CERN-ACC-2019 0053
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PROCEEDINGS OF THE 2019 MPP WORKSHOP

Bogis-Bossey 7th to 8th of May 2019

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Cern, Geneva, Switzerland

Keywords: CERN LHC, Workshop-Proceedings, Machine-Protection, LS2

Abstract:

This report contains the proceedings of the MPP Workshop on LHC Machine Protection, held in Bogis-Bossey from 7th to 8th of May. This MPP Workshop on LHC Machine Protection focuses on the upgrade work in LHC during the Long Shutdown 2 (LS2) for mid-and longer term improvements of the LHC MP Systems.

Geneva, Switzerland

August, 2019

This report should be cites as:
Proceedings of the 2019 MPP Workshop, edited by S. Strachinescu, CERN-ACC-XXXX (CERN, Geneva, 2019)

A contribution in this report should be cites as:
[Author name(s)], [contribution title], in Proceedings of the 2019 MPP Workshop, edited by S. Strachinescu, CERN-ACC-XXXX (CERN, Geneva, 2019), pp. [first page] – [last page]

MPP Workshop
Bogis-Bossey 7-8 May 2019

The principle aims of the workshop are to:

Review the status, foreseen and required changes in the machine protection system during LS2 to prepare operation with LIU beams. The workshop will cover LHC and injector related topics:

- Learning from Run 2 (injectors and LHC).
- Foreseen changes to the machine protection and related systems.
- Challenges in injectors and LHC with LIU beams and other new operational parameters (optics, beam energy, 11 T).
- Preparatory tests or MDs which need to be performed during Run 3 (in the injectors and the LHC), which are outside the operational envelope, to prepare for HL-LHC.

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Workshop site:	https://indico.cern.ch/event/803870/

The write-ups for the 2019 MPP proceedings were based on the JaCoW templates, for which the JaCoW team is gratefully acknowledged.
The authors are thanked for their high quality contributions, written during a very busy period.

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Presentations can be accessed from: https://indico.cern.ch/event/803870/timetable/#20190508

EXECUTIVE SUMMARY OF THE MPP WORKSHOP 2019

M. Gasior, V. Kain, A. Mereghetti, D. Mirarchi, B. Salvachua, R. Secondo, F. Tecker, J. Uythoven, J. Wenninger, C. Wiesner, D. Wollmann, M. Zerlauth CERN, Geneva, Switzerland

Introduction of the workshop

This report summarises the 2019 MPP Workshop, which was held 7th-8th May 2019 at the Château de Bossey. Following the two preceding workshops in 2013 and 2015, the main aim of this workshop was to review the status, the planned and the required changes of the machine protection systems during LS2 to prepare operation with LIU beams. The workshop covered both LHC and injector related topics, in particular:

- Learning from Run 2 (injectors and LHC)
- Foreseen changes to the machine protection and related systems
- Challenges in injectors and LHC with LIU beams and other new operational parameters (optics, beam energy, 11 T)
- Preparatory tests or MDs that need to be performed to prepare for HL-LHC during Run 3 in the injectors and the LHC and that are outside the normal operational envelope.

The workshop was organized in 4 sessions (see details here), two of which were devoted to a review of the various MP systems (chaired by **B. Salvachua / M. Gasior** , respectively **A. Mereghetti / R. Secondo**), a session on protection related tools, MPP and experiments (chaired by **C. Wiesner** and **D. Mirarchi**) and a dedicated injector session (chaired by **V. Kain** and **F. Tecker**).

The workshop organizers would like to acknowledge the outstanding work done by the speakers and session chairs during the preparation of this very successful workshop. Many thanks as well to all participants for the lively discussions which formed the basis of this summary and yielded a number of follow-up actions that will be followed-up through the appropriate committees.

Figure 1: Workshop picture.

SESSION 1

Abstract

Session "Systems 1" starts the workshop so the goals and the structure of the entire workshop are introduced in the first presentation of this session. The second presenta- tion reviewed previous Machine Protection Workshops and highlighted items deserving special attention. The running scenario for Run 3 was presented, with the focus on machine parameters relevant for protection systems. Sessions related to beam instrumentation systems providing machine protection started with three presentations related to beam loss monitors. The first presentation covered the standard monitors, the second the diamond monitors and the third one dump threshold levels. The following presentation dealt with other beam instrumentation systems related to machine protection, with focus on changes foreseen for Run 3. One talk covered interlocked BPMs, new Beam Current Change Monitor (BCCM or dI/dt), orbit interlocks on collimator BPMs with DOROS electronics and abort gap monitor (BSRA). It also introduced two SPS systems, namely the new BPM system (ALPS) and the dI/dt system on DC beam current transformer. The next presentation gave and overview of materials for collimators, experiment detectors and superconducting magnets. The last presentation of the session reviewed safe limits for injection and extraction devices.

INTRODUCTION - WORKSHOP GOALS AND STRUCTURE, A. SIEMKO AND D. WOLLMANN

An introduction of the workshop was given. The detailed agenda can be found in [1]. The scope of the workshop was to review the status, foreseen changes and requirements of the machine protection systems for the LHC and the injectors in view of the future operation with LIU beams [2] during Run 3.

REVIEW OF MP WORKSHOP 2013/15, M. ZERLAUTH

The design of the LHC machine protection system was already reviewed a few times:

- 2001: design/architecture document [3].
- 2005: external machine protection review of the overall system [4].
- 2006-2009: beam interlock system (BIC) audit. [5]
- 2007-2009: LC beam dump system (LBDS) audit.

- 2008-2009: Beam Loss Monitoring (BLM) system audit.

During beam operation periodic reviews took place in order to evaluate the performance of the system, in particular during the increase of the stored beam energy:

- MPS internal review 2010 [6].
- Periodic reviews of the collimation system.
- External LHC machine protection review, September 2010 [7].
- Machine Protection Workshop, March 2013 [8].
- Machine Protection Workshop, June 2015 [9].

The reviews and audits came out with a series of recommendations that mostly have been addressed.The main actions for follow-up of the 2015 workshop concerned the BLM-sunglasses, AGK issues, diamond BLMs, interlocked BPMS and injection steering.

RUNNING SCENARIO FOR RUN 3 - OVERVIEW, J. UYTHOVEN

The beam requirements and expected machine configuration for Run 3 is discussed in the LHC Run 3 Configuration Working Group [10].

The expected beam intensities and emittances delivered to the LHC during Run 3 are shown in Table1. Due to various equipment constraints, the LHC can aim at maximum bunch intensities up to 1.8×10^{11} p/b in Run 3, as of the end of 2022. This intensity is to be compared with the typical bunch intensity of 1.1×10^{11} p/b in 2018. An increase of the stored energy is therefore expected from about 300 MJ in 2018 to about 500 MJ in 2022.

The proposed strategy for the machine configuration is as follows:

- β^* levelling in ATLAS/CMS to limit the peak luminosity to 2×10^{34} cm^{-2}s^{-1} with parametric crossing angle variation in Stable Beams. For a β^* range of 1.5 m down to 0.24 m, the half-crossing angle increases from 100 μrad to 160μrad.
- No squeeze beam process, i.e. start with β^* levelling in stable beams at the end of the energy ramp.
- Two optics variants are being evaluated, a round optics and a flat optics.
- Offset levelling in LHCb to limit the peak luminosity to 2×10^{33} cm^{-2}s^{-1}.
- ALICE kept with β^* of 10 m and peak luminosity of 1.4×10^{31} cm^{-2}s^{-1}
- Larger beta function in the LHC arcs with ATS telescope.

The proposed dynamic configuration in Stable Beams is complex. The general strategy for the validation of the machine configuration during commissioning and after technical stops has to be agreed. The configuration of tertiary collimators and operation of roman pots is also affected and needs to be followed up.

Discussion

- **J. Uythoven** explained that moving RP during Stable Beam is excluded for the time being. The settings structure does not easily allow for movements. **S. Fartoukh** explained that β^* levelling at constant crossing angle of 160 μrad can be envisaged as well, although this has no impact on the RP movements. For constant interlock limits, the 'least bad' option would involved 2-3 discrete steps which are however difficult to protect.

Follow-ups

- **MKD-TCT and MKD-TCDQ:** define desired and minimal values of phase advances.
- **TCDQ / TCT /XRP:** define strategy with position, thresholds and movements during collide and squeeze with β^* levelling and crossing angle change. Define strategy for redundant limits (BETS, energy and β^*). Evaluate if the added complexity is needed and what is the impact on HL-LHC.
- **Bunch intensity:** a safe distribution of the peak bunch intensity is desired for 'TCDQ levelling'. Evaluate if interlocks on bunch intensity are needed, depending on the operational scenario.

BEAM LOSS MONITORING SYSTEM, CH. ZAMANTZAS

The BLM system is currently the only system capable of interlocking on high beam losses at the LHC and its performance is essential for the protection of the machine. During Run 2 automatic daily monitoring and preventive actions during technical stops were implemented, resulting in a significant reduction of system faults during 2018. This should be continued during Run 3.

There are no major upgrades of the system foreseen during LS2. However, the LHC diode consolidation project (DISMAC project) requires the disconnection of BLM monitors and the lifting of cable trays of signal and power cables. This work impacts nearly half of the system, around 1500 monitors. Between November 2019 and June 2020, the BLM system will have to be re-installed, this will be followed by a complete system checkout including the test of each monitor with a radiation source.

The on-going upgrades of the beam loss system for the LHC are:

- Modification of the BLETC firmware, including the full deployment of the "Injection Inhibit" feature.

Table 1: Maximum beam intensities and minimum beam emittance from injectors.

