PREPARING THE MACHINE PROTECTION SYSTEM FOR THE 2011 RUN

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Abstract

The expected performance of the Machine Protection System for 2011 is presented. An overview of the foreseen modifications to the machine protection system components during the Christmas stop and the required time for recommissioning is given. The possible impact of the MPS on the operational parameters of the LHC, like beam intensity, beta*, emittance and maximum beam energy, are discussed

INTRODUCTION

During the 2010/2011 Christmas Technical stop interventions have taken place on many different systems which form the heart of the LHC Machine Protection System (MPS). This paper concentrates on the modification to the main players of the MPS: the Beam Interlock System (BIS), the Safe Machine Parameters (SMP), The Quench Protection System (QPS), the collimation system, the Beam Loss Monitoring System (BLM), the Power Interlock Controlling System (PIC for the cold magnets and WIC for the warm magnets), the Fast Magnet Current change Monitoring system (FMCM), the Software Interlock System (SIS), the injection and the beam dumping systems. For each of these systems the changes and the required re-commissioning time are given, together with any possible impact on the operational parameters for 2011, like maximum beam energy and beam intensity.

THE BEAM INTERLOCK SYSTEM

Changes to the system

The LHC BIS has not been touched during this Technical Stop. Changes have been made to the SPS Extraction BIS to allow for extraction to the new TT66 extraction line towards HiRadMat. Consequently the Master BIC managing Beam 1 will be updated.

Time required for re-commissioning

Prior to beam operation a few hours of commissioning time is required. No commissioning time with beam is required

Limitation on operational parameters

There should be no limitation to the LHC operational parameters due to the BIS system

SAFE MACHINE PARAMETERS

Changes to the system

Important changes are taken place to the SMP for 2011 operation: two Beam Energy sources are now required, instead of the single source so far. Both sources are from the beam dumping system, but coming from different octants. Also for the Beam Intensity two sources are required for 2011 operation instead of a single source. Both the BCTF-A and BCTF-B will be required by the SMP system during the year.

At start in 2011 up for the energy and beam intensity the largest of the two values will be used for the SMP but in the future the system will be configured to create a beam dump in case of disagreement of the signals.

For the Beam Presence Flag dedicated hardware is used from a BPM in addition to the Fast BCT, using a voting strategy. The Movable Device Flags will have next to the existing modes Stable Beams and Unstable Beams a new mode Beam Dump. The Setup Beam Flag will have next to the status of Normal and Relaxed two new statuses Very Relaxed and Ion.

Time required for re-commissioning

Commissioning without beam should be finished during the hardware commissioning period. Several tests will need to take place with beam, but this should be in the shadow of other work. Test ramps with different beam intensities are required.

Limitation on operational parameters

There should be no limitation to the LHC operational parameters due to the SMP system.

BEAM LOSS MONITORING SYSTEM

Changes to the system

Several upgrades in the FPGA firmware have taken place together with preventive actions on the tunnel installations.

Time required for re-commissioning

Commissioning without beam should take place in the shadow of other activities. About one shift with beam at injection will be required for testing the BLM system.

Limitation on operational parameters

Due to noise on some BLM signal cables the operational energy is limited between 4 and 5 TeV. Tests with double shielded cables for future operation are foreseen.

QUENCH PROTECTION SYSTEM

Changes to the system

An important number of changes has taken place on the Quench Protection System: Installation of snubber capacitors on the 16 extraction switches of all Main Dipoles; removal of ‘old’ global busbar protection (replaced everywhere by simplified detector and nQPS);

replacement of input power switches of all quadrupole quench heater power supplies: 900 units & broken ones on dipoles; QPS of all Q8, Q9 and Q10: modified to be less sensitive to noise pick-up: change of voltage dividers & firmware modification.

Time required for re-commissioning

During the Chamonix workshop it was decided that the snubber capacitors will be commissioned for all octants, requiring approximately one week of additional hardware commissioning. The busbar detector protection can be tested parasitically on the first ramps. The new quench heater will be tested during the Individual System Tests, independent of the Hardware Commissioning Tests. The QPS changes will be tested parasitically during the first ramps.

No tests are required with beam.

Limitation on operational parameters

There should be no limitation to the LHC operational parameters due to the QPS system.

COLLIMATION SYSTEM

Changes to the system

For 2011 operation the collimation settings will depend on the distributed squeeze factor parameter. Changes have been made to the internal logic of the collimation system and a recalibration of the sensors has taken place. Details can be found in [1].

Time required for re-commissioning

Commissioning without beam should take place in the shadow of other activities. Set-up and qualification with beam needs to be done at injection energy, about 4 shifts, and at full energy for about 5 shifts. Approximately 6 to 10 additional ramps will be required. In 2010 about 12 shifts were spent setting up collimators.

Limitation on operational parameters

The limitation on the $\beta^* \approx 1.5$ m, foreseen for 2011, is closely linked to the expected collimation system performance [2]. No limits on beam energy, beam intensity or emittances are imposed by the collimation system on operation during 2011.

