# LHC ABORT GAP CLEANING STUDIES DURING LUMINOSITY OPERATION

W. Bartmann, A. Boccardi, C. Bracco, E. Bravin, B. Goddard, W. Höfle,
D. Jacquet, A. Jeff, V. Kain, M. Meddahi, F. Roncarolo, J. Uythoven, D. Valuch
CERN, Geneva
E. Gianfelice-Wendt, Fermilab*, Batavia

*Abstract*

The presence of significant intensities of un-bunched beam is a potentially serious issue in the LHC. Procedures using damper kickers for cleaning both the Abort Gap (AG) and the buckets targeted for injection, are currently in operation at flat bottom. Recent observations of relatively high population of the AG during physics runs brought up the need for AG cleaning during luminosity operation. In this paper the results of experimental studies performed in October 2011 are presented.

## INTRODUCTION

For all LHC filling schemes it is mandatory to keep an empty abort gap of at least 3 $\mu$s to accommodate the beam abort kicker rise time. Fig. 1 shows the position of the LHC Abort Gap in front of the first bucket. The particles first entering the gap are those from the first bucket with $dp/p$ <0 and those from the last bucket before the gap, #34438, with $dp/p$ >0.

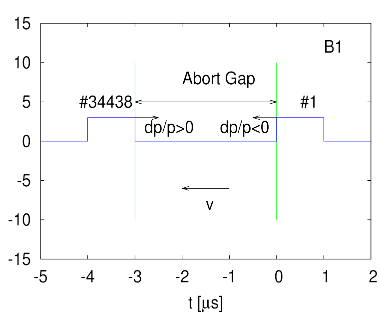


Figure 1: Scheme of AG position.

The LHC AG cleaning relies on the transverse feedback system [1] which includes four horizontal and four vertical electrostatic kickers per beam, each providing a maximum kick of 0.5× 450/energy[GeV] $\mu$rad. The wide band power amplifiers allow the simultaneous use of the kickers for AG cleaning and feedback purposes. The flat top of the kicker pulse within the abort gap may be modulated as desired. The AG population is monitored through synchrotron light monitors [2] (BSRA), which also provide bunch-by-bunch emittance measurements (BSRT).

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During the approximately 20 - 30 minutes required for filling the machine for physics, the build-up of un-bunched beam was noticed. While this relatively modest un-bunched beam was not harming the machine, those particles crossing the area to be filled at the moment of injection were kicked out by the injection kicker causing significant beam losses, close to the beam loss monitors (BLM) threshold to dump the circulating beam. A strategy was worked out and is operational since 2010 which involves simultaneous cleaning of the AG by the vertical dampers, and of the target injection region by the horizontal ones.

During luminosity operation abort gap cleaning is only required in case of non-optimal operation of the RF system, indicated by a measured increase of the abort gap population. It is crucial to prove that the beam in the AG can be cleaned without causing beam losses close to the BLM thresholds.

In December 2009 AG cleaning studies had shown a large trailing tail effect. The culprit was found to be the dispersion in the cable transmitting the signal from the surface to the LHC underground cavern UX45. A suitable filter was installed in the shutdown 2009/2010 to correct for the attenuation and group delay variation of this cable with frequency. The new corrected pulse shape was tested with beam in September and October 2010 at injection.

In October 2011 experiments were carried out to study the cleaning efficiency at 3.5 TeV and check the influence of AG cleaning on luminosity operation.

The results are summarized in this paper; more details can be found in [3, 4].

## AG CLEANING AT 3.5 TEV

On October 7, 2011, a dedicated fill of three batches of 12 bunches each was injected, accelerated and brought into collision. The vertical dampers were used for AG cleaning, as at injection. Relevant parameter values are summarized in Table 1 together, for comparison, with the settings used at injection. The total kicker voltage was 2.4 kV for Beam 1 (B1) and 2.0 kV for Beam 2 (B2) corresponding to a total kick of 0.02 and 0.017 $\mu$rad respectively. The kicker rise/fall time was 250 ns and the time at flat top 750 ns. The asymmetric range with respect to the nominal tune was chosen having in mind that mainly particles with $dp/p$ <0 would populate the AG; the momentum collimators set the maximum $|dp/p|$ for circulating particles to about $2\times10^{-3}$.

Table 1: AG Cleaning Parameter Values

| | $q_{start}$ | $q_{end}$ | # steps | $dq$ | $q_y$ |
|---|---|---|---|---|---|
| Injection | .30 | .32 | 15 | .0013 | .31 |
| 3.5 TeV | .29 | .33 | 30 | .0013 | .32 |

The value of $q_y$=0.29 corresponds to a chromaticity of 15 units for a particle with $dp/p$=-2×$10^{-3}$. Non-linear chromaticity in collision optics has not been measured.