	2021	**2022**	**2023**	**2024**
Bunch charge [10^{11} p]	1.3 − 1.4	1.4 − 1.8	1.8 − 2.1	2.1 − 2.3
Normalized emittance [µm]				
BCMS or 8b4e	1.30	1.30	1.30−1.55	1.30−1.70
Standard 25 ns	1.65	1.65	1.65−1.90	1.90−2.10

- Modification of the BLM software: upgrade to FESA 3 and 64 bits OS, improve the speed of sanity checks and review and consolidate all diagnostic applications, including the daily checks with access to NXCALS.
- Redesign of the radiation source with trolley aiming to reduce failures and dose to operators.
- Radiation source with TIM (train inspection monorail) with the objective of building an autonomous system for the complete BLM validation.
- Development of a generic processing module for all BLM installations.
- Development of a new crate for future upgrades of the BLM acquisition system (SPS and LHC).
- Development of a BLM ASIC with the same functionality as the current electronics but allowing to place the new electronics based on the ASIC very close to the detector reducing the noise from long cables, like in IR3.
- Development of cryo dBLM to be installed in the interconnects QQBI.9L5 and QQBI.9R7.
- Testing of a new prototype of a LIC detector in HiRadMat (HRMT); full production expected for LS3.
- Development of a proportional chamber, with a higher sensitivity than the standard ionization chambers (IC). However, the proportional chamber is not suitable for machine protection but can be used e.g. as a replacement of the BLM IC bundle in cases like 16L2 or 31L2.

Discussion

- **D. Wollmann** asked if the deployment of the new processing boards is planned already for Run 3. **Ch. Zamantzas** replied that as long as they do not have reliability issues with the current boards this would happen most likely during LS3 or at another convenient moment.
- **J. Uythoven** asked if the injection inhibit firmware will be installed in the full BLM system. **Ch. Zamantzas** replied that although the firmware will be installed in all BLM crates, the implementation acts only on the maskable BLMs. This part is expected not be active during the first year of operation, due to the lower intensities, but the firmware will be deployed.

Follow-ups

- **Injection interlock inhibit:** define the procedure for early commissioning.
- **New processing module:** define the required revalidation in case of (urgent) exchanges from a current processing board to a new processing module during a run.

DBLMS IN RUN 3, J. KRAL

During the last years of Run 2, several diamond BLM detectors (dBLM) were installed in the LHC and in the SPS extraction regions. For injection loss diagnostics, the signal from dBLMs was used regularly in operation. The dBLM losses are displayed in a module in the Injection Quality Check monitor (IQC).

For the dBLM installed in the LHC ring a new read-out electronics (VFC card) was developed that was used in parallel to the old setup. The new read-out provides bunch-by-bunch losses in histogram mode. Additional features could be implemented, such as the integral loss per bunch, the analysis of fast frequency losses and an internal trigger based on the signal shape of per turn losses.

dBLM data has also been used for machine development studies, such as beam diffusion measurements and UFO studies. The development of the FESA class was started and a GUI was provided to the CCC to display the losses. Data is logged in NXCALS.

The dBLM system is not connected to the interlock system and it is not foreseen to be connected to it. It is however ideal for bunch-by-bunch detection of fast losses provided a proper trigger can be setup.

Discussion

- **D. Wollmann** asked about the long-term vision for those detectors. **J. Kral** explained that these are devices for additional measurements. Any further function or development will require additional resources. A data availability at the level of 80% is considered to be reasonable for the system.
- **A. Siemko** asked what the advantage of the internal trigger is. **J. Kral** replied that it can be added to the data and that it can be processed offline.

Follow-ups

- **Specifications:** define clear specifications for the different use cases: injection, dump, collimator losses, etc.

- **Data in Post Mortem:** evaluate if dBLM data is needed in Post Mortem since it is already logged in NXCALS.

BLM THRESHOLDS, A. LECHNER

During Run2 3525 BLMs were actively interlocking on beam losses, grouped in 113 threshold families. Thresh- old changes were documented in 36 ECRs. A summary of the main changes regarding the LHC BLM thresholds was presented:

- Implementation of a new model for the LHC magnets in 2015.
- Empirical corrections to the UFO model in 2015 and 2016.
- Adjustments due to special loss cases, like ULOs, 31L2 or 16L2.
- Regular adjustments with measurements for collimation losses and collision debris.
- Thresholds for ion runs.

The proposed strategy for Run 3 is to start with a similar configuration. For the magnet model no major changes are planned in LS2 but still some studies will be done for the new configurations e.g. the introduction of the 11 T dipole. Regarding collimation, new thresholds will be defined for the collimators with new materials and the model will be reviewed. No major changes are expected since the thresholds were already fine tuned with data. There is a new collimator layout and new BLM shielding for the injection regions in view of LIU beams. It is foreseen to re-install the filters that have been removed in 2018. The usage of the injection inhibit could be evaluated in the case limitations are observed.

Discussion

- **H. Timko** explained that the RF system might be limited with RF power for Hi-Lumi in the future, mitigation strategies should be evaluated. The RF voltage will have to be lowered at injection and energy matching to the SPS will become more critical. Ways to increase the strength of abort gap cleaning without too much beam degradation should be considered.

Follow-ups

- **LIC in IR7:** evaluate the use of LIC detectors in IR7 as main interlock system allowing more margin to dump on fast losses. This would allow an increase of short RS thresholds by a factor of about 14. Define strategy for fast losses interlocking in preparation for HL-LHC.
- **Collimator BLM thresholds:** update models for (new) collimator materials.
- **BCM thresholds:** ensure coherence between BLM and BCM thresholds of the experiments.
- **BLM threshold in IR3:** define maximum allowed momentum losses in IR3 due to lower RF voltage at injection to mitigate power limit. Possibly update thresholds in IR3. Improved energy matching between LHC and SPS

CHANGES TO OTHER BI SYSTEMS, T. LEVENS

Two redundant BPMs are used to measure and interlock the local beam orbit around the dump extraction channel. The system triggers a beam dump if circulating bunches have orbit excursions above 3 mm. The current system, based on the standard WBTN electronics, is not compatible with doublet bunches, therefore an upgrade project was launched after LS1. The new interlock BPM electronics will be based on high speed digitizers and a time multiplexing of BPM electrode signals, providing a single processing chain for both electrodes to minimise the effects of aging and drifts. The system will provide bunch-by-bunch positions and intensity information. The major components of the system, namely the high power combiner, the delay line filter and the 14-bit ADC module accommodated on the BI standard VFC-HD carrier, were developed and tested during Run 2. The new acquisition system will be installed during LS2 on a single BPM to evaluate the performance.

The Beam Change Current Monitor (BCCM), also called dI/dt system, was re-designed from scratch. The system is now based on the sum of signals from four BPM electrodes. The sum undergoes an RF envelope detection and a low-pass filtering. The resulting signal is digitised with 16-bit resolution and 40 MHz sampling synchronised to the beam. The beam current change is detected using a one-turn digital line concept and running subtraction of 40 MHz samples, performed on a standard BI VFC board. During the 2018 run, prototypes were installed for both beams, providing good performance. The most challenging requirement of detecting a one-turn total intensity change of 3×10^{11} p was achieved with an important margin. Due to time constrains the full interlock logic was not implemented. Detailed analysis of logged data did not show any unexpected false beam dump triggers. The system sensitivity can be improved for integration times that are multiple of 20 ms to average out mains harmonics. During LS2 the system will be finalized and its tunnel installation optimised. After LS2 the system will restart at first with a disabled interlock channel. It will be enabled once the system is fully validated with beam.

In total 10 collimators with embedded BPMs have SIS interlocks on their orbit readings: 4 TCTs in IR1, 4 TCTs in IR5 and 2 TCS in IR6. Orbit readings are provided by redundant DOROS electronics: BPM signals are split passively and processed by two independent sets of DOROS front-ends. The system has been operated with very good performance and excellent reliability, without any hardware faults and no false dumps, therefore it will be restarted after LS2 with no changes.

The Abort Gap Monitor (BSRA) surveys the particle population in the LHC abort gap. It is based on the detection of synchrotron radiation with gated photo-multipliers. The absolute calibration of the system is performed manually against fast beam transformers. During LS2 the system will be upgraded with new charge amplifiers and the new VME FMC carrier (SVEC). However, the functionality of the system will remain unchanged.

Following an incident in August 2018 with fast beam losses, the SPS operation requested safety improvements to better protect the machine:

- new dI/dt interlock;
- new BPM interlocks;
- BLM software upgrade.

The SPS dI/dt interlock will be based on DC beam current transformers (DCBCTs) to take into account also unbunched beam. A dedicated development is carried out in the BI group with the goal of installing the first system prototype during LS2.

SPS BPM interlocks will be based on the new BPM electronics, so called ALPS, replacing the current MOPOS system. The interlock functionality is foreseen in the firmware of the new system.

Discussion

- **D. Wollmann** asked about the interlocking plans regarding the additional collimators equipped with DOROS BPMs. **R. Bruce** replied that it could be envisaged to interlock the orbit at the collimators, in particular the new collimators with coating, as it was done for the tertiary collimators. He commented that a hardware based interlock could be useful. **B. Salvachua** and **J. Wenninger** commented that a possible hardware interlock has to be planned well in advance.

Follow-ups

- **dI/dt for LHC and SPS:** review and update the interlock specifications for BE-BI.
- **BPMs in IR6:** define how to start with the prototype system in parallel to the operational system in Run 3. Define the strategy how to switch if successful.
- **DOROS IR7 collimators:** define how many collimators need to be interlocked in Run 3 including TCDS in IR6. Evaluate if the current SIS implementation is sufficient or a BIS implementation needs to be prepared.
- **SPS BPM:** the current beam position interlock on the SPS extraction bump was implemented in the MOPOS front-end to be able to interlock as close as possible to the extraction ($\approx$50-80 ms) and connected to the two extraction interlock systems, clarify how this logic will be transfered to the new ALPS system.

