Experience with MPS during the 2010 run

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Abstract

In 2010 the LHC stored beam energy was pushed to 25 MJ, ten times above TEVATRON, in little over 6 months. No machine protection issues were recorded, and the reliability of the machine protection system (MPS) did not impact beam operation in a significant way. After an initial phase of low intensity beam operation that was used among other things for the commissioning of the MPS, the intensity was increased in steps of a factor 2 up to 2 MJ. Following a stability run at 2 MJ, the intensity was increased in steps of around 3 MJs every few days during train operation. The intensity steps and upcoming MP issues were approved and discussed in the restricted Machine Protection Panel (MPPr) composed of representatives from the main MP sub-systems. Two reviews of the MPS were organized in 2010, one internal and one external review. This presentation will discuss the performance of the MPS, the experience from the MPPr and of the intensity increase and the outcomes of the reviews.

INTRODUCTION

March and parts of April 2010 were largely devoted to commissioning with beam of the LHC MPS following the predefined procedures. The test plans where uploaded on WEB pages and the test results were filled by the MPS experts. The MPP chairman checked the results and ensured that no steps were skipped or forgotten. The discipline for filling in test results was good and the plans were followed. No major issues or availability problems encountered in this phase.

The same period saw the first collimator setups, including validations with loss maps and de-bunched beams (asynchronous beam dump simulations). The setups were verified periodically, but not at the predefined rate of once per week. The alignment (or at least retraction) of TCT collimators was verified by a MPP responsible for each fill of the high intensity period using the post-mortem data. The performance of collimation and protection systems was stable along the year, outlining the excellent stability of the machine (orbit, optics and collimator positioning). But it must be noted that the stability is not yet sufficient for nominal tolerances.

STEERING THE INTENSITY INCREASE

The intensity increase was steered in 2010 through the restricted Machine Protection Panel (MPPr). It was composed of MPS experts from the main MP sub-systems, the head of the LHC OP group and the LHC physics coordinator (R. Assmann, B. Goddard, J. Uythoven, B. Dehning, M. Zerlauth, A. Siemko, R. Schmidt, J. Wenninger, M. Lamont, M. Ferro-Luzzi). The MPPr provided recommendations on the MPS envelope (maximum intensity) to be approved by the LMC. From the beginning the plan foresaw 3 phases:

- Low intensity for commissioning and early experience.
- Ramp up to 1-2 MJ followed by a stable operation period of around 4 weeks that intensity.
- Breaking the World record of stored beam intensity and move into 10s of MJ regime.

The actual intensity ramp up in 2010 is shown in Fig 1, and the three phases are clearly visible.

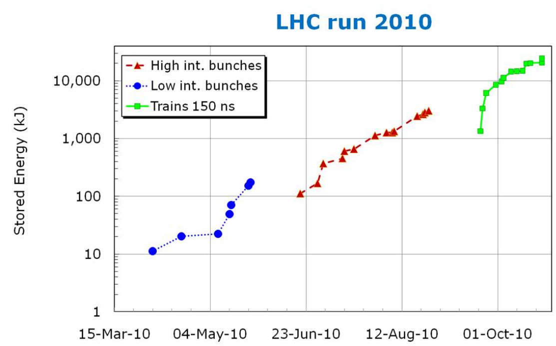

Figure 1: Evolution of the peak stored beam energy in stable beams in 2010.

Figure 2 compares the intensity ramp up plan approved by the LMC in February 2010 with the achieved ramp up. There are a number of notable differences. The plan assumed that commissioning for the different phases (for example single bunches to trains) would be performed in the shadow of physics operation. Train operation was assumed to be run with 50 ns trains of 8×10^{10} p/bunch. The reality turned out to be rather different:

- Commissioning was not transparent and could not be done in parallel to physics operation. Dedicated periods were devoted to commissioning of higher bunch charge (June) and trains (September).
- Higher bunch charges were eventually used (up to 1.2×10^{11} p/bunch).

