ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-MOPRO031

ABORT GAP CLEANING FOR LHC RUN 2

J. Uythoven, A. Boccardi, E. Bravin, B. Goddard, G.H. Hemelsoet, W. Höfle, D. Jacquet, V. Kain,
S. Mazzoni, M. Meddahi, D. Valuch, CERN, Geneva, Switzerland.
E. Gianfelice-Wendt, Fermilab#, Batavia, USA

Abstract

To minimise the beam losses at the moment of an LHC beam dump the 3 μs long abort gap should contain as few particles as possible. Its population can be minimised by abort gap cleaning using the LHC transverse damper system. The LHC Run 1 experience is briefly recalled; changes foreseen for the LHC Run 2 are presented. They include improvements in the observation of the abort gap population and the mechanism to decide if cleaning is required, changes to the hardware of the transverse dampers to reduce the detrimental effect on the luminosity lifetime and proposed changes to the applied cleaning algorithms.

INTRODUCTION

The nominal LHC filling pattern consists of 2808 bunches separated by 25 ns with some longer gaps between bunches to accommodate for injection or extraction kicker rise times. The extraction kicker of the LHC beam dumping system requires a 3 μs particle free gap, the abort gap.

In case the population of the abort gap becomes too important, several superconducting magnets could quench at the moment of a beam dump. These quenches should be avoided if possible as any quench has a limited risk of resulting in magnet damage and quenches at full beam energy require several hours to recover from.

The transverse damper system in the LHC has been used to remove the particles from the abort gap, which will then be lost in the transverse plane, this process is called cleaning of the abort gap [1]. The abort gap cleaning could not be left on continuously throughout the fill, as the cleaning was found to have a negative effect of several percent on the integrated luminosity of the experiments, up to 13 % over a complete fill [1].

The abort gap population is monitored by the Abort Gap Monitor (AGM). Light from the Synchrotron Radiation Telescope (BSRT), gated for the 3 μs of the abort gap is used to measure the abort gap population. When the abort gap population exceeds the given threshold of $5 \cdot 10^9$ protons, the abort gap cleaning is switched on by the operator at a low cleaning strength and the cleaning strength is manually increased when no dangerous losses on any Beam Loss Monitors or a significant decrease in beam lifetime is noticed.

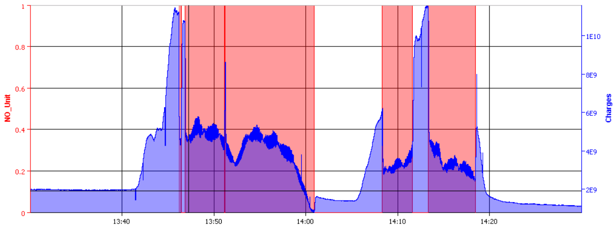

Figure 1: Example of abort gap cleaning showing on the left axis (red) cleaning on/off, right axis (blue) the abort gap population.

EXPERIENCE WITH ABORT GAP CLEANING DURING LHC RUN 1

An example of abort gap cleaning during normal LHC operation at full energy is illustrated in Fig. 1. It shows the abort gap population as a function of time and when the abort gap cleaning was switched on. Once the cleaning threshold is exceeded [2], an automatic announcement in the control room asks the operator to switch on the abort gap cleaning. The operator can manually increase the cleaning strength if required.

Operation of the abort gap cleaning during the LHC Run 1 (2009 – 2013) showed the following areas where improvement is desirable:

- An improved reliability of the abort gap population measurement by the Abort Gap Monitor.
- An automatic start and stop of the abort cleaning based on the abort gap population measurement, without the intervention of the operator.
- Improved performance of the abort gap cleaning by the transverse damper system with a reduced negative impact on the integrated luminosity.