REVIEW OF SAFE LIMITS FOR NEW COLLIMATOR MATERIALS, EXPERIMENT DETECTORS AND SUPERCONDUCTING MAGNET COMPONENTS, F. CARRA

Material damage by the beam is induced by the energy absorbed in the material, and damage thresholds depend on two parameters: peak energy density and average density per target section. Three damage levels are defined for collimator materials:

- threshold 1: onset of damage;
- threshold 2: damage to the surface, which can be corrected with a 5^{th} axis jaw displacement;
- threshold 3: damage cannot be corrected with a 5^{th} axis displacement.

Experimental tests and numerical simulations were carried out to study materials used in the LHC collimators. For primary and secondary collimator materials, thresholds 2 and 3 have never been reached experimentally. For tertiary collimator materials threshold 3 is expected for tungsten. In case of CuCD material, threshold 3 is not reached.

Experimental tests done on superconducting magnet components allowed assessing damage thresholds for the insulation as well as behaviour and damage limits of different superconducting materials.

In the experimental tests, expected damage mechanisms were mimicked. However, in order to completely validate the full scale devices, it is important to perform tests with the beam energy corresponding to LIU/HL-LHC operation.

Discussion

- **S. Fartoukh** asked why there is no number given for the async dump test. **F. Carra** explained the numbers are not yet available for all materials. The async dump case is not more critical than the beam injection error. **F. Carra** will update the figures as Stephane considered them extremely important.
- **D. Wollmann** asked if the additional experiments presented will be done in HighRadMat. **F. Carra** replied that indeed this is how it is going to be done.

Follow-ups

- **Test with LIU beams:** future material tests in HiRadMat with LIU beams are necessary. Dump line elements that were never tested for these intensities (like BTVDD) should be included.
- **Limits for asynchronous beam dump:** define damage limits for asynchronous beam dump cases for all involved materials.

REVIEW OF SAFE LIMITS FOR INJECTION AND EXTRACTION DEVICES, A. PERILLO

TDIS abosorbers provide protection in case of beam missteering during injection into the LHC. They intercept beam in case of malfunctions of the MKI kickers. A TDIS module was tested with HRMT beam with the result that the TDIS imposes no limits on HL operation.

For the TCDS thermal and structural simulations were carried out. They revealed a risk of failure by high stress and elevated temperature in graphite block 19 and plastic deformation in the titanium block. Therefore a design optimisation is recommended.

Simulations for the TCDQ showed that the integrity of the targets is expected to be kept, but the lack of material data prevents more reliable simulations. Therefore, detailed material characterisation is needed.

The LHC dump will undergo a number of improvements during LS2. The following system parts will be upgraded:

- downstream window,
- mechanical connections,
- upstream window (YETS 21/22),
- restraining of dump movements
- instrumentation.

The upgrades are expected to result in fewer interventions during Run 3. However, large dump displacements are still possible, so they should be monitored. Also in case of dilution failure, the graphite core temperature may be at the acceptable limit. This will be even more critical during HL-LHC operation. For this reason the core material should be characterised in detail.

Follow-ups

- **TDE:** stresses on housing of the downstream window require the complex simulations to be continued.

SESSION 2

LBDS - SYSTEM OVERVIEW, C. BRACCO

C. Bracco gave an overview of the main issues concerning the operation of the LHC Beam Dumping System (LBDS). She reported on the failures observed in Run 2 and showed how the hardware upgrade during Long Shutdown 2 (LS2) will improve the expected performance in Run 3. The extraction kickers MKD will be running at a lower voltage in Run 3 at 7 TeV than in Run 2 at 6.5 TeV beam energy. The relevant hardware changes are addressed in the following presentation by **N. Magnin** .

After recalling the working principle of the LBDS, **C. Bracco** gave a brief recap of the types of asynchronous beam dumps and the implications on the operational functions of the TCDQ collimator. In view of Run 3, she showed that the Beam Energy Tracking System (BETS) would limit the dynamic range of the β^* levelling presently proposed. She proposed a possible way to overcome this limitation, i.e. to implement more relaxed BETS limits around operational functions and attain the necessary TCDQ settings through squeeze at flat top via LVDT offsets.

C. Bracco also reported about erratics and flashovers at dilution kickers (MKB) in the beam dump lines. Both types of failure imply a reduced sweeping pattern at the front face of the dump absorbing blocks, with potential local increase of temperature of the absorbing block beyond tolerable values. The MKBV will be running at a higher voltage at 7 TeV, while the MKBH will be running at a lower voltage. The effect of the missing dilution is more relevant for MKBHs than for MKBVs since the former are fewer.

A test at 7 TeV without beam showed that parasitic electromagnetic coupling through the re-triggering line can lead to effectively losing the kick of more than two MKBs, contrary to what was foreseen by design. For this reason, MKB retriggering will be implemented in LS2 to avoid anti-phase in case of erratic. Moreover, during LS2, the MKBHs will be upgraded for operating at 7 TeV to operate at voltage lower than that one used at 6.5 TeV during Run 2, which should reduce the risk of erratics of the MKBHs, which are more critical for this failure case. It should be noted that the occurrence of erratics can lead to a limitation on the number of protons allowed per bunch and on the beam spot size due to the limited strength of the front window of the dump.

Concerning flash-overs, it was seen that, contrary to design assumptions, the kick of more than two MKBs can be lost due to the propagation of the flash-over through the suspected formation of a plasma to the magnet sharing the same vacuum tank.

The expected number of erratics per beam per year is < 1 for the MKD system and also < 1 for the MKB system.

Failures in Run 2 were briefly recalled, showing that their occurrences follow expectations. **C. Bracco** confirmed the goals for operation at 7 TeV and outlined the strategy to achieve it, namely:

- reducing the risk of erratics with lower voltages, monitoring the switch status and faster reaction in case of failures, with the aim of increasing reliability;
- several upgrades foreseen on generators and control system in LS2 including MKB re-triggering, to decrease the probability of erratics and avoid anti-phases;
- if needed, applying required modifications to improve HV bus-bars insulation in YETS;
- if approved, adding 2 MKBH per beam in LS3, which would allow to reduce the voltage of a single MKBH by around 30%.

Discussions

- **J. Wenninger** acknowledged the proposal of **C. Bracco** as a viable solution. He remarked that TCDQ position limits should anyway follow the collimator movement, and once this is achieved, the TCDQ will have to face the same problem of running pieces of functions, as for regular collimators. **C. Bracco** replied affirmatively to both remarks.

Follow-ups

- are there less invasive ways to properly setup the dump protection devices? The new ATS optics changes a lot in IR6. In particular, can asynchronous beam dump tests be complemented with losses at each dump with the bump method? What needs to be additionally studied to allow for this?
- is an increased beam size at the upstream window of the TDE a viable option?
  - due to bunch intensity- and optics-dependent limitations, this option can add complexity elsewhere;
  - is such option the way forward? Can it buy time until the new window is installed? How can this be done safely and reliably? What is the impact on MDs?

LHC BEAM DUMPING SYSTEMS - CHANGES IN LS2, N. MAGNIN

N. Magnin presented the upgrades related to the LBDS hardware planned for LS2. After reminding the audience about the main concerns about erratic firing of high-voltage (HV) generators, he presented the strategies to limit their occurrence, i.e. to upgrade the HV generators, and their impact, e.g. updating the re-triggering systems.

The upgrade of the HV generators that will take place in LS2 includes:

- the addition of a third capacitor, smaller than the two already present, to reduce the risk of erratics; the system reliability and availability for 7 TeV operation are expected to improve at the expense of a ~200 ns longer rise time.
- the re-design of the GTO stack, increasing its sparking immunity in presence of pollution. The upgrade comes at the expense of an increased rise time by ~15 ns.
- a new Power Trigger Module (PTM), which improves the GTO switching, decreases the global LBDS re-triggering time, avoids partial triggering of the PTM, and detects IGBT problems before breakdown. The new PTM will be faster than the present one by ~50 ns.

The upgrade of the HV generators will not imply any change in the length of the abort gap (AG), as the upgraded LBDS will still comply with an AG of 3 μs, and a faster re-trigger time by ~100 ns.

N. Magnin presented the schematics of the current re-triggering line and the main issues encountered in Run 2. The hardware upgrades that will take place in LS2 will be focussed on:

- A new MKD Re-Trigger Box (RTB) design, proposed to solve a diagnosis problem related to the observed attenuation of TSU/BIS pulses. The attenuation problem affects the IPOC, but it is not an issue for safety.
- Shortening of the cables between RTBs; in particular, 50 m could be saved, lowering the propagation delay by ~200 ns.
- The installation of the MKB Re-Trigger System, to avoid anti-phases between MKBs, and mask the generator coupling problem. The system is expected to make the probability for “no dilution” failures negligible at the expenses of a very limited increase in expected frequency of asynchronous dumps per year and an increased complexity of the LBDS.

Discussions

- **J. Uythoven** underlined the efforts made in the hardware design to increase safety and reliability, and appreciated the reduction in total re-triggering time.
- **D. Nisbet** wondered if the improvement on the probability of failure is given only by the decreased HV or whether there are other sources of improvement. **N. Magnin** underlined that the decrease in probability by a factor 20 is due to the decreased voltage on the HV switches (by 5 %) and to the new PTM design, which will use higher voltage rated IGBTs. Moreover, the erratics occurred so far were mainly due to dust on the HV GTO switch, whereas there are no indications that High Energy Hadrons (HEH) may have been a source of erratics with the current operational intensity and energy. In fact, the HEH rate is so low in the LBDS underground areas that RadMons measure nothing. Very sensitive sensors are under development by ABT.

Follow-ups

- A full recommissioning of the LBDS is required after the numerous upgrades.

