MACHINE PROTECTION WORKSHOP REVISITED
OPEN ISSUES, PROGRESS AND DECISIONS ON MAJOR TOPICS

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Abstract

At the Machine Protection Workshop, held in March 2013, the upgrades / changes in the machine protection systems planned for LS1 were discussed. Furthermore it gave an outlook on challenges and possible solutions for future LHC upgrades. This paper summarizes the status and progress in the machine protection and related systems relevant for the restart of the LHC with beam. Furthermore, issues that still have to be addressed will be discussed. The follow-ups from the Machine Protection workshop cover the topics material damage and failure scenarios, moveable devices, injection and LHC beam dumping system (LBDS), circuit related protection and electrical distribution, beam instrumentation, operation and software tools, commissioning of MP systems and MPP.

INTRODUCTION

The machine protection workshop in March 2013 addressed the planned and required changes during LS1 in the LHC machine protection systems. The major items of each session of the workshop can be found in the session summaries of the workshop proceedings [1]. Since March 2013 the work on these changes and upgrades has well progressed in the different teams. The detailed changes are described in the different papers of these proceedings. This paper summarizes the status and progress in the machine protection and related systems relevant for the restart of the LHC with beam.

MATERIAL DAMAGE AND FAILURE SCENARIOS

The detailed understanding of failure scenarios causing sudden beam losses is essential to guarantee a safe operation of the LHC. In combination with material damage limits these give the input to set interlock limits, which protect the machine and at the same time allow for efficient operation.

- Review the parameters of the setup beam flag (SBF) in view of onset of damage (beam emittance, impact distribution, operational scenarios, collimation):

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A proposal for the updated SBF equations has been compiled for proton-proton operation and are discussed in more details here [2].

- Review and update the single kicker asynchronous beam dump failure scenario and its consequences:

  Studies are ongoing and intermediate results on beam impacting on tertiary collimators were presented by L. Lari and R. Bruce to the 83rd/85th [3] and 95th MPP [4].

- Understand protection level of triplet with presently allocated margins between TCT and triplet apertures:

  A new method to check the margins between TCT and triplet aperture with circulating beam is currently studied by MPE-PE and will be presented to MPP in autumn 2014.

- Update damage limits for tungsten collimators (TCT, TCL) with realistic impact distributions:

  Work ongoing in Collimation team, FLUKA team and EN-MME. Results are expected by the end of 2014.

MOVEABLE DEVICES

The LHC collimation system together with the injection and dump protection devices play an important role for passive machine protection of the cold LHC aperture against fast beam losses (injection failures, dump failures, powering failures in normal conducting magnets, instabilities...). Although the central parts of the LHC collimation system (IR3, IR7) remained in principle unchanged, a few movable devices like tertiary collimators, secondary collimators in IR6, dump (TCDQ) and injection protection (TDI) devices have been either replaced or experienced a substantial overhaul.

- How will collimators with jaw-integrated beam position monitors be used in beam operation (interlocking, linking of LVDT-gap and BPM measurement...)?

  A functional specification has been prepared and is under discussion [5]. The hardware changes in the collimation system for run 2 are discussed in detail here [6].

- Define and optimize the qualification strategy of the collimation system for run 2:

A first proposal has been prepared and was implemented into the re-commissioning procedure for the Collimation system (EDMS889345). More details can be found in [6].

- Upgrade of the position measurements and controls of the TCDQ (separation of position control and interlocking, redundant interlocking of *gap* in the beam energy tracking system (BETS)):

  Controls and interlock logic have been separated. The LVDTs for jaw position measurements were replaced by potentiometers. The third potentiometer has been implemented in the BETS and will be interlocked there. More details can be found in [7].

- Interlock the tertiary collimator position as function of the beam-beam separation:

  This functionality has been prepared in the firmware. It will, though, not be implemented for the start-up with beam. As the tertiary collimators will have jaw-integrated BPM buttons it is expected that the interlocking of the beam offset in the collimator can be done more precisely and reliably with these devices. This needs to be shown with beam during the commissioning at the beginning of run 2.

- Review the hardware changes in the Roman pots (XRP) and their impact on interlocking and re-commissioning:

  The changes in the hardware of the XRPs were presented to the 86th MPP [8]. This topic will be further followed up by the machine protection panel (MPP) in collaboration with the Collimation Working Group (ColWG).