- In the last phase the intensity followed a much steeped slope than anticipated because no problems were encountered, see also Fig. 3.

In the final phase the slope was four times steeper than what had been planned: this was possible thanks to the excellent performance of the entire machine and in particular of the collimation [1] and MPS.

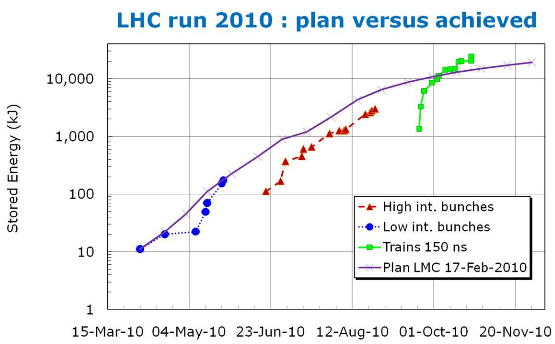

Figure 2: Evolution of the peak stored beam energy in stable beams in 2010 compared to the plan outlined at the LMC in February 2010.

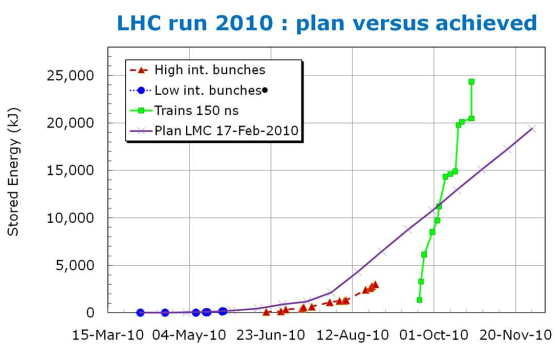

Figure 3: Evolution of the peak stored beam energy in stable beams in 2010 compared to the plan outlined at the LMC in February 2010 on a linear scale. In the last high intensity phase the achieved slope is 4 times steeper than the planned slope.

Too fast or too slow?

When everything went well it is easy to conclude (a posteriori) that we could have progressed faster! We tend to forget that we had a steep but also sometimes rocky learning curve (OP + MPS) in parallel to the intensity increase . MPPr recommendations were the outcome of agreements (or compromises) among ALL MPPr members some more conservative, some more aggressive. In many cases operational issues played a significant role (QFB versus damper, orbit stability). Afterglow of the TT40 incident was still on some minds. More aggressive colleagues and coordinators were a bit frustrated

The intensity increase in the last phase corresponded to stored energy steps of 3 MJ every 3 fills + 20 hours collisions. Within a factor 2 of a super-aggressive rate: 1 fill of 10 hours. Issue of controlling UFOs in this phase: BLM threshold increase first by a factor 3, towards the end even by a factor 5. We could have considered larger steps towards the end when the fractional increase became rather small.

The intensity increase plan was reasonable given that we were in a commissioning year. Overall the progress followed recommendations of MPPr. MPPr was over-ruled twice. Intensity within factor 2 of recommendations.

REVIEWS

Two reviews of the LHC MPS were organized in 2010, first an internal review [2] in June 2010, and later an external review [3] in September 2010. The internal review was help before increasing the intensity towards one MJ, and it also served as a preparation for the external review. The external review took place after the longer operation period in the range of 1-2 MJ and before ramping up the stored beam intensities to new World records. The external review committee was composed of MPS and operation experts from FNAL, BNL, GSI, DESY, SNS and CERN. It was chaired by R. Bacher of DESY. The external review provided a detailed snapshot of the MPS state. The review committee made 11 recommendations:

- None of the recommendations was a show stopper for the intensity increase.
- The committee expressed strong concerns around configuration and sequencing. As a consequence a major sequencer clean-up was made by the OP group under the super-vision of L Ponce [4].
- All points have been (or will be) addressed.

In parallel to those main reviews, two sub-system reviews have been organized:

- BLM system FPGA code review.
- LBDS TSU review (Trigger Synchronization Unit).