INJECTION - OPERATION, F. VELOTTI

F. M. Velotti reported about issues encountered in Run 2 concerning beam injection into the LHC and what are the actions planned for LS2. He showed that losses at injection into the LHC have a similar behaviour in both 2017 and 2018, with the interconnection BLM being the most sensitive one and the one with the highest number of events with injection losses above 20 % of the dump threshold. In LS2, these BLMs will be equipped with a filter (with an attenuation factor of 20), bringing the signals with the expected losses in Run III in the same ballpark as 2018. He also reported two peculiar cases of losses in the injection region. In both cases, time was essential to understand the source and apply consistent corrective actions. Experience showed that it is important not to rush to continue with physics, while trying to minimise the time needed for investigation.

F. M. Velotti also reviewed key operational aspects of transfer line (TL) steering and TCDI collimator setting up. TL steering is encouraged even every fill, if necessary; it can be done more frequently if 2 trains of 12 bunches were fit in every filling scheme. It was also proposed to dynamically change the filling scheme with less than 12 bunches in case steering is not needed, but the feasibility of this option is still under evaluation. If necessary, steering could also be done without the need for re-injecting a 12-bunch train provided that the correction does not exceed the FEI limits (i.e. any adjustement of the FEI settings from the SPS OP crew must be evaluated with a 12 bunches injection). For Run 3 he also proposed to maintain the present interlock logics on injection oscillations. Moreover, dedicated beam processes for different TL and SPS optics could be used, storing TCDI collimator settings, with a software check of settings and optics in the software interlock system (SIS).

New TCDI and TDI devices will be installed during LS2, aimed at providing sufficient protection against fast losses with LIU beams. The experience gained in automating the setting up of the old devices will be re-used; hence, commissioning time with the new devices is not expected to increase.

Discussions

- **J. Wenninger** wondered if the new TDI could follow the same automatic procedure as that of the other collimators. **C. Bracco** replied affirmatively, underlying anyway that its validation will still follow not the standard one for collimators, but a dedicated one.

- As a reply to **J. Uythoven** , **F. M. Velotti** reminded the audience that the maximum oscillation amplitude obtainable with corrections inside the FEI window using a single corrector is in the order of 1 σ, with kicks of 10 μrad. He reminded that the suggested procedure is still to perform steering at the beginning of the fill.

- As a reply to **S. Fartoukh** , **F. M. Velotti** underlined that new power converters will be installed on the TLs and the optics will be indeed slightly different, as a consequence of new TCDI positions, mainly in TI8. Optics measurements are usually carried out after restarting from a Long Shutdown (LS), hence this change will not add time to the already allocated commissioning time.

- **J. Wenninger** underlines that bouncing between two injection beam processes will make hardware interlocking almost obsolete as all protection will come from software (SIS).

Follow-ups

- Evaluate interlocks and SIS checks in case of dedicated beam process with TCDI jaw positions for each TL optics.

- Evaluate potential deployment of TL steering with full trains or the use of two 12 bunch trains in dedicated filling schemes.

COLLIMATION, D. MIRARCHI

After a brief recap of the collimation layout, **D. Mirarchi** gave an overview of the performance of the LHC collimation system in Run 2, underlying all the changes that allowed to accommodate the pushed crossing angle conditions achieved in 2017 and 2018 while ensuring machine protection, with no quenches induced by the circulating beam. He gave also an overview of the evolution of the collimator settings and the validation strategy throughout Run 2.

D. Mirarchi reported also known near-misses in Run 2:

- a step in the β^*-levelling was executed before finishing the crossing-angle anti-levelling. The collimators would not have protected the aperture, but the beam was dumped by reaching position limits. He underlined that the redundancy in the system avoided a potentially dangerous condition. It must also be noted that with collimator interlock functions this problem would not have occured.

- during the machine development (MD) activity with asymmetric crossing conditions, the scan was extended to a a wider range without moving collimators accordingly; the safety of the collimators was not guaranteed in case of asynchronous beam dump (which did not take place).

- crystals were left in cleaning position after the last physics fill of the high-β run at injection, causing dumps on injection losses when setting up the Van der Meer cycle.

D. Mirarchi presented the hardware changes foreseen for LS2, stressing the importance of BPMs for a fast setting up of the collimators. He also outlined a possible working point for the system and the plans for automation in view of Run 3.

Discussions

- **A. Siemko** asked what is the level of stability of the alignment and if there is any need to correct it dur- ing the operational year. **D. Mirarchi** replied that no correction is necessary along the year, thanks to the very good stability and reproducibility of the machine. **D. Wollmann** asked why qualification loss maps (LMs) should be taken every three months. **R. Bruce** replied that in 2017 the hierarchy was found broked during a qualification campaign, and the orbit had to be corrected.

- **J. Uythoven** underlined the 500 % dynamic range in β^* -levelling foreseen for Run 3, and he wondered what will be the requirements for validation. **D. Mirarchi** replied that both betatron and off-momentum loss maps should be performed at each static point of the cycle during the initial commissioning with beam. Betatron loss maps should be performed at each static point also after technical stops, while off-momentum loss maps can be alternated. The same strategy was adopted in Run 2. **J. Wenninger** underlined that while betatron loss maps do not cost much in terms of operational time, asynchronous beam dumps have a considerable impact on commissioning time.

- **S. Fartoukh** wondered why the IR7 cleaning inefficiency changes in IR7 during the ramp if the optics does not. **D. Mirarchi** replied that losses depend on beam energy and collimator settings, changed along the ramp.

- **D. Wollmann** appreciated the proposal of automatising the analysis of loss maps. He also wondered if qualification loss maps could be skipped and the qualification of the collimation system could come from operational losses. **D. Mirarchi** underlined that with dedicated loss maps, beam losses are better under control and known, whereas with operational losses the beam and plane of losses are not known with adequate accuracy.

- **D. Wollmann** asked what is the robustness level of BPMs. **F. Carra** replied that HiRadMad tests showed that the tapering material plays an important role in the survival of the BPMs to direct beam impacts. BPMs embedded in a MoGr tapering suffered way less than those embedded in GlidCop, which suffered melting. **M. Gasior** underlined that, having two pairs of buttons per collimator, interlocking can be granted if the jaws are kept parallel.

Follow-ups

- possible implementation of automatic loss map checks. Once they would be fully reliable, they might be integrated into the regular post-mortem analysis...

- check on the possibility to use validation with bumps instead of / in addition to the traditional asynchronous beam dump tests.

- what are the desiderata for MKD-TCT and MKD-TCDQ phase advances?

- strategy for TCDQ, TCT and XRP settings for collide&squeeze beam process in presence of β^* -levelling and crossing angle changes:
  - identify positions, thresholds and adequate jaw movements;
  - set properly redundant limits, i.e. BETS, energy and β^* thresholds;
  - how much complexity is necessary in Run 3, what do we need to learn for HL?

- identify strategy to change limits. Should discrete limits be executed in steps by outside instances such as the sequencer, as done in 2018?

QUENCH PROTECTION SYSTEMS, J. SPASIC

In his presentation **J. Spasic** introduced the Quench Protection System (QPS) and described the changes planned for the QPS during LS2. The QPS upgrades are summarized here below:

- Renovation of the DYPQ for the main quadrupoles: upgrades in terms of core functions, diagnostics, maintenance and tolerance to radiation.

- New QPS for 11T dipoles, new design of a Universal Quench Detection system.

- General consolidation of the QPS for Individually Powered magnets (IPx).

- Upgrade of QPS Supervision and Control.

Discussions

- **D. Wollmann** asked a question on the improvement of the Post Mortem timing in QPS for MQ. **J. Spasic** confirms absolute timing resolution for Post Mortem data of less than 1 ms.

- **D. Nisbet** questioned how many 600A Extraction circuits were planned to be by-passed. **J. Spasic** replied that 600A EE systems in the circuits with operational current less than 300 A will be by-passed, since MP3 concluded that EE systems for these circuits were not necessary for protection. **M. Zerlauth** clarified this latter point, stating that this action was additionally taken in order to reduce interventions and needless piquet time.

Follow-up

- Define the extent and necessary mitigation actions for the reduction of operational 600A EE units in the LHC for Run 3.

- Upgrade of QPS Supervision & Control to be operational before QPS IST and LHC HWC.

INTERLOCK SYSTEMS, I. RAMIREZ

I. Romera Ramirez presented the LS2 plans relative to the different Interlock Systems: BIS, SMP, PIC, WIC and FMCM. He outlined the new SPS injection interlock architecture following the SBDS relocation to LSS5, the generation of new SMP TED flags, the new PIC interlocks for the 11T dipoles and the planned new WIC installations for LS2. No notable changes are foreseen for the FMCM.

Discussions

- **J. Wenninger** asked about the logic foreseen for the SMP TED flags, and where will the flag fit in. **R. Secondo** and **J. Uythoven** replied that the flag will be distributed by the SMP via GMT, the new flags will be fed into the PLC logic that currently moves the TEDs, in order to protect the TEDs from high intensity LIU beams. The TED controls will then interlock extraction as a a function of its position and the beam intensity in the SPS.
- **D. Nisbet** noted that the RD1.LR1/5 recombination dipoles will become superconducting in LS3, therefore the 2 RPADO power converters that feed these circuits will be removed. In LS3, one could study the possibility to deploy these power converters on some other sensitive circuits (i.e. RQ4.LR3/7 or RQ5.LR3/7).
- **M. Zerlauth** had a question regarding the BBCW connection to the WIC for BBLR compensation.
  I. Romera Ramirez answered that a testbed has been setup in the lab to measure the failure response time between the FGC3 and the WIC. The time response measured was of 1.2 ms. **V. Montabonnet** specified that no change is scheduled for the FGC2 controller, but a test will be needed during LS2 to measure the FGC2 response to the BIS since BBCW will be powered by a converter controlled by an FGC2.