- Improve verification of collimator settings by implementing plausibility checks:

  An application to verify the collimator settings has been developed by the Collimation team. To be deployed in the CCC.

INJECTION AND LBDS

Following to the experience in run 1, important upgrades of the injection protection devices and the LHC beam dumping system were proposed for LS1. The major changes affecting machine protection and their status are listed below.

- Implement a redundant link from the LHC Beam Interlock System (BIS) to the re-triggering lines of the LHC Beam Dumping System (LBDS). Due to this link a beam dump can be initiated directly from the BIS without going through the trigger synchronization units (TSUs) of the LBDS:

  The new link has been designed to fulfil strict requirements for reliability (less than 1 additional asynchronous beam dump within ten years, less than 1

additional synchronous beam dump per year). The so-called CIBDS-cards (two per beam) have been installed in the LHC tunnel. Their functionality will be tested during the reliability runs of the LBDS. More details can be found in [7].

- Interlock the transfer line optics via virtual beta* limits of the transfer line collimators (TCDIs):

  The necessary functionalities have been implemented in the low-level software of the collimators. A timing telegram to transmit the optics information has been reserved. The final implementation and tests will be performed in autumn 2014.

- Interlocking of SPS-LHC beam transfer against timing issues, which cause injection into the wrong LHC beam, as experienced during 2012:

  These issues will be mitigated with the new LHC central timing, which will be deployed in October 2014.

- Consolidate issues in the redundant powering of the LBDS, which were discovered during run 1:

  A new configuration of the trigger synchronisation units (TSUs) of the LBDS has been implemented. The mitigations will be fully validated during the reliability runs of the LBDS and the UPS powering test campaign in autumn 2014. More details can be found in [7].

- Interlock of MSI currents and TDI gaps in Beam Energy Tracking System (BETS):

  All cables necessary for the implementation are pulled and the implementation is progressing. Note that for 2015 only the TDI gaps calculated from the LVDTs at the extremities of the jaws will be interlocked. A redundant interferometric gap measurement is under development (see below). More details can be found in [9].

- Following several weaknesses discovered during run 1, the injection protection absorbers (TDI) have undergone significant refurbishment during LS1 (reinforcement of beam screen, additional temperature sensors, gearbox, RF fingers, ...). The above mentioned interferometric gap measurement system will be installed on spare TDIs, which could be installed into the LHC during a Christmas stop (e.g. 2015/16). More details can be found in [9].

- TDE dump block:

  Repeated dumps at 6.5/7TeV could cause a rise of the pressure above the venting levels. The effect has been studied and it was concluded that this is not critical for run 2, as there is enough reserve in the N_2 bottle in case of limited venting.

- The upgrades of the MKI have been executed as planned:

Reduction of impedance by adding strips, improved cleaning to reduce UFOs, NEG coating of by-pass tubes, etc. More details can be found in [9].

- Scan the MKD waveform with beam and test the dump via the direct BLMs at injection energy:

  These tests are planned for the commissioning with beam beginning of 2015.

- Improve transparency in case of operating the LBDS in *degraded* mode with reduced redundancy:

  New procedures have been put in place for the replacement of power converters in the LBDS to avoid enlarging of tracking and interlock windows.

- Interlock the beam position in the TCSG (IR6) through the BIS instead of the SIS:

  A decision will be taken after first experience with beam in 2015.

- Mitigate the problem with the MKB vacuum interlock:

  The vacuum gauges and pumps have been replaced. Studies are ongoing to identify, if the required improvement was achieved through this measure.

- Review the number and necessity of (test-)pulses of MKDs in local mode:

  The upcoming reliability runs of the LBDS have been defined taking this in consideration.

CIRCUIT RELATED PROTECTION AND ELECTRICAL DISTRIBUTION

The LHC quench protection system (QPS) has experienced a major renovation during LS1. Besides that, mitigations have been implemented in several other systems, which are responsible for the protection of electrical circuits.

- Perform a complete revalidation of the LHC quench protection system (QPS):

  The QPS has been completely dismantled and experienced an overhaul during LS1. Therefore a full revalidation of the system is necessary to ensure the required protection levels before the magnet system can be powered. This process is currently ongoing.

