LHC Collimation Review 2019

Mandate

The main objective is to review the collimation system of HL-LHC in view of the LHC Run1 and Run2 experience and the suitability for installation in the LHC. The review will examine the upgrades in the experimental and cleaning insertion regions as well as the new cleaning systems in the dispersion suppressor regions of P7 and P2.

Review Panel

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General Comments:

- The excellent performance of the collimation system contributed to the success of LHC, particularly the increase of luminosity via reduction of beta* over time.
- Efficiency and reliability of operation was strongly improved by automated methods and the use of integrated BPM's.
- Particle tracking, impedance calculation and radiation transport simulations were improved over time, showing good agreement with measurements.
- With the development of MoGr collimators and low impedance coating important improvements were achieved.

Further comments and recommendations:

- Overpopulated beam tails (5% beyond 3.5σ) were measured using collimators; improved diagnostics should be made available for monitoring the tail distributions during the run.
- Perform an accelerator physics study trying to develop a diffusion model for the LHC that reproduces the observed amount of beam in the tails.
- Using the hollow electron lens would allow to remove tails in a controlled way and would widen the impact parameter distribution on primaries; the committee supports the realization of the electron lens concept.
- Provide an overview on power loss to elements around the ring during different operating phases (how many watts to collimators, walls, magnets, dump, …).
- Explore the limit of beta* for HiLumi LHC with the collimator upgrade, exploring all capabilities of the upgraded system. Find the limiting device (TCDQ?) and develop mitigation strategies for this limit.
- Perform a simulation of cleaning efficiency and energy deposition taking into account a multiple imperfection model (jaw flatness, gravitational sagitta, angles, aperture imperfections).

Charge Questions I

Is the collimation system in the present baseline addressing the design criteria required for the HL-LHC operation?

Are the original design criteria of the collimation system validated by the LHC Run1 and Run2 experience and by the various tests carried out on each component?

Is there room for modifications or simplification after the LHC Run1 and Run2 evaluation and what would be the resulting risk implications?

What should be learnt in Run 3 as feedback to the LS3 plans?

Findings

- **Design criteria from LHC used for HL (x 2 Intensity)**
- (Normal Operation)
  - **Slow losses**
  - ▪ **Continuous: 1 h Beam Life Time (BLT)**
  - ▪ **Peak: 0.2 h BLT during 10 s**

- (Accident Scenarios)
  - ▪ **Beam Injection Error**: impact of **288 bunches** at 450 GeV, impact parameter up to 5 σ (σ = 0.7 mm)
  - ▪ **Asynchronous beam dump**: impact of **8 bunches** at 7 TeV on TCSPM, TCPPM, impact parameter up to 5 σ
  - ▪ **Asynchronous beam dump**: impact of **1 bunch** at 7 TeV on TCTPM, impact parameter up to 5 σ

Findings

- Operational experience shows low probability of lifetime below 1 hour
- Peak losses in ADJUST phase (when putting the beams in collision)
- Excellent cleaning efficiency
- Critical limiting loss location still in DS
- Cleaning efficiency improved over the years with tighter collimator settings
- No operational experience with LIU beams before Run III
- Impact tests done with 55% HL bunch intensity (but equivalent density)
- Design choices for collimation upgrade in the cleaning insertions driven by impedance reduction
- DS losses addressed with TCLD → needs 11 T dipoles
- IR cleaning with metal jaws, TCT W proposed to be replaced with CuCD
- Only one asynchronous dump so far
- Some discrepancies (Factor2 in Mo tune shift, factor 2 in LO strength to ensure stability, factor 3 on observed loss signal in BLM, quench limits)

Comments

- It not known how overpopulation of tails will scale with intensity
- Considered the complexity of simulation, a factor 2-3 agreement with measurements is a good achievement

Answers/Recommendations I

Is the collimation system in the present baseline addressing the design criteria required for the HL-LHC operation?

- Yes

Are the original design criteria of the collimation system validated by the LHC Run1 and Run2 experience and by the various tests carried out on each component?

- Yes, all concepts have been validated by tests
  - TCP.C6L7.B1 , TCSPM test in beam OK
  - In Jaw BPM fully validated
  - Required impedance,
  - outgassing
  - Quench limits
- Quench tests are necessary to validate the simulations and should be given adequate priorities, in particular for the 11 T

Charge Questions II

Review the observed hardware performance during the present prototype production: are there non-conformities and how relevant are they for the HL-LHC operation and could they limit the HL-LHC performance reach (or the LHC performance for the collimator installed in Run3)?

Are the observed hardware characteristics compatible with the HL-LHC operation requirements?

Review in particular the motivation for using coated MoGr as collimator material [robustness, likelihood of damage and impact of damage on the rest of the machine] also based on the LHC Run2 operation: Is the use of MoGr as collimator material well justified or could other materials with better conductivity or other combination of jaw bulk material with coating be used instead?

Findings

- MoGr bulk material close to acceptance limit, in some case a factor 2 above acceptance. Mitigated by NEG cartridges.
- Impedance question well addressed first from material point of view with the use of MoGr less resistive material + Mo-coating for the secondary collimators and second from geometrical aspect by implementing tapering.
- Coating complies vacuum standards of adherence.
- Mo-coated MoGr was tested for vacuum with one surface coated. Vacuum performance was a factor 2-3 worse than without coating. An additional heat treatment of coated MoGr at 400°C allowed to recover uncoated MoGr outgassing level.
- 5th axis with +/- 10 mm range in case of "soft damage" of the jaw allowing longer operation time without impacting too much the impedance budget for secondary collimators

Comments

- The committee is impressed by the presented results on R&D, design, prototyping and production of advanced jaw materials, optimized collimators and critical hardware components for the system.
- We congratulate the teams on the careful follow-up on the prototyping and production, carefully addressing non-conformities and developing mitigation measures.
- In particular we acknowledge the outstanding performance of the collimator controls including the sensors and actuators. The availability of the system is remarkable.