Follow-ups

- No hardware chages are foreseen on the FMCMs, beyond controls upgrades (i.e. FESA classes). For operation at 7 TeV, circuit currents are to be reviewed and voltage dividers re-adjusted at the input stage of all FMCMs in the LHC.
- Future interlocking requirements for HL-LHC need to be clarified: SMP bunch intensity, review of Beam Permit Loops linking due to beam-beam kick effects.
- Measurement of the time response between WIC and FGC2 to be perfomed in LS2.

POWER CONVERTERS, V. MONTABONNET

V. Montabonnet gave an overview of the planned activities related to the power converters for LS2. In particular there are 104 LHC600A-10V units and 60 LHC4-6-8kA units in exposed radiation areas that are scheduled to be replaced by new rad-tolerant versions. The control is based on the FGCLite, already reviewed by MPP in 2014. The procedure to remotely power cycle the FGCLite was described. A new “PMD" Post Mortem service will be deployed and changes are planned to the FGC API, aiming at reducing the impact on systems using FGCs or FGC data. Finally a new EPC concentrator (EPIC CIBU) to serve as interface to the BIS (in the injectors where large number of converters need to be interfaced) was presented.

Discussions

- **M. Solfaroli** had a comment: in point 3 the 600A converters are not scheduled to be changed. It is required to have a mixed configurations on trims for different Power Converters, which implies certain risks. This matter is to be followed up with Quentin.
- **A. Siemko** asked for a clarification regarding the failure mode "communication lost" of the FGCLite. **V. Montabonnet** described the different steps of the procedure after a lost communication issue: a power cycle is immediately perfomed following a fully automatized procedure, the converter goes in “FAULT" when this happens. The SIS also dumps the beam to act as a second line of defense (there is no hardware connection to the PIC for the 60 A converters).
- **J. Uythoven** had a question on the timeline regarding the test of the EPIC concentrator. **V. Montabonnet** and **D. Nisbet** replied that it is foreseen for end of August 2019 at LINAC4.
- **M. Zerlauth** had a question regarding the internal redundancy of the R2E-LHC600A-10V Power supplies, and if they are completely transparent to the loss of one module. **V. Montabonnet** replied that yes they are redundant and the loss is transparent if the output current requested is below ±400A, as the R2E-LHC600A-10V are made of 2x -400A±10V redundant high frequency current sources.

Follow-ups

- Replacement of 104 LHC600A-10V and 60 LHC4-6-8kA during LS2.
- The CIBU connections to the EPIC concentrator require electrical re-qualification.
- Linac4 is to be considered as a milestone in terms of identification of further dependencies.

SESSION 3 - PROTECTION RELATED TOOLS, MPP AND EXPERIMENTS

Abstract

This session discussed the role of protection-related tools, the (r)MPP and the machine-experiment interface. It included presentations about the *"ADT"*, *"LSA configuration and Lumi server"*, *"Collimation MPP-related software and settings generation"*, *"LHC SIS, β* reconstruction and PC interlock"*, *"Post Mortem, AccTesting, Logging"*, *"MPP, rMPP experience during Run 2"*, and the *"Machine Experiment Interface"*.

ADT, D. VALUCH

D. Valuch gave an overview of planned ADT upgrades during the Long Shutdown 2 (LS2) and operations during Run 2 and beyond, with particular attention to implications for machine protection. The main system upgrades during LS2 will be: new signal processing to shorten delay in the feedback loop allowing for a faster damping, new control software and settings management, and new functionality requested by operation (mainly automated excitation and acquisition). The shorter delay (down to 5 turns), leads to faster growth rates in case of failures. The power system and kickers will remain the same, while new beam position modules will be deployed but are not expected to have any impact on machine protection aspects. In conclusion, the maximum power limit of the system will stay the same, but it will be used more efficiently / can react faster.

Nevertheless, more users, machines, and automated sequences will be able to interact with and control the ADT hardware. Thus, several RBAC roles for different functions are present and no incidents related to settings protection were experienced so far, while there have been few isolated incidents related to humans dealing with those settings. Sometimes there is the need to relax protection limits in order to improve automation and flexibility, such as during MDs. Special modes and MDs are typically run by experts and require a thorough preparation, test and loading of special settings. Very good results have been obtained in MDs that had a clear schedule and timeline. On the other hand, end-of-fill (EoF) MDs were usually more problematic because of the reduced time allocated for thorough testing, given their nature of floating MDs. The main lessons learnt are: it is not possible to be flexible and responsive if tests require time to be prepared. Unorganised/unplanned EoF MDs penalise tests which require such thorough preparation.

The ADT will need to be re-commissioned “as new” after LS2, following a two stage validation: the new firmware is always thoroughly tested in the laboratory, a full dedicated test with few bunches is always run when deployed in the machine, the excitation is checked without and with circulating beam by means of an oscilloscope on the deflection plates.

More discussions are required to address if improved abort gap cleaning is possible.

No impacts on operations at 7 TeV are expected, because there is not much difference with respect to operation at 6.5 TeV.

Discussion

J. Uythoven asked whether the energy in the machine or the reduced efficiency leading to losing the beam is the main worry in case of mishaps. **D. Valuch** replied that it is mostly about how the beam is lost that determines possible damages to the machine. **J. Uythoven** commented that maybe relying only on BLMs in not fast enough. **D. Valuch** replied that a dump triggered by BLMs can take 3 turns, while the ADT can double the oscillation amplitude in 5 turns. Thus, there is enough time and margin before inducing an oscillation able to reach the aperture. **J. Uythoven** asked if it means that there is no need to put other machine protection (MP) constraints that can reduce the flexibility of the ADT. **D. Valuch** replied that no mishaps were experienced during standard operations, while there were some events during machine development (MD) studies. **J. Uythoven** asked if then more emphasis on MP aspects should be put on MDs. **D.** Valuch replied that this would cost in term on flexibility, which is needed during MDs.

D. Wollmann commented that it would be good to define the time needed to deploy and validate changes when requested by users for MDs. **D. Valuch** replied that this information is already given to users, but for End of Fill MDs it is not always straightforward because of their nature of floating MDs.

J. Wenninger commented that a shift at the beginning of MD blocks could be envisaged to validate the ADT working point, if necessary. **D. Valuch** replied that everything used during MDs is always properly prepared and tested in the lab. Nevertheless, it would be useful to have some time at the beginning of the MD to perform checks in the operational conditions and with (safe) beam.

J. Wenninger commented that it would be useful to have a better feeling of applied changes, for example to the firmware, to avoid that the ADT becomes a black box.

Follow-ups

- Define re-commissioning/testing procedure for changes/adaptations of the ADT (especially for MD).
- How to provide more transparency to OP after changes to the ADT firmware?
- Who decides to unlock ADT protections for MDs? How to assure no short-cuts are taken in procedures in particular for such potentially critical equipment?
- MDs: Foresee dedicated slot for special MD conditions and preparations (ADT, COLL, ...)

LSA CONFIGURATION AND LUMI SERVER, M. HOSTETTLER

M. Hostettler reported on LSA Settings protection, on the Lumi Server and on β^* levelling.

Two mechanism of settings protection are present: restricted trims of "critical" settings limited to role-holders that are implemented in CMW/FESA and restricted LSA settings changes (CCC or role holders for outside CCC). A few loopholes are still present: protection for context editing and optics related actions to be added, Power Converters (PC) Interlock references to be protected, protection against accidental mis-manipulations but not against malice.

Regarding the lumi server, the main steps are: identify start and destination match points from a repository function Beam Process (BP), prepare functions on top level, calculate currents that are sliced and/or inverted, trim on actual resident BP. The orchestration process controls collimators, orbit feedback, LSA/PC, and Timing system to synchronise all of them. The steps followed by the β^* levelling orchestration are essentially the same of the sequencer except for the initial calculations. Regarding machine protection aspects, currents, orbit feedback reference and collimator centres are dynamically calculated from orbit response, while a safe protection envelope is provided by external systems, such as collimator limits and PCInterlock. Thus, the Lumi Server should not be critical for machine protection. Several MDs on β^* levelling were carried out in 2017 and 2018, and a solid operational experience was also acquired during Run 2.

The present strategy for the restart in Run 3, is the simultaneous crossing angle and β^* levelling. No issues are forseen for PCs, and orbit feedback, while the safe handling of collimator limits remains to be defined. The possible strategies are: use of 1-3 sets of discrete limits that allow for centre changes as done in Run 2, implement the arming of partial limit functions that will require a complete re-validation of the control system, make position limits non-critical.

Discussion

S. Fartoukh asked clarifications about potential problems with TCTs during the β^* squeeze in Run3. **M. Hostettler** replied that they come from the change of crossing (Xing), which has a larger range than in 2018. Thus, static lim- its that allow to follow the reference orbit with TCTs, be- come too large. **S. Fartoukh** commented that the gymnastic was tested during MDs. **J. Uythoven** added than although something is done in MDs, it is not automatically feasible in operations with several 100 MJ of stored energy in the beams. Moreover, it should be avoided that the lumi server can sign collimator limits, because it would become critical for MP. **M. Solfaroli** commented that the best option would be using fixed static limits slightly opened in steps to allow TCTs movements, as already done during 2018 operations. **E. Bravin** asked if a collimation hierarchy breakage can be experienced if limits are opened. **D. Mirarchi** replied that the required opening of the limits will not make it possible to brake the hierarchy. Moreover, the only difference with respect to 2018 operations would be to load new static limits twice instead of only once, in order to cover the larger range of Xing angle change. When the jaws position limits of one side is opened, the other side is automatically closed, and limits are symmetrized again when the Xing change is finished. **D. Wollmann** asked if the missing loading of appropriate limits would cause a beam dump. **D. Mirarchi** replied that this is not possible because the expected jaw movement is computed in advance, it is automatically rejected if it exceeds position limits and the lumi server would not initiate the Xing change. **M. Hostettler** added that indeed the movements are pre-calculated and steps refused by the lumi server in case they would drive the collimators into interlock limits. However, this is a courtesy function of the lumi server and should not be taken as a 100% reli- able safeguard. In particular, all lumi server calculations are based on the motor positions, not on the LVDTs, so in case of a large LVDT offset in the “bad” direction and a step that moves the settings right to the edge of the dump limits, it could theoretically dump (that never happened so far).