- During run 1 fast power aborts in the CMS and LHCb solenoids caused orbit distortions, which finally caused a protection dump due to beam losses. To mitigate this, MPP requested to interlock a fast ramp down of these magnets:

  The magnet safety system (MSS) for the experimental magnets has been re-designed during LS1. The CMS

and LHCb solenoids will be interlocked by this system. Discussions are currently ongoing if the interlocking strategy of the experimental magnets in ATLAS and ALICE has also to be revised.

- The simultaneous trip of the 60A orbit correctors in one sector caused orbit distortions which finally caused a protection dump due to beam losses:

  The logic implemented in PVSS for the 60A correctors has been found to have been erroneously implemented and was corrected during LS1. This will prevent the simultaneous trip of many orbit correctors in the future. Furthermore, it is planned to change the PP60A timing telegram, which will give an additional protection against this type of event. Detailed information to the implemented changes can be found here [10].

- QPS: ease the implementation of critical upgrades by integrating the possibility to download the firmware remotely.

  This functionality was not implemented during LS1 and will only be implemented in a future QPS2 system (LS2 or later).

- Decrease system vulnerability of QPS by sanity checks, dependable configuration tools, enhanced automatic analysis, enforced validation of changes etc.:

  Improved supervision of parameter management and remote configuration has been implemented in the QPS hardware. Software tools to fully exploit these functionalities are currently under development.

- Improve rejection of electrical network disturbances by thyristor power converters to avoid triggering the Fast Magnet Current Change Monitors (FMCM):

  Following studies by TE-EPC the D1 power converters will be replaced in the Xmas break 2015/16. A replacement of the power converters of the warm D3s and D4s is pending due to budget constraints.

- Extend power converter interlock to other non-orbit corrector (COD) power converters:

  As a first step the tolerances in the existing COD will be improved by optimization of the functions. In a second step the quadrupole magnet currents will be added to the COD. This activity is planned for autumn 2014. The interlocking of the COD currents will be removed from the SIS, as the power converter interlock is sufficient.

- Review and unify strategy for circuits classification (maskable / non-maskable/ transparent):

  The circuit classification has been reviewed for the PIC in collaboration with BE-ABP (see [11]). It still needs to be clarified if this strategy should also be applied to the circuit classification in the cryogenic system and OP.

- Perform a full-scale test of redundant powering for the Machine Protection Systems after the UPS consolidation during LS1:

  The preparations for this test are ongoing. Pre-tests have been performed and the full-scale test has been scheduled.

- Check interference of new UPS switching frequency with ADT:

  The switching frequency of the UPS has changed from 8kHz to 7kHz and the noise level has been reduced by a factor of 5. Therefore no interference with the ADT is expected by the experts. Nevertheless a final test will be performed in autumn.

BEAM INSTRUMENTATION

The beam instrumentation systems in the LHC play an important role for machine protections (BLMs, BPMs) and for diagnostics. A significant number of improvements in these systems have been performed during LS1.

- A full implementation of a Fast Beam Current Change Monitor (FBCCM) was requested by Machine Protection to improve the redundancy in beam loss detection after LS1:

  The hardware for such a system is under test in the lab. The final performance has to be validated with beam in 2015. Only then can the decision be taken to interlock on the FBCCM or not. More details can be found in [12].

- Improve dynamic range for the interlocked BPMs in IR6 to enhance availability and machine safety:

  The required mitigations in the hardware have been performed. The sensitivity threshold between high and low intensity range is expected to be $\sim$ 2e10p/bunch. More details can be found in [12].

- The data from the interlocked BPMs in IR6 should be sent to the XPOC:

  The XPOC data, which are sent to the post mortem are already used in the TCDQ module. This will be optimized during run 2.

- Ensure a reliable monitoring of the abort gap population with an improved BSRA and foresee automatically initiated cleaning and dumps:

  Together with the BSRT the BSRA has been completely re-designed during LS1 to solve the problem with heating mirrors and improve the reliability. The specification of the BSRA calibration procedure can be found in the document EDMS1337184. More details can be found in [12].

- Beam loss monitors:

  - A full revalidation of BLM system after LS1 is required as the system was completely dismantled and removed from the tunnel:

    The re-validation of the BLM system is ongoing.