Answers I

- *Review the observed hardware performance during the present prototype production: are there non-conformities and how relevant are they for the HL-LHC operation and could they limit the HL-LHC performance reach (or the LHC performance for the collimator installed in Run3)?*
  - The speakers presented the status of collimator production. Several non-conformities or potential issues were identified, e.g. in the roller screw quality, measured resistivity of material, vacuum outgassing. All of them were carefully analyzed and solutions were implemented. A few studies are still ongoing, in particular on radiation hardness of the final material. For the presented results we conclude that the ongoing collimation upgrade has no evident short-comings, it can be expected to fully deliver the specified hardware improvements and it will therefore maximize collimation performance reach for the next decades of LHC operation.

Answers II

- *Are the observed hardware characteristics compatible with the HL-LHC operation requirements?*
  - The presented collimation upgrade plan includes novel hardware components that address several critical issues for HL-LHC operation, namely a reduction of both resistive and geometric impedance, materials for improvement of cleaning efficiency, a new local collimator in the dispersion suppressors, a hollow electron lens for limiting power in the beam tails, improved controls for longer component lifetime, a crystal assistance system for ion operation and NEG cartridges for vacuum optimization. The presented hardware specifications and results are fully compatible with the HL-LHC requirements. As only residual major worry we identify the radiation hardness of the MoGr material with coating.

Answers III

- *Review in particular the motivation for using coated MoGr as collimator material [robustness, likelihood of damage and impact of damage on the rest of the machine] also based on the LHC Run2 operation: Is the use of MoGr as collimator material well justified or could other materials with better conductivity or other combination of jaw bulk material with coating be used instead?*
  - The Mo coating of the jaws with MoGr bulk material reduces the collimator-induced impedance and therefore directly maximizes performance reach of the LHC. The speakers presented careful investigation of the coating in terms of resistivity, adherence, robustness against damage and vacuum performance. The committee is impressed with the quality and completeness of the studies. The choice of MoGr material with Mo coating is supported, subject to successful radiation robustness tests.

Recommendations I

- The presented high level of quality control during production should be maintained.
- Above tolerance heat induced flatness deformations in the design should be accepted for the short periods of times concerned and not be addressed by reducing the collimator length. However the improved cooling and machining approach should be pursued as a first alternative.
- Review the radiation hardness once the data on the MoGr material is available, both for bulk MoGr material and MoGr coated with Mo.
- Complete and present the studies for radiation impact of the upgraded collimation system with the new materials installed, e.g. on peak doses to personnel.

Recommendations II

- Think about a vacuum test to quantify outgassing in conditions that resembles the machine configuration with one surface coated by Mo and compare with the case of uncoated surface (bare MoGr), taking into account local heating sources in operation and closure of surfaces when installed.
- Try a real destructive coating test with prototype in IR7 and under the LHC vacuum conditions.

Charge Questions III

Is the cleaning upgrade envisaged for the DS still justified and good enough for both proton and ion beams at their maximum intensities or are there alternative solutions?

Is the IR cleaning envisaged for the HL-LHC well justified or are there alternative solutions?

Is the choice of installing collimators in the dispersion suppressors of point 7 still adequate taking into account the results of proton and ion operation in Run 1 and 2 including crystal tests.

Findings

- The presented scheme of DS collimators in-between a pair of 11T magnets in IR7, and in a connection cryostat in IR 2 leads to just acceptable heat deposition in s.c. magnets, both for proton and ion operation
- The development of the 11T magnet prototype is sufficiently advanced and performance requirements are inline to be met
- The upgraded IR cleaning schemes with additional tertiary collimators for IP1/5 provide sufficient suppression of losses; the situation is well understood

Comments

- power deposition for the case of 0.2h lifetime of 50mW/cm3 in the 11T magnet coil is just below the calculated limit of 70mW/cm3; for such critical parameters margins should be specified and potential mitigation measures be established
- In case of operational problems going back to the original baseline could be considered as a long term solution
- the schedule of the 11T magnet production is rather tight and presents a risk that installation in LS2 cannot be achieved; the possibility of installation in EYETS is a backup
- situations with 0.2h lifetime were not observed in run II; however, with higher intensity and crab cavities conditions might change and it is recommended to respect this limit

Comments

- IR1/5 cleaning will be less constraint in HL era due to absent Roman pots.
- TCTs in cells 4 and 6 made either from W or CuCD are fully safe over a realistic range of setting; thus W can be chosen as cost effective solution; in the unlikely case of a singe bunch impact the collimator had to be exchanged
- If CuCD should be pursued, the case should be strengthened
- Crystal collimation shows excellent performances, this option should be further developed especially for ions but not be considered as a replacement for DS collimators

Answers/Recommendations

Is the cleaning upgrade envisaged for the DS still justified and good enough for both proton and ion beams at their maximum intensities or are there alternative solutions?

Yes, the IR7 DS collimator upgrade and proposed position is required for ions, is a reasonable compromise and should be executed.

Is the IR cleaning envisaged for the HL-LHC well justified or are there alternative solutions?

The proposed IR1/5 cleaning with TCLX collimator and masks provides a good solution with sufficient margin for power deposition.

Is the choice of installing collimators in the dispersion suppressors of point 7 still adequate taking into account the results of proton and ion operation in Run 1 and 2 including crystal tests.

The DS upgrade in point 7 is still adequate, taking into account the results from runs I, II.