S. Fartoukh commented that only a factor 2 in Xing range is present between 2018 operations and the present scenario for 2021. Thus, it would be possible to not move TCTs during levelling. **R. Bruce** replied that this scenario would imply asymmetric settings of the TCTs, which is not optimal given the BPM interlock that requires constant centring of TCTs around the local orbit.

J. Wenninger commented that a potential problem with discrete settings can be the proliferation of dedicated Beam Process (BP) needed to store them. **M. Hostettler** added that few actual beam processes (linked to the appropriate times in the β^* levelling function BP) can be a solution to store discrete limits. This would at least formally “attach” these settings to the right points in the levelling BP, and the actuals could be generated from function limits in the BP (given the roles to do so). This looks like the best compromise and further follow up are needed as soon as the implementation in the lumi server is performed.

Follow-ups

- Define how collimator limits can be changed! Use discrete limit steps executed by outside instance such as e.g. sequencer, similar as in 2018? Sufficient, but not very safe?
- Same for pcinterlocks, mainly on orbit correctors.

COLLIMATION MPP-RELATED SOFTWARE AND SETTINGS GENERATION, A. MEREGHETTI

A. Mereghetti presented an overview of collimator alignment, settings generation, testing and verification, to then move to Roman Pots, temperature interlocks and a wish list of changes in view of Run 3.

Very good performance of the system was achieved in Run 2, with no quenches from circulating beam recorded with up to 300 MJ of stored beam energy. The performance depends critically on correct collimator positioning along the entire cycle. Collimator jaws are moved by means of 4 stepping motors placed at each corner, which are equipped with resolvers and LVDT sensors. Discrete and time-dependent (function) settings that are sent to the hardware, are stored in LSA and are determined by means of higher level parameters. Interlock thresholds on jaw positions as a function of time are also present, together with redundancy interlocking on gaps and temperature interlocks.

Jaw corner positions and gaps are generated based on collimator alignment, normalised settings depending on the collimator functionality and LVDT offsets. Time functions are generated via MAD-X simulations and folded with values of centres measured at each static point. An excellent agreement between simulated and measured centres has been achieved for TCT centre functions, complicated by the changes in the crossing conditions taking place in the various beam processes. These settings are automatically generated with dedicated software trying to minimizes human intervention. Testing and verification is carried out both with and without beam, with final validation carried out by means of loss maps.

The collimator alignment has evolved significantly during the years, with the introduction of a semi-automatic alignment in 2011 and the fully-automatic one in 2018, leading to a drastic reduction of experts and time needed for the alignment. Tests of the latest development on the fully-automatic collimator alignment show the same results as those obtained with the semi-automatic method, indicating that the fully automatic algorithm is reliable.

Regarding Roman Pots, they were successfully inserted in almost all physics fills in Run 2 showing only few faults, such as: initial problems with PXI, rare problems with LVDTs (one dump was triggered and pots automatically retracted by springs), and occasional problems with micro switches. Main interventions during LS 2 will involve the vertical alignment of LSS5, the installation of new detector packages, more RF shielding, and changes to the movement system. The commissioning at restart in Run 3 will involve: movement and full interlock tests, and beam-based alignment.

Loads on collimators due to slowly varying dips in beam lifetime are monitored by temperature sensors, which are interlocked. Issues with faulty temperature readings led to disabling some sensors in Run 1 and Run 2, triggering one dump in Run 2. An upgraded algorithm to automatically identify faulty sensors is being developed.

Main wishes for Run 3 are: implement collimator settings generation in LSA, full deployment of fully automatic alignment, time-dependent limits to crystal control system, automatic disabling of temperature sensors with erratic readouts, online loss maps pre-analysis in the CCC before final validation, improvements in settings checker.

Discussion

C. Schwick asked if the LVDT system of the collimators is the same as the one of the Roman Pots (XRP), because XRPs suffered of spurious spikes in LVDTs signal. **R. Bruce** replied that collimators have more LVDTs than XRPs, providing more redundancy. Moreover, a slow drift is observed in the LVDTs reading at collimators, rather than spikes for which margins on interlock limits are accounted. **J. Wenninger** commented that differences are present also at the level of the PXI, with less collimators connected to a single PXI with respect to the XRP case. **D. Wollmann** added that in the long-term it would be good to converge back together the low level for XRP and collimators.

M. Zerlauth asked which is the priority between items in the wish list of changes. **A. Mereghetti** replied those closest to reach are the automatic disabling of temperature sensors with erratic readouts and the implementation of limit functions for crystal, while the fully automatic alignment is technically operational (its deployment is just a matter of deciding to use it) and the rest are floating, especially in terms of man power. **M. Solfaroli** commented that the generation of collimator settings directly in LSA is also very critical and important for OP because it requires a huge amount of work and the present approach is more error prone although standardization was developed during the years.

Follow-ups

- Define wish list priorities for collimation software upgrades with OP and MPP. E.g. generation of collimators settings in LSA, revised temperature interlocks disabling, ramp functions for crystals, ...

LHC SIS, BETA* RECONSTRUCTION AND PC INTERLOCK, J. WENNINGER

J. Wenninger gave an overview on the LHC Software Interlock System (SIS), β^* reconstruction and aspects of the PC interlock.

The SIS is a server used for subscriptions to LHC devices and LSA settings, tests and state/data export to several systems. 2800 parameters are subscribed to and 82000 tests are performed. About 4000 tests concern power convert- ers. Local instances of the sis-server can be run, together with the sis-gui to test configurations or to observe operation parasitically. The results of these tests can be found in the LHC OP logbook and/or the LHC MP test spreadsheet. The generation of Post Mortem (PM) by the SIS has been added during Run 2. Many maskable and a few unmaskable tests were present in the Run 1 configuration. However, more flexibility was needed for MDs that required to mask something that should never be masked during operations. Thus, a new masking logic was introduced in 2017 with two masking levels, without the automatic removal of masks in sequences. A possible change for Run 3 could be the introduction of a third masking class dedicated for MDs and the development of a sequencer task and sis-server changes that reset this class only. Nevertheless, there is a small risk that some MDs can loose the beam, if the re-masking is forgotten between two fills. Main work during LS2 will be on configuration maintenance and clean up, software upgrade, and implementation of new tests for more interlocks expected at collimators.

Orbit related interlocks are the second largest interlock category after PC related interlocks and are divided into different classes. A possible change for Run 3 could be the use of new SVD inversion algorithms that would allow to reconfigure the orbit feedback on the timescale of below 1 second. Thus, it may become possible to avoid dumps when 60 A CODs fail. The orbit corrector kicks were initially surveyed by SIS in three phases, while in Run 2 only the injection interlock remained. The PC interlock server currently tracks all orbit corrector and quadrupole currents and references are retrieved from clones of the operational beam process. The possibility to protect the PC interlock reference settings needs to be taken into account for Run 3. Proposed changes for Run 3 are the addition of a few converters that are missing and to split the status signals by beam (and plane where applicable), while sextupoles, octupoles and spools should be kept out of the PC interlock. Also the global orbit is surveyed by the SIS in 3 phases and interlock references and tolerances can be updated, imported and visualised with YASP. The orbit feedback references are stored as LSA functions for each BPM since 2016. Possible changes for Run 3 could be the extension of the PC-interlock concept to the BPMs by adding a tolerance function for each BPM reading, which will provide much tighter interlocking along the cycle. SIS interlocks on BPM positions in the TCTs and TCSP6 were introduced in 2017, using a β^* dependent tolerance. In 2018, no reading exceeded about 60% of the tolerance. Changes for Run 3 could be an improved diagnostics GUI and the addition of more collimator BPM interlocks in IR7. On the longer term timescale, these BPM interlocks should be moved to the hardware.

The present concept for β^* reconstruction is based on the current ratio between two selected quadrupole PCs per IP, and it is used as machine protection parameter for collimator gap/BPM interlocks and the Stable Beams flag. This concept had to be extended for the telescopic part of the squeeze, by adding a second table with 2 PCs from the tele-squeeze IPs. However, no solution was found for the flat optics and a new concept should be put in place for Run 3. A possible solution could be the deployment of the LHC State Tracker (LST), which tracks the execution of the active beam process. It is based on the PC-interlock concept, but follows any LSA parameter function in the beam process, instead of interlocking PCs. A prototype LST was implemented and tested at the end of 2018. The aim is to operate an operational LST in Run 3, which can be used to replace the current β^* reconstruction. A drawback could be that swapping active beam process will result in wrong data publications. An alternative solution for β^* reconstruction is also available, but is not yet proven to work and should therefore be studied in the coming months.

Discussion

D. Nisbet asked if the automatic SIS unmasking may be based also on time limits. **J. Wenninger** replied that this can be dangerous because the mask could be reset during an MD. **E. Bravin** commented that the two options could be combined, i.e. SIS masks are automatically reset by the operational sequence when played after a certain time limit.

S. Fartoukh commented that many changes are expected with ATS optics that would imply different ways of β^* reconstruction, and the best option would be the implementation based on the LHC State Tracker (LST). **J. Wenninger** replied that the LST prototype is already working.

