space allocations in IR7 (collimators between quadrupoles, splitting of quadrupoles, . . .).

- Complicated phase advances and conditions for tilts of the jaws.

As an alternative approach a collimation system based on a 90° FODO cell was considered. The objective was to restrict the maximum amplitude of the halo particles – regardless of the source of the halo – by putting collimators every 45° phase advance.

6.2 A different optics scheme for IR7

The core of the alternative optics scheme are two 90° FODO cells with a length per cell of 175m, $\beta_{\mathrm{max}} \sim 300$m and $\beta_{\mathrm{min}} \sim 60$m. This corresponds to the conditions we already find in the insertion ($\beta_{\mathrm{max}} \sim 350$m, $\beta_{\mathrm{min}} \sim 50$m). 4 collimator families are introduced (horizontal, vertical, skew1 (tilt=45°) and skew2 (tilt=135°)). Every family consists of one primary collimator and 4 secondary collimators. The phase advance between two members of one family is 45°. Enough space for phase 1 and phase 2 is provided for each collimator location (primary collimator: 1m, secondary collimator: 3m).

Two optics possibilities for locations of the collimators in the FODO-lattice were investigated. In optics version 1 the 45° phase advance condition is achieved by putting the collimators right after the quadrupoles. In optics version 2 the impedance problem is taken into account and the collimators are placed at locations with equal beta functions in the horizontal and vertical plane. Thus the collimators are put in the middle between two quadrupoles (version 2: for the primary collimators the half gaps are are 1.6mm with squeezed optics and 6mm at injection/ramp; for the secondary collimators the half gaps are 2.8mm and 7mm).

As the collimators in version 1 are always located downstreams of the quadrupoles, collimators of the counter-rotating beam can be put on the other side of the quadrupole. Thus it could be guaranteed that collimators of different beams do not sit next to each other. Equally for version 2: all secondary collimators which should have a phase advance of e.g. 45° from their primaries are put downstream of the exact phase advance point. At 90° they are all installed upstream of the exact point, and so on. The collimators of the other beam could be placed in the opposite order.

6.3 Cleaning efficiency

Several schemes were compared:

- Cleaning efficiency: full system:
  The collimators' settings were $6/7\sigma$. No collimators removed.
  At 10σ version V6.2 (full C) gives an inefficiency of $3.49 \cdot 10^{-4}$, 90° optics version 2 (full C) $1.66 \cdot 10^{-4}$.
  For efficiency the different solutions work well, although the characteristics of the cleaning efficiency change. While there is more halo below 9.5σ, it shows a nice improvement in inefficiency above 9.5σ.
  Based on a rough estimation by L. Vos for the highest impedance collimator, an improvement of at least a factor of 2 for the total impedance in IR7 can be expected.

- Cleaning efficiency: reduced system:
  Also the alternative optics scheme has the flexibility to remove collimators and thus to reduce cost, impedance and complexity (for dependency of inefficiency on halo amplitude see slides). Up to 1/3 of the collimators can be suppressed.
  Comparison of the V6.2 version (6 collimators removed, inefficiency at 10σ=$5.04 \cdot 10^{-4}$) and new versions:

  - alternative optics, 5 collimators removed:
    inefficiency at 10σ: $4.33 \cdot 10^{-4}$
  - alternative optics, 7 collimators removed:
    inefficiency at 10σ: $5.52 \cdot 10^{-4}$

- Cleaning efficiency for $7/10.5\sigma$ settings:

- Full system:
  The 90° FODO-lattice (without removing collimators) is better above 12.5σ than the original system and would allow for somewhat smaller β^*.
- Reduced system (V6.2: 6 collimators removed, alternative optics: 5 collimators removed):
  The situation is somewhat worse for optics version 2. The collimators to be removed for the new versions were chosen for version 1 and then just applied for version 2 (so this might be optimized). But with the improvement in impedance for version 2 the collimators could be moved further in.

In order to conclude whether the alternative optics layout offers advantages, the detailed impedance for the full IR7 system must be calculated. And last but not least the optics team must be asked to see whether it is possible to match the IR7 optics as close as possible to a 90° FODO-lattice.

JBJ pointed out that it has to be clarified how many quadrupoles are needed for the cleaning FODO cells as the requirements should be compatible with the availabilities in IR7.

7 Round-table Discussion on Future Work

By end of August 10 pages for the LHC design report describing the LHC collimation system are due.
It was agreed by the optics team to put the full aperture model into the LHC sequence also including drifts. Additional markers with allocated apertures will be used for this purpose. The data will be fed into the data base which will then produce MAD sequence files. The time estimate is unclear. B. Holzer and VK therefore will begin with the aperture model of the dispersion suppressor and the arc downstream of IR7 for tracking simulations for BLM studies.

7.1 Concept of the TCL collimators

Load assumptions in the transfer lines as well as the TCL collimators have to be defined. A working assumption shall be one full batch. O. Aberle and LB will have to look for spacing, materials and layout.

The next meeting will be announced.