  - Install small ionisation chambers (LICs) in the injection region to increase the dynamic range of the BLM system in case of injection losses:

    The LICs have been implemented. More details can be found in [13].

  - Implement a mechanism to inhibit the beam interlock for BLMs in the injection region during injection:

    The BLMs in the injection region have been regrouped and connected to two special crates per injection region. The interlock request from these crates could be inhibited, without influencing the rest of the BLM system. The mechanism to implement this interlock inhibit is currently under discussion. The agreement for the implementation method and the deployment strategy is expected for October 2014. More details can be found in [9].

  - Review the BLM thresholds with the experience from run 1 and the performed quench tests with beam:

    A first proposal for the BLM thresholds for the magnets in the superconducting arcs has been presented by the *BLM threshold working group (BLMTWG)* and is currently under discussion. Furthermore, in the future the BLM thresholds will be generated directly in LSA. Therefore the algorithms will be implemented there. More details can be found in [13].

  - Displace one out of three BLMs from the arc quadrupoles to the interconnects of the neighbouring dipoles to increase the detection sensitivity in case of UFO losses:

    The change of the BLM configuration in the superconducting arcs has been approved and the installation has been performed. The post LS1 configuration is described in EDMS1307356. More details can be found in [13].

  - Send separated buffers with BLM data for B1 and B2 to XPOC:

    The implementation of this request is subject to a hardware test and can only be confirmed thereafter. More details can be found in [13].

- Will the interference between tune feedback and QPS thresholds reappear after LS1?

  The magnets used by the Q-feedback will run with low operational currents at 6.5TeV, thus, the QPS thresholds can be increased. Therefore, no problems are expected for run 2.

- Improve reliability of OFB:

  The work in this direction has started. Significant improvements can only be expected during run 2 but not from the start-up. More details can be found in [14]

- Perform a sanity check to verify the BPM functionality before every fill: to be discussed.

OPERATION AND SOFTWARE TOOLS

- Implement a tool for tracking of changes (exchange of hardware, expert masking, ...) in machine protection systems:

  For the long term this is planned within the AC-CTESTing framework. For the short and medium term we will still rely on procedures.

- Review SIS interlocks - which are obsolete, which should be replaced by hardware interlocks, which are newly required:

  A proposal concerning the SIS interlocks was presented to the 85th MPP [15].

- Propose a strategy to track beam induced heating after during start-up and routine operation:

  A first proposal of the strategy for the follow-up on beam induced heating in the LHC during run 2 was presented to the 91st MPP [16].

- Improve the injection quality check (IQC) to require fewer resets: Improvements could be achieved by adjusting the warning and latching levels: To be discussed.

- Implement tools to facilitate loss-map checks by the operations crew: To be discussed.

COMMISSIONING, REVALIDATION OF MP SYSTEMS AND RMPP

- Review and update commissioning procedures for the machine protection systems. Update existing commissioning procedures, define non-negotiable re-validation tests in case of system changes as function of risk:

  The discussion of the revised commissioning procedures in the MPP is ongoing. The re-validation tests are specified in the commissioning procedures of the respective machine protection system.

- Update membership of rMPP after LS1 and define an rMPP contact person, who coordinates the dump analysis and functions as rMPP contact to operations and machine coordinators:

  To be discussed by MPP and proposed to LMC.

- Implementation of a fault tracking system, to improve consistency and quality of fault data:

  The Accelerator Fault Tracker (AFT) has been kicked off and will be available in the LHC at the start-up with beam to ease and standardize the tracking of faults by OP. The closer inclusion of equipment in the AFT will come during run 2.

CONCLUSION

An impressive amount of work has already been performed to improve the different machine protection systems following the experience from run 1. Many changes still need to be finalized, but the vast majority of defined actions and mitigations is on track for the commissioning and restart with beam. The re-commissioning procedures for the machine protection systems are currently being updated as vital input to update the follow-up and tracking of commissioning steps in the different systems and their correct order. Additional work has been identified in operational and software tools. For some systems - e.g. collimator with jaw-integrated BPMs or interlock inhibit for BLMs in the injection region during injection - the experience with beam will have the final word on how they will be used.

ACKNOWLEDGEMENTS

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