Follow-ups

- SIS masking policy to be extended by 'MD type' and automatic removal (e.g. PM injection interlock, ...)?
- Decide the approach to be taken for beta* reconstruction (LST or ki space)? Future solution ideally to work for all optics (high beta, ATS, flat,..)

POST MORTEM, ACCTESTING, LOGGING, J.C. GARNIER

J.C. Garnier presented the status of Post Mortem, Logging and AccTesting. He first discussed the Control System Upgrade Strategy for LS2, stressing that Run 3 will use an entirely new and upgraded control system. He explained the transition from CALS to NXCALS, and presented the new PM Architecture, based on NXCALS, Kafka and Spark. He highlighted that analysis jobs can then be sent directly to Spark rather than extracting the data for local analysis. The Spark implementation is fast and parallel. However, there is still a latency issue before the data is available for read- ing, which could be a potential problem for fast use cases like XPOC, IQC and SPSQC and has to be studied in more detail to find the best solution. In the last part of the talk, he showed the planned upgrades to the AccTesting framework, including a plan to support BIS and WIC commissioning with AccTesting. He concluded by stating that the Control System LS2 Baseline should be ready for the LINAC4 LBE Run by end of June 2019, so that core BE-CO products can already be validated in operation.

Discussion

J. Wenninger commented on the approach to use Spark capabilities to analyse the data. He stressed that the main use case in the control room is to directly observe the behaviour of BLMs and BPMs without performing further analysis. **J.-C. Garnier** replied that for the present system, one needs to extract the data before analysing it, while with the new system there exist the additional possibility to analyse directly without extracting. However, the mere data extraction remains possible and is considered an important part of the framework. **M. Zerlauth** confirmed that indeed this core functionality will be preserved while the direct analysis will be included as additional option.

J. Uythoven commented on the SPS quality check and the required interlocking. He stressed that it is crucial that the data is available when required, e.g., in case of an incident. Therefore, one needs a fundamental check, which doesn't require a complex analysis but makes sure that the data is properly stored. **J.-C. Garnier** answered that one has to distinguish between whether the data is correctly stored and whether the data is visible by the users. **J. Uythoven** remarked that one has to avoid that some part of the system that pushes the data stops working without being noticed until there is an incident where the data would be needed. **V. Kain** emphasised that also for the operation of the machine it is important that the information is readily available. The required data includes the XPOC analysis for the new SPS beam dump system, but even without beam dump analysis, the quality check data is required for machine operation within a reasonably short time delay. It has, thus, to be avoided that the data is received only several cycles later, which would reduce its purpose and make the work impractical.

Follow-ups

- Define data volume and latency requirements for XPOC, IQC, and SPSQC use-cases within PM so that it can be used for operation and interlocking.

MPP, rMPP EXPERIENCE DURING RUN 2, C. WIESNER

C. Wiesner gave an overview of the activities of the Machine Protection Panel (MPP) and the restricted MPP (rMPP) during Run 2. He reminded that, thanks to the fruitful and successful collaboration between MP equipment teams, OP and MP experts, no damage occurred in the LHC during the Run, even though several issues were encountered. He suggested that in the future the rMPP should get stronger involved for the Special Runs, including recovery procedures and discussion of short-term changes. He reminded that the MPP activities have been focused on LHC and, to a lesser extent, the SPS. However, the cooperation with the injector experts is increasing and an extension of the activities to LINAC4/PSB/PS is under discussion. He reckoned that the checklists used during the intensity ramp-ups have been proven a valuable tool to verify MP readiness for the next intensity step. The cruise checklists during regular operation should be issued in 4-6 weeks periods, possibly with flexible check periods in the future. As a follow-up from the discussion at the 9th LHC Operations Evian Workshop, he presented a proposal to issue major machine-protection-relevant event reports and gave examples of past events. Finally, he summarized the required updates for the emergency and commissioning procedures, and concluded with a discussion of the MP challenges for Run 3.

Discussion

A. Lechner asked regarding the classification of Major Event Reports and whether injection kicker (MKI) erratics, which are acceptable failure cases, and magnet quenches should be considered as major events. **C. Wiesner** responded that a quench for a well understood reason, e.g. caused by an UFO event, should not be considered a major event, and would normally cause a downtime of less than 24 hours. Similarly, the erratic firing of an injection or dilution kicker, where the behaviour and the beam losses are understood and as expected, wouldn't be classified as a major event. However, if the losses are higher than expected or the loss pattern is non-understood, it would be worth to document it in a Major Event Report. He gave two additional examples: 1) An asynchronous beam dump with full intensity at top energy, causing more than 24 hours of downtime, should be consider a major event, which is worth to be documented, even though it is an accepted failure cases. 2) A triplet quench would not be per se a major event, but if one of the two beams is unexpectedly moving due to the quench, and non-understood losses are created, that would be a reason to classify it as major event. **J. Uythoven** stressed that even for a failure that is considered acceptable, one wants to be sure that the protection systems reacted as expected. He reminded that this analysis is normally done anyway, but so far it is not documented in a standardised way. He added that an important part of the report will be the required follow-up actions in order to prevent similar events in the future. **C. Wiesner** summarized that the idea is to document these events in a more centralised, more concise, and more rigorous way, without creating unnecessary overhead. This implies that the number of major events should be limited to a few per year. Using the presented criteria, it would have been a few major events per year during the last run. If we had much more events per year, then either the criteria would not be set adequately, or we would have a real issue with the machine.

Follow-up

- The membership of MPP and rMPP has to be updated in LS2. The rMPP should be more involved during Special Runs (MD like process?).
- The emergency procedure for non-working beam dump has to be updated during LS2 and tested after the machine restart. The commissioning and recovery procedures for MP systems (like for an asynchronous dump) have to be reviewed in LS2.
- Propose template for Major Event Reports for MP-related events before end of LS2.
- The intensity cruise checklists have to updated and the feasibility for a new online tool has to be evaluated.
- Check if signing of the PM is still a valid procedure.
- Evaluate whether/how to extend the (r)MPP work to the injectors.

MACHINE EXPERIMENT INTERFACE, C. SCHWICK

C. Schwick presented the input of the Experiments and LHC Physics Coordinators (LPC) to the MPP workshop. He first discussed the interlock handling in the experiments. After reminding that all experiments are connected to the injection as well as to the beam interlock system, he summarized the detailed interlock strategy for ATLAS AFP/ALFA, CMS, ALICE, LHCb, and TOTEM/PPS. He then reviewed the handling of Accelerator and Beam Modes, which are relevant for the experiments because they trigger automatic actions in case of state changes. He concluded that, in principle, the current system can stay in place as it is now. However, there is no objection from the experiments to remove the modes “UNSTABLE BEAMS”, “CIRCULATE&DUMP”, and “INJECT&DUMP”, while LHCb even prefers to have “UNSTABLE BEAMS” removed. Finally, he reported on the interlocking strategy for the Roman Pots, TOTEM and the LHCb VELO. He examined the issues encountered and presented the required actions.

Discussion

M. Hostettler asked if there are also plans to remove the "Movable Device allowed in" flag. **J. Wenninger** answered that the flag will stay, but it is the choice of the different experiments whether they want to use it or not.

J. Wenninger clarified that the Roman Pot Input interlock (Slide 16) is only maskable on the experiment side, while it is not maskable on the BIS side. **C. Schwick** confirmed that it was meant like this.

J. Wenninger commented that concerning the beam modes, he has discussed with the involved people, and for “CIRCULATE&DUMP”, and “INJECT&DUMP” it is almost a non-issue. For the question of “UNSTABLE BEAMS”, there are two solutions to suppress them, and both of them have different implications. Therefore, he proposed to organise a dedicated meeting, also involving MPP, to discuss the best way how to proceed. **C. Schwick** added that it is also important that the experiments participate in this discussion.

J. Wenninger then clarified that the spectrometers are normally not ramped and that they are protected at injection, where it is more critical, by a software interlock that takes the spectrometer strength plus the compensators and adds the deflection to make sure that the result is a closed bump. This way, one protects the aperture in case of, e.g., a wrong polarity setting. However, after injection, there is indeed no more extra protection and, in principle, one could change the magnet currents. In this case, one would rely on the beam loss detection. He highlighted that one option for the future would be to use the PC interlock to survey the constant current in the 8 magnets.

A. Lechner asked whether the BCM thresholds for ATLAS and CMS will be reviewed. He reminded that 20% of all UFO dumps were triggered by the BCMs of the experiments and these were typically small UFOs, where the losses had been hardly visible at the other (machine) BLMs. **C. Schwick** replied that he has no information that the review of the thresholds is foreseen. He reminded that the thresholds are currently set about a factor 500 below the damage threshold. **A. Lechner** proposed to have a dedicated meeting together with the experiments to discuss the topic. **C. Schwick** agreed that this would indeed be useful.

Follow-ups

- Evaluate the removal of the beam modes “UNSTABLE BEAMS”, “CIRCULATE&DUMP”, and “INJECT&DUMP”.
- Test additional cooling for AFP (required due to potentially increased heating of the pots with LIU beams) in 2019.
- Mitigation of LVDT issues planned for ALFA (add cables for better electrical separation of signals)?
- The manual retraction of the VELO should be tested every year possible to ensure its functionality (moving without damage to cables).
- The functional specifications for the new CO_2 cooling system of the VELO need to be documented and reviewed. Failure scenarios have to be described with the expected consequences.
- The new movement safety system for the VELO has to be reviewed.
- Additional springs to be installed in AFT. Full changes to be discussed with MPP.
- Evaluate possibility to add EXP magnets (solenoid/toroid) to the PC interlock.
- Organise a meeting with experiments to discuss the beam loss thresholds for the BCMs for Run 3.