MODIFICATIONS FOR LHC RUN 2

Changes to the Abort Gap Monitor

The Abort Gap Monitor was not conceived as a machine protection element and no specific requirements on reliability of the measurement were defined. A series of changes to the AGM are taking place during the LHC Long Shutdown 1 (2013 – 2014) to improve the reliability of the AGM.

The main modification to the AGM instrument is related to the complete re-design of the BSRT. Following the problems encountered in 2012-2013, where the light extraction mirror introduced a significant distortion of the wave front due to problems of excessive heating (caused by RF coupling to the beam), a mirror with a new design has been installed in April 2014. In addition, the optical

---

[#] Operated by Fermi Research Alliance,
LLC under Contract No. DE-AC02-07CH11359 with the United States Department of Energy.

line has been modified with the objectives to decouple as much as possible the AGM from other optical instruments of the BSRT and to reduce the distance between the sensor and the extraction mirror to minimise the beam displacement on the sensor.

At time of writing, a new PhotoMultiplier (PMT) charge sensitive amplifier with bandwidth 0-100 MHz and switchable amplification (1x and 100x) is under development and is planned to replace the present one (Hamamatsu C5594) to reduce amplification noise.

In addition to hardware modification, it is the AGM control software that is being heavily modified to increase its reliability in view of its future connection to the Software Interlock System (SIS). The modifications include the definition of a series of automated calibration procedures:

- PMT gain to voltage calibration, to be performed before injection or during energy ramp down.
- PMT signal to charge population calibration, to be performed at the beginning of the injection sequence by observing a pilot bunch of which the population is measured by the beam current transformer (FBCT).
- The above calibration shall be repeated periodically (e.g. every hour) using a bunch of known intensity to ensure the good performance of the AGM.

Besides calibration procedures, a more sophisticated management of the abort gap population measurement is introduced. The instrument enables an AG CLEANING flag and a BEAM DUMP flag depending on the measured value of the population. Glitches in the acquisition system or spikes from EM perturbations can cause single, isolated bad readings. Both Beam Dump and AG cleaning flags are activated when at least 5 out of the last 10 readings are above the corresponding threshold [3].

Changes to Interlock Levels and Logic

For LHC Run 2, starting in 2015, the planned collision energy of the LHC is 6.5 TeV per beam. The expected quench levels of the quadrupoles affected by the beam present in the abort gap during a beam dump have been re-evaluated by performing FLUKA simulations. These results were used by electro thermal calculations to determine quench and damage levels of these superconducting quadrupoles (Q4 and Q5 at IP6), most affected by an asynchronous beam dump [4]. The results are summarised in Fig. 2. The cleaning should be started at about 10 % of the lowest quench level between the Q4 and Q5 quadrupoles. For 6.5 TeV operation this would indicate a start of cleaning at an abort gap population of about $5\cdot 10^9$ protons, which is the level which was used for operation at 4 TeV during Run 1 and seems to be realistic.

The same calculations also show that in the case of a fully filled abort gap, or a beam dump asynchronous with the abort gap, no damage to the mentioned quadrupoles is expected.

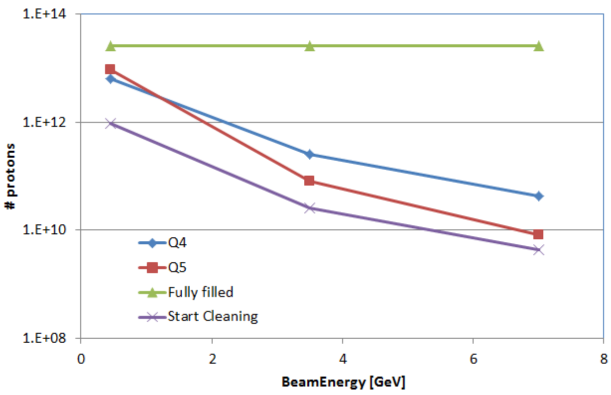

Figure 2: Quench levels and abort gap cleaning levels.