SURPRISES

Quench and damage

A real surprise of the 2010 run was the absence of ACCIDENTAL beam induced quench was with circulating beam. This outlines the excellent performance of BLM and collimation systems.

The only (known) damage to an LHC machine component is the beam2 wire-scanner that almost evaporated during a quench test, when the wire speed had to be reduced to 5 cm/s (from 1 m/s) in order to quench the D4 separation dipole [5]. This test was almost fatal to the wire: the Carbon wire diameter was reduced from 30 to 17 μm over a length corresponding to size of the beam.

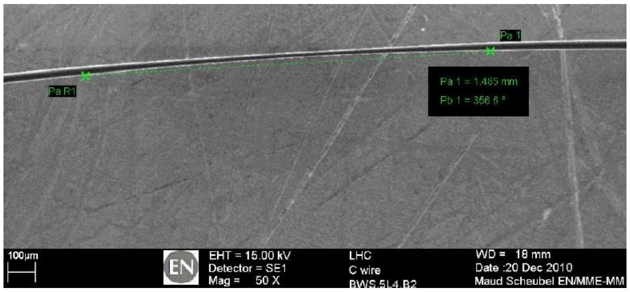

Figure 4: Damaged beam2 wire. Over a length corresponding to the width of the beam, the wire thickness is reduced to 17 μm (nominal 30 μm).

UFOs

The very fast beam loss events (time scale of 1 ms) in cold regions of the machine have been **THE other surprise** of the 2010 run, see Fig. 5. Those events have been nicknamed UFOs (an acronym borrowed from nuclear fusion community where similar events are observed in plasmas). 18 dumps were triggered by UFO-type events, and more than 100 events that remained below the BLM dump threshold have been found in the logging data. The most likely cause of the UFOs are small μm sized objects (dust) entering the beam. Some events were correlated in time and space to roman pot movements. Depending on the mass, it is possible that the particles charge up by ionization and are re-expelled from the beam. More details can be found in Reference [5].

Figure 6 shows the correlation of the number of UFOs that dumped the beams and the integrated circulating beam intensity. After the increase of the BLM threholds by a factor of 3, the number of UFO triggered beam dumps per integrated intensity decreased by a factor 4.1. A simple extrapolation for the 2011 run with 950 bunches leads to one UFO induced dump every 10 hours

Asynchronous dumps

The first asynchronous dump was recorded for beam1 on Friday November 19th at 450 GeV with a circulating pilot bunch. The event therefore occurred in rather favorable conditions as seen from MP. The event was initiated by a fault on a trigger fan out unit. Both diagnostics and reactions to the event were correct:

- The faults were detected by the LBDS IPOC and XPOC systems.
- A test dump revealed a missing trigger (reduced redundancy).

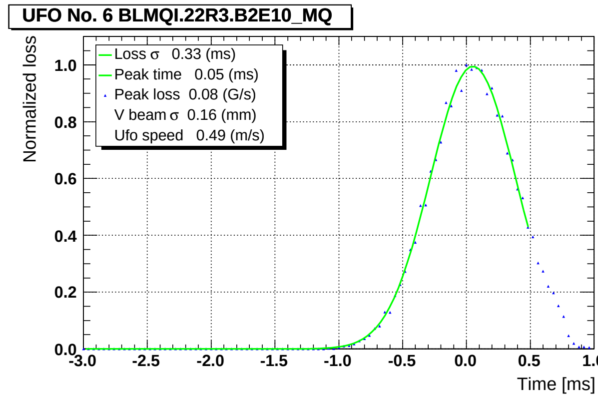

Figure 5: Time evolution of the losses for a UFO that dumped the beam. One bin corresponds to a 40 μs time interval.