SESSION 4

MACHINE PROTECTION IN THE SPS, K. LI

K. Li introduced the machine protection and interlocking strategy applied in the SPS. The concepts are very similar to those used in the LHC, but due to the machine’s multipurpose tasks, more complex. It has a hardware ring interlocking system and two hardware extraction interlock systems. The three interlock systems are independent. Master Beam Interlock Controllers (BICs) are used for the extraction permits that in spite of not being timing aware can multiplex the interlocking between different beams (HiRadMat, AWAKE, LHC) through various flags generated by the SPS SMP (beam energy) together with the positions of the beam stoppers in the transfer lines (TEDs). The setup beam flag is not used automatically to remove masks in the SPS ring.

Discussions

- **J. Uythoven** asks about the slow extraction interlocking, whether this is part of the NA consolidation project.**V. Kain** answered that slow extraction ring interlocking is not part of it. **J. Uythoven** proposed a meeting on this topic.

- **D. Nisbet** remarks that the measured delay of 0-1ms for the new interlocking of the main circuit needs to be checked to find out the exact delay. **J. Uythoven** replies that measurement have been made from the CCC, with the details for a fault triggered at the power converter, looking at relative measurements. The newly proposed solution of interlocking via the WIC is faster than the system previously in place.

- **B. Schoefield** comments that other methods might be available to speed up the post-mortem data streaming/storage. **J.C. Garnier** replies that this is being investigated.

- **E. Bravin** remarks that BGI and BSRT not only require energy but also the maximum current information to protect themselves, which one could take from PSB. **K. Li** replies that the PSB could change rings. **V. Kain** adds that there are many possibilities, and the question is whether the information is required to be real-time.

Follow-ups

- Management of masking depends on OP to track. Should there be an automatic time-out for masks? The SPS is a big user of the SIS system (1035 subscriptions and many more interlocks) and the Management of Critical Settings (MCS). The protection with the new SPS beam dump system will be much improved (better synchronization, no forbidden energy zone). A proper injection interlocking system will be put in place and adequately designed interlocking through beam instrumentation for dI/dt interlock, running sums for the BLMs, turn-by-turn interlock and also improved extraction bump interlocking will be provided.

- MDs and slow extraction interlocking are far from sufficient or adequate. Needs improved concepts for the future.

LINAC 4 - EXPERIENCE AND OPEN POINTS, D. NISBET

The LINAC4 protection system had to grow with the various commissioning phases requiring unprecedented flexibility from a system rigid by design. Lesson (re)learnt (long known from SPS-to-LHC commissioning): deploy- ment phases and commissioning scenarios need to be taken into account during the BIS design phase. Several incidents had occurred with beam-induced holes in bellows, instrumentation broken by beam, etc. These incidents highlight that despite the low energy, machine protection and damage protection need to be taken seriously. In addition, most of the incidents had occurred during non-standard operational modes. The LINAC4 interlock system uses the LHC like solutions such as BIS and SIS, but also external conditions for availability and efficiency. Power converters, BLMs were available and BCT watchdogs are all interlocked with PPM thresholds.

Discussions

- **J. Wenninger** remarks that the use of Machien Critical Settings (MCS) with PPM is tricky. **V. Kain** confirms that something in addition is needed.

- **C. Wiesner** wonders why the downtime for the various beam induced holes was different. **A. Lombardi** replies that in one case a bellow was changed, in the other a quick fix was applied, while the HW was repaired only later.

- **J. Uythoven** commented that MPP discussions should start pretty soon in view of the LBE run. **B. Mikulec** replied that the setting management has to be defined, like BLM thresholds while dephasing cavities.

- **V. Kain** asks if the machine protection for LINAC4 has the required attention. **D. Nisbet** answers that LINAC4, after a long commissioning phase, is maturing into an operational entity. It still needs daily attention, as it is changing continuously, often MD-like, and needs disabling interlocks. **V. Kain** adds that input from other commissioning experience could be given.

Follow-ups

- Threshold management and setting up need discussion and appropriate tools.

- Knowledge sharing with higher energy machines to be put in place.

- The feasibility of continuous cesiation in terms of machine protection (contamination of RFQ) needs input from MPP.

- Continuous cesiation: Decision to be taken during the summer 2019 to implement for LBE line run

- Body required to discuss operational scenarios in the light of protection questions. MPP?

- Does the current MPP have enough know-how and mandate to guide for LINAC4 machine protection issues?

- Which modification of source interlocking and when to best implement it to be decided.

SIS, EXTERNAL CONDITIONS AND TIMING SYSTEM, G. KRUK

G. Kruk explains the concept of the General Machine Timing (GMT) monitoring, with Central Timing Software and Distribution Failure Detectors. The External Conditions (EC) serve as inputs to the LIC Central Timing (CT) and are used to decide the beam sequence from the Beam Coordination Diagram (BCD) (‘normal’, ‘spare’, no beam, or cutting a particular PSB ring). They are delivered by HW links from equipment and inhibit buttons, CMW sets and CMW subscriptions from SIS, and requests from the SeqManager GUI and the LHC Sequencer. In addition to the EC, also the SIS, the BLMs, and the SPS can inhibit the beam through the tail clipper timing. The external condition concept must remain for beam time optimization but CMW subscriptions are considered sufficient for this purpose. The infrastructure of collecting HW conditions will be renovated during LS2. Inhibit buttons and vacuum will be handled by a PLC (hardware but including software processes), power Converters (FGC) by CMW subscription (status published at 2Hz, no update for 1 sec will result in ‘BAD’ status). Beam stoppers and kickers could be either way. Typical reaction times are in the range of 2-4 cycles. In total there are three systems with different roles interlocking the beam: LIC CT (for operational efficiency), SIS (flexible), and BIS (for safety but non-PPM).

Discussions

- There is a question if hardware conditions can be done through SIS and then set as an external condition. **J. Uythoven** comments that BIS should be ued where reliability and safety is required.
- **G. Kruk** repeats that scheduling for beam efficiency and inhibits through the tail clipper should remain.

Follow-ups

- Define if the Central Timing should continue playing the role of an interlocking system (taking thresholds and equipment information into account) or only be the receiver of the interlock system (e.g. SIS).
- If the BIS could and should interlock all external conditions (would have to be aware of the beam configuration).
- SIS, as successfully implemented in the SPS, can provide flexible interlocking on complex conditions that can be used to enable / disable beam destinations in the same way than external conditions. Given the reaction time of the timing system, SIS is generally well adapted to this role, preventing the installation of cables. To be discussed if this can be used for main converters, vacuum valves when no BIS is available.
- If the LIC CT would still enable the tail clipper in specific cases (disabled batch, BHZ377 rule, cut single ring, ...)

PS AND MACHINE PROTECTION, K. HANKE

The present machine protection in the PS is widely based on External Conditions, complemented by SIS and the BLMs acting directly on the LINAC2 timing, with typical reaction times of 2-4 cycles.

The external conditions will be modified during LS2 (PLC based, ”soft-ECs”), the BLMs will be acting on the LINAC4 pre-chopper timing, and there will be a Warm Interlock Controller (WIC) for the majority of the PS auxiliary magnets. A specific BIS for the PS will not be implemented but two devices will be connected to the BIS of other machines (PS internal dump to PSB extraction BIC, and F16.BHZ377/378 to SPS BIC). One could think of a BIS for the PS in the long term, in order to harmonize with the other machines and in order to have a fast and fail-safe system. The WIC is planned to be extended for main magnets, low-energy quadrupoles and eventually PFWs.

There are very few (if any) cases where equipment can be damaged in the PS, even with LIU beams. The goal of machine protection is therefore to avoid long term activation but it must preserve the flexibility and efficiency of the PS.

Discussions

- **J. Uythoven** asks why there are two internal dumps. One is actually a spare.
- The vacuum valves and the POPS status could be connected to a BIS, possibly connected to the LINAC4 chopper, but it would need another destination aware master BIC.
- **F. Tecker** comments that there is also an interlock between SEM-grids and the ’ralentisseur’ to protect the grids from circulating beam. It was bypassed for multi-turn injection studies, when the protection was assured by four redundant kickers aborting the beam after 30 turns.

BOOSTER INTERLOCKING AND OPERATIONAL SCENARIOS, B. MIKULEC

The PSB machine has no internal nor external dump. With the introduction of LINAC4 an integrated PSB-LINAC4 hardwired Beam Interlocking System was put in place. The limited flexibility of the current BIS implementation requires the External Conditions to be used for more complex interlocking that affects individual rings/destinations. The extraction interlock system cuts the extraction kicker and the beam would then be lost in the PSB. All the other interlocking strategies (SIS, WIC) are/will be deployed as well. Both POPS-B as well as MPS as fallback solution will be compatible with the interlocking system based on BIS and EC. Any interlocking solution in the PSB will have to allow for sufficient operationl flexibility with hundreds of different operational cycles, while guaranteeing a minimum of protection. Damage protection is second priority. Interlock diagnostics for fast cycling machines is a challenge and needs to be taken into account specifically when providing interlock monitoring applications.

Discussions

- **J. Uythoven** asks why the POPS-B is also connected to the external conditions. Answer: there is still the possibility to have beam to the LBE line or LINAC4 dump in case the POPS-B is interlocking.
- **M. Zerlauth** was surprised that the BIS GUI provided by MPE is not suitable for the monitoring in fast cycling machine. Bettina answered that both, the OP GUI by **J. Wenninger** as well as the one by MPE, will be tested during the LBE run later on this year to give feedback. The idea is to deprecate the OP one eventually.

Follow-ups

- Work is still required to define PPM threshold management for various systems.
- Management / procedures of masking interlocks in the BIS will also need to be defined.
- Consultancy from a knowledgeable team consisting of members from TE/MPE and BE/OP is required.

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