Changes to Transverse Damper System

The LHC transverse damper system (ADT) undergoes a major upgrade during the long shutdown 1. In an effort to further reduce the noise floor of the system, the number of pickups will be doubled for Run 2. Corrugated coaxial transmission lines were exchanged for smooth wall lines to reduce the dispersion effects and the new beam position electronics is being designed using current, state of the art components. The use of the most recent programmable logic devices (FPGAs) will allow more sophisticated signal processing algorithms to be deployed for the Run 2.

As already mentioned, AGC during physics showed a detrimental effect on the fill's integrated luminosity. The ADT frequency response is a bandpass, where the lower cut-off frequency is defined by the AC-coupled components. The upper cut-off frequency is defined by the first order RC low-pass formed by the deflection plate to ground capacitor and the anode resistor. Both cutoff frequencies have a significant impact on the cleaning pulse quality.

The upper frequency defines pulse edge duration. With the available power and the "standard bandwidth" operation, the large signal rise/fall time is about 650 ns. The length of the excitation pulse during the run 1 was therefore set to cover only 30 to 50% of the abort gap (1 to 1.5 µs out of the total 3 µs). If a full power, large kick amplitude is not needed, the bandwidth of the transverse damper could be extended by pre-distorting the drive signal. It was demonstrated, that the system impulse response could be significantly shortened to target even individual bunches, at the nominal 25ns bunch spacing (at about 10% available kick strength) [5]. This allows prolonging the cleaning pulse to cover larger portion of the abort gap increasing the cleaning effectiveness.

The currently used unipolar cleaning pulse does not have a zero DC component. When passed through an AC coupled system, it leaves a small, exponentially decaying tail. The minimum "polarity switch time" is limited by the bandwidth and available power of the ADT system. A technical minimum is about 25 ns, however this value imposes a stress to the ADT power system, which may lead to a power amplifier reliability and life time degradation and further tests are required.

Changes to Cleaning Algorithms

The implementation of the di-polar kick as presented above is expected to reduce the trailing tail effect and thus the impact of AGC on luminosity. After the energy ramp the AG is expected to be populated by particles with $\Delta p/p < 0$, the minimum value being $-1.37\text{x}10^{-3}$ fixed by the momentum collimator. With a slip factor $\eta=0.137\text{x}10^{-3}$ and $T_{rev}=88.92$ µs the minimum time required for crossing the 3 µs long abort gap is 6.9 sec i.e. 77686 turns. The cleaning process taking a few thousand of turns we can assume that each particle sees a constant polarity and cleaning works as with mono-polar kicks.

A simplified tracking code was used for simulating the effect of the di-polar kick with finite switching time. Figure 3 shows the AG population vs. time after the cleaning process has been initiated with mono-polar (red) and di-polar (blue) kicks. In both cases the same excitation amplitude and frequency program is applied to the vertical dampers, namely the excitation tune is repeatedly varied from 0.314 to 0.320 in 3 steps each 630 turns long, 0.32 being the fractional part of the beam nominal vertical tune. After about 2400 turns all 2200 starting particles are lost at the betatron collimators when the mono-polar program is used, while 6 survive for the cleaning procedure with di-polar kicks, reduced to 1 when the polarity switch time is reduced from the challenging 0.02 µs to a non-realistic 0.002 µs. No particle survives when the time is further reduced by a factor 10 and the curves in Fig. 3 become identical to those of mono-polar cleaning.

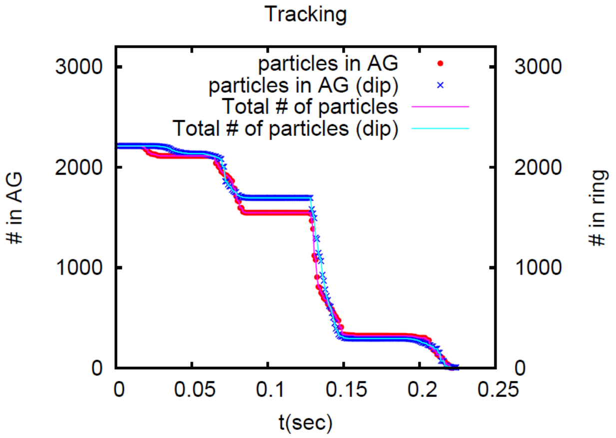

Figure 3: Cleaning with mono-polar and di-polar kicks with 0.02 µs switching time.