PIC/WIC/FMCM

Changes to the system

During the Christmas stop an upgrade of the PIC PLCs has taken place, with the aim of improving the diagnostics in the case a PLC gets stuck. A WIC at point 8 has been moved from UA83 to US85 following the results of Radiation to Electronics studies (R2E). A WIC in TI8 has been moved away from the collimator position following a unique SEU in 2009.

Time required for re-commissioning

Most of the re-commissioning can take place during the hardware commissioning period. The re-commissioning of the PIC-BIS interface is expected to take 6 hours. Possible tests with beam include FMCM checks for D1 and the MSD with the newly applied β^* for 2011, which can normally be done as an 'end-of-fill study'. When increasing the beam intensities checks on the reaction time of the different systems are required.

Limitation on operational parameters

No limits are imposed on the operational parameters by the PIC/WIC/FMCM systems, assuming that the tests with beam mentioned above are passed successfully.

SOFTWARE INTERLOCK SYSTEM

Changes to the system

For 2011 the SIS will produce the β^* values, which will transit through the SMP and it is subsequently transmitted over the timing system. A new injection oscillation interlock will be in place and the intermediate beam intensity during injection will be enforced. The SIS will include a more performing, and more complex, orbit interlocking to handle special conditions like special optics and Van der Meer scans. There is an improvement of the settings management for special conditions.

Time required for re-commissioning

Most testing without beam can be done parasitically. About 1 – 2 shifts dedicated time for testing with beam are required.

Limitation on operational parameters

The SIS imposes no limitations on the operational parameters.

INJECTION SYSTEM

Changes to the system

Many changes to the injection system are made for the 2011 start-up. On the hardware side it can be noted that one MKI injection kicker magnet (B point 2) has been replaced because it showed some occasional break-downs during 2010 operation. Improved diagnostics and controls and improved interlocking of MKIs has been implemented. Fine synchronisation of kicker modules and AGK will be performed for 2011. New TI2 BPMs with dual acquisition has been installed. Diamond BLMs in IP2 and IP8 for bunch by bunch diagnostics are installed.

Modifications are made to the Injection Quality Check program (IQC), including interlock on injection oscillations, the checks on B1 and B2 will be independent and change in functionalities and latching philosophy are made (see Evian follow-up meeting 19/01). The MKI operational settings will have an envelope to only allow limited trims. New injection procedures with intermediate beam intensity will be enforced. New TCDI interlock

logic will be applied at start-up and automatic set-up procedures are foreseen for later during the year. Shielding of ring BLMs from TCDI showers is being installed in different phases. The BLM interlock thresholds on TDI and TCLI are under discussion and possible TDI shielding is being studied. Also BLM 'sunglasses' which will temporarily disable the interlock from some BLMs at the moment of injection is being studied and could possibly be implemented after the summer. 'Sunglasses' for the LHCb and ALICE experiments, temporarily increasing the thresholds of the BCMs, will be available from start-up. Abort gap cleaning and injection gap cleaning to limit the beam losses on the TDI during injection will be commissioned.

Time required for re-commissioning

About 1 shift without beam, but the BIS loop closed, is required for setting up and machine protection tests. With beam approximately 3.5 shifts are required for setting up the injection protection plus 1.5 shifts for general machine protection tests with beam, totalling in 5 shifts of tests with beam. During the year another 3 shifts are expected to be required during the injection intensity increase and another shift every 2 – 4 weeks for maintenance of injection protection.

Limitation on operational parameters

During 2010 operation injection of 48 nominal bunches per injection took place successfully. Taking into account the BLM signals during these injections, it is expected that in the configuration at start-up the injection is limited to 144 nominal bunches per injection [3, 4]. For higher injected intensities the measures discussed above (shielding, sunglasses etc.) are required.

BEAM DUMPING SYSTEM

Changes to the system

The extraction kicker MKD Trigger Fan Out (TFO) system is re-cabled to minimise the probability of obtaining and asynchronous dump with multiple MKD kickers. The MKD generators will be working at a higher thermal working point of 26 °C, instead of the 23 °C during 2010, to obtain experience for future higher energy operation. The TCDQ has undergone several controls and diagnostics improvements. The TCDQ sequences will be separated from the collimator sequences. The extraction septum MSD will have corrected settings for 2011, following a recalibration of one of the MSD magnets at CERN, and degauss cycles of the MSD magnets will be performed during machine cycling. The eXternal Operational Check (XPOC) will include an additional module with compares the position of the TCDQ with measured beam position at the TCDQ. The BLM limits used by XPOC will be calculated in a different manner, relative to reference BLMs with the largest losses, it will include the BLMs at the TCTs and generally the limits will be lower for higher beam intensities which were not very effective during 2010 operation, see fig.1.

Other modifications to the beam dumping system include the replacement of 2 MKD and 2 MKB generators, following the program to counteract contact erosion. As a result all kicker settings and references will be regenerated. The Trigger Synchronisation Unit (TSU) will undergo a firmware upgrade following the recommendations of the external audit. The BEM firmware will be updated to correct communication errors between BETS and PLC. The development of abort gap population monitoring and cleaning will continue during 2011.