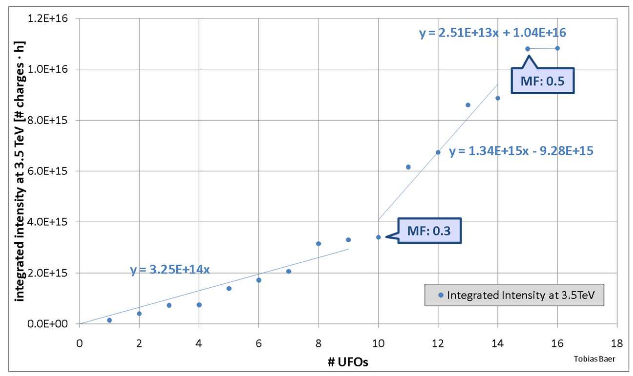

Figure 6: Correlation between the number of UFOs and the integrated circulating beam intensity. The slope change occurred after an increase of the BLM thresholds by a factor 3.

- Access to repair followed by revalidation.

The dump was however doubly asynchronous since it involved 2 MKD kickers and not one as expected. This was due to a change in the trigger fan out signal distribution (with respect to the initial design) following a reliability analysis. The cabling of the trigger fan outs will be restored in 2011 to the nominal specifications.

STATISTICS

A detailed analysis of the protection dumps was performed by M. Zerlauth at the Evian Workshop in December 2010 [6]. We present here only some selected points.

Above injection energy 47 of 370 (13%) of protection dumps were triggered by the BLMs. Most of the dumps occurred prior to the increase of the BLM thresholds on various cold and warm elements. The causes of the BLM dumps are shown in Fig. 7: the UFOs were dominant, other triggers occurred mostly during MPS tests and setups such as loss maps, wire scans and quench tests. All failures were captured by the BLMs before quenching any magnet (the QPS providing the ultimate redundancy).

The dependability and availability of the machine protection systems has been a major design criteria. It was subject to extensive studies using the FMECA approach (Failure mode, effects and criticality analysis). The MPS dependability studies were confirmed in 2010, see Table 1.

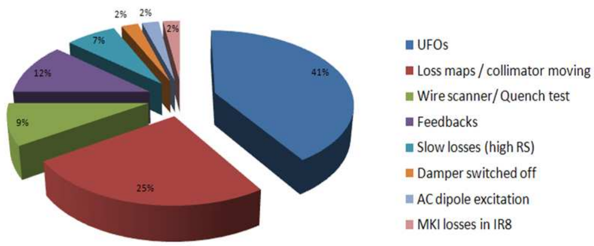

Figure 7: Initiating events for the protection dumps triggered by the BLM system.

CONCLUSION

The LHC Machine Protection Systems have been working extremely well during 2010 run thanks to the commitment and rigor of operation crews and MPS experts. Most failures are captured before effects on the beams are seen, no quenches occurred with circulating beam.

Controlling (and understanding) UFOs could become a main issue in 2011. The BLM thresholds may have to be adjusted and possibly increased to probe the limit of the quench.

Steering of the intensity increase through MPPr should be pursued in 2011. The intensity increase plan for 2011 must be be defined, and the experience of 2010 should be integrate to optimize the plan.

An improved tracking system for ALL MPS changes must be put in place for 2011, in particular in view of the MD periods: a safe recovery and pre-flight MP compatibility checks will become essential.

System	Expected	Observed
LBDS	4	9
BIC	0.5	0.5
BLM	17	3
PIC	1.5	2
QPS	16	11
SIS	–	4.5
Total	41 ± 6	31

Table 1: Expected and observed number of 'false' (internally triggered) dumps for each of the main MPS subsystems. One event is shared and BIC and SIS. The observed dumps correspond all to energies above 450 GeV.

REFERENCES

[1] R. Assmann, *these proceedings*.

[2] Internal review of the LHC MPS, June 17th-18th 2010, http://indico.cern.ch/conferenceDisplay.py?confId=97349

[3] External review of the LHC MPS, Sept. 6th-8th 2010, http://indico.cern.ch/conferenceDisplay.py?confId=103908

[4] L. Ponce, *these proceedings*.

[5] M. Sapinsky, *these proceedings*.

[6] M. Zerlauth, *Proceedings of the Evian Workshop*, December 2010.