This code was also used for assessing the maximum trailing tail effect which could be tolerated not to blow up the beam emittance more than beam-beam interaction or other effects do. In Fig. 4 the emittance growth is shown when the kick seen by the particles in the core is reduced by a factor $1\text{x}10^{-4}$ (blue), and $2\text{x}10^{-4}$ (magenta) wrt the kick needed for AG cleaning. The frequency program is the same as described above. The emittance growth measured for fill 1372 [6] during luminosity operation w/o AG cleaning is shown for comparison (red). The measured beam size has been linearly interpolated between starting and final values and the starting emittance adjusted to the starting emittance of the 10000 particles tracked, namely $4.682\text{x}10^{-10}$ m. Simulations show that different frequency programs may have smaller impact on the beam core w/o compromising cleaning efficiency. The cyan curve in Fig. 4 shows for instance the emittance growth when the upper frequency is 0.31975 and the reduction factor is $1\text{x}10^{-3}$.

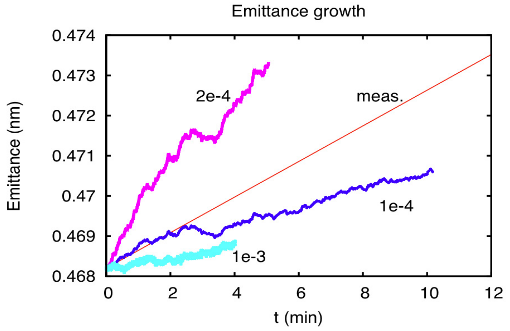

Figure 4: Emittance growth of a single bunch for various attenuations of the residual kick seen in the AG and two different frequency programs.

CONCLUSIONS

During the LHC Long Shutdown 1 several changes have been made to the transverse damper system and the abort gap monitor which should allow for a more reliable and efficient cleaning of the abort gap. The abort gap population levels at which cleaning should be started have been reassessed for different beam energies. Simulations of different cleaning algorithms are presented which show the potential of effective abort gap cleaning with a reduced negative effect on the beam emittance and luminosity. The proposed cleaning algorithms will need to be verified experimentally during the LHC run 2.

REFERENCES

[1] W.Bartmann et al., "LHC abort gap cleaning studies during luminosity operation", IPAC 2012 New Orleans, May 2012, http://www.JACoW.org

[2] E.Gianfelici, B.Goddard, V.Kain, M.Meddahi, J.Uythoven, "Procedures for abort gap cleaning at full energy", CERN edms document 1204352, 16-04-2012.

[3] A. Boccardi, E. Bravin, S. Mazzoni. "Calibration procedures and automated actions for the Abort Gap Monitors of LHC", ref. LHC-BSRA-ES-0001, edms no. 1337184, rev. 1 (draft).

[4] B.Auchmann, G.Steele, A.Verweij, "Quench and damage levels for Q4 and Q5 magnets near point 6", CERN Technical Note, edms number 1355063, 10-02-2014.

[5] W.Höfle, F.Dubouchet, G.Kotzian, D.Valuch, "Performance of the LHC transverse damper with bunch trains", IPAC 2013, Shanghai, http://www.JACoW.org.

[6] A.Ratti et al., "Using the BRAN Luminosity Detectors for Beam Emittance Monitoring During LHC Physics Runs'', IPAC2012, New Orleans, LA, USA, 20 - 25 May 2012, pp.966-968.