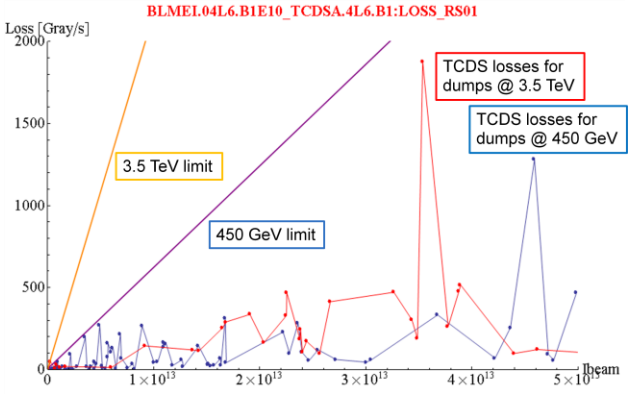

Figure 1: Measured beam losses on BLM at the TCDS during 2010 operation at 450 GeV and 3.5 TeV together with the XPOC limits used. This clearly shows that the XPOC BLM limits were not very effective for higher beam intensities.

Time required for re-commissioning

About 4 shifts are required for commissioning the beam dumping system without beam and about 10 shifts with beam of which 3 shifts for basic checks, 3 shifts for setting up the TCDQ/TCT protection, including ramps up to full energy, and 4 shifts for abort gap cleaning and monitoring.

Regular simulations with beam of asynchronous dumps will need to be performed at injection and at full energy to test the protection set-up. During the intensity increase and the change of filling patterns the BPMS interlock system needs to be verified, requiring about 30 minutes at injection for each test.

Limitation on operational parameters

The beam energy is limited to 4.5 TeV due to the increased risk of a HV break down alongside the MKD kicker switch for higher operating voltages. The switch is waiting for new isolators to be installed before the 2012 start-up.

Detailed calculations of the maximum load of the TCDQ absorber are ongoing. Rough calculation indicate an operational limit of a bunch intensity between $7 \cdot 10^9$ and $7 \cdot 10^{10}$ protons, assuming 28 bunches with 25 ns spacing and 7 TeV energy impinging on the collimator. This is only important in the case of an asynchronous dump and spare TCDQs exist. Precise loss measurements are required as a reference to be able to check on any

possible damage. The effect of small emittances on any possible TCDQ damage is unknown.

The presently installed number of MKB diluters, still 2 magnets missing per beam, is sufficient for nominal beam intensity.

COMMISSIONING AND OPERATIONAL LIMITS

Adding up the different system commissioning times mentioned above, the time required for machine protection tests during the cold check out is about 8 shifts, plus one week for testing the QPS snubber capacitors. Machine protection tests with beam will require an estimated 28 shifts, which means about 10 days, before the beam intensity can be increased. During the intensity increase on average a few shifts per week will be required for system set-up and maintenance.

The maximum beam energy is limited between 4 to 5 TeV due to noise on some BLM cables and to 4.5 TeV due to HV breakdowns in the generators of the beam dump extraction kicker magnets MKD.

There is no explicit limit on maximum beam intensity, although the TCDQs risk to be damaged in case of an asynchronous dump with high beam intensities. The number of bunches per injection is limited to 144 in the present configuration.

The β* at the interaction points is limited to about 1.5 m due to collimation, taking into account orbit stability, beta-beat etc.

PERFORMANCE OF THE MPS

The performance of the Machine Protection System has to be evaluated considering safety and availability. During 2010 operation the safety of the MPS was good: no damage and no beam induced quenches above 450 GeV occurred. Procedures remain the weak point considering safety. The '2010 Safety Events' include the MKD erratic with two magnets, for which the TFO logic is modified for 2011 operation. Injection took place onto a moving TCDQ. As a measure the TCDQ controls will be made more conform to the other collimators and work on the sequences is performed. Other 2010 safety issues concern mainly the operational procedures and the sequencer and don't affect the MPS as such [5].

The availability of the MPS during 2010 was basically as expected. It is shown [6] that as expected most of the 'down time' is coming from the large MPS systems: QPS, Power Converters and Injection. In all these fields important improvements are foreseen for 2011 operations, as is detailed in this paper.

The impressive amount of changes to the Machine Protection System in the Technical Stop are shown to focus on known weaknesses of the system, as experienced during 2010 operation, and affect both Safety and Availability. Taking into account the already good performance of the MPS during 2010, one can expect a Safe and Available LHC in 2011.

CONCLUSIONS

The commissioning of the Machine Protection system for 2011 operation will require about 10 days during the cold check out without beam and another 10 days with beam before the beam intensity can be increased. During the intensity increase a few shifts per week will be required for machine protection system set-up and maintenance.

The energy for 2011 operation is limited to 4.0 TeV due to noise on some BLM cables. The maximum injected number of bunches under the present configuration of the injection system is 144. The β* at the interaction points is limited to about 1.5 m.

A large number of machine protection system modifications has taken place during the Christmas technical stop. This should further improve the performance of the machine protection system compared to the already good safety and availability performance in 2010.

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