After squeeze, the cleaning was switched on for B2 and then for B1. As expected, losses increased on the right and left side of IP7, B2 and B1 betatron collimators location, respectively. No anomaly was observed in the single bunch lifetime measured through the fast Beam Current Transformer (BCT) during the following 30 minutes. AG cleaning was turned off and beams brought into collision.

After switching on cleaning for B1 only, a signal at the damper frequency was clearly seen also in the B2 spectrum. While beam emittance measurement and BCT did not show any noticeable difference between AG cleaning on/off, a clear correlation could be observed in the luminosity measured by CMS (Fig. 2).

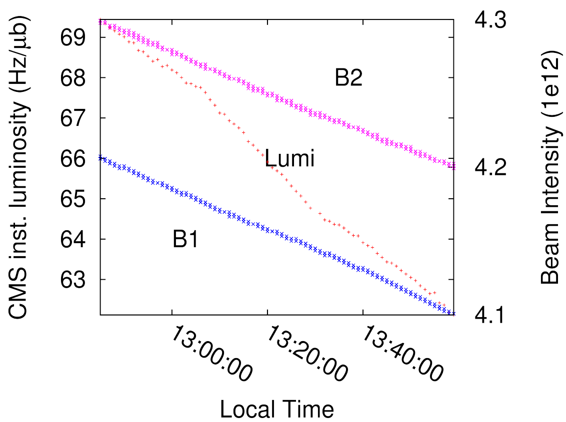


Figure 2: Luminosity vs. time (red) shows a kink at about 13h10 corresponding to the moment B1 and B2 cleaning is switched on. The second kink at about 13h34 corresponds to the moment the cleaning is turned off. The BCT (blue for B1, magenta for B2) does not show kinks.

The observed kinks in the luminosity vs. time could be explained by a transverse oscillation of the interaction point and/or by an increase of the bunch emittance. The first hypothesis is supported by the fact that the reaction is immediate and by the bunch-by-bunch emittance measured by the BSRT, while the fact that the slope of the luminosity changes is in favor of the second explanation.

Bunch-by-bunch luminosity averaged over the bunches for each of the 3 batches shows the same kinks (Fig. 3).

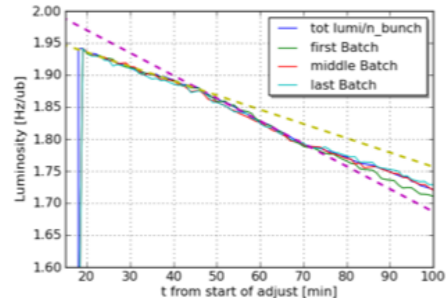


Figure 3: Bunch-by-bunch luminosity averaged over each of the three batches.

## AG CLEANING DURING LUMINOSITY OPERATION

After the previous preliminary test, it was decided to continue the AG cleaning tests at the end of a normal luminosity run on October 13, 2011. AG cleaning studies started after about 7 hours of luminosity operation with 1380 bunches in each beam.

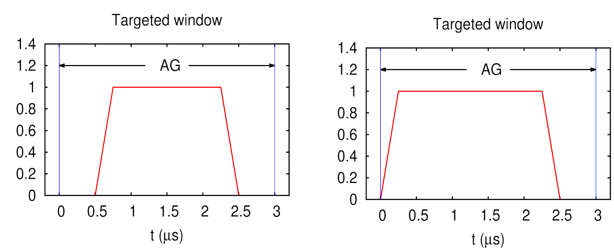


Figure 4: "Short" (left) and "long" (right) kicker pulse.

Shorter and longer kicker pulses were used (Fig. 4) at 50 % and 100 % of the voltage used during the previous test (here referred to as "nominal" power), while the frequency program was as in Table 1.

In summary cleaning was set as follows:

1. 10h17 Short pulse, 50 % nominal power.
2. 10h44 Short pulse, nominal power.
3. 11h38 Long pulse, nominal power.
4. 13h09 Short pulse, nominal power.
5. 13h38 Switch off cleaning.
6. 14h24 Switch on to short pulse, 50 % nominal power.
7. 15h37 Long pulse and nominal amplitude.

Measured CMS luminosity and AG population are shown in Fig. 5.

As shown in Fig. 6 for B1, during a normal luminosity run some un-bunched beam reaches the AG. Part of it is cleaned by the momentum collimators, but the natural cleaning due to synchrotron radiation is not sufficient for balancing the production of un-captured particles. When active cleaning starts, the AG is effectively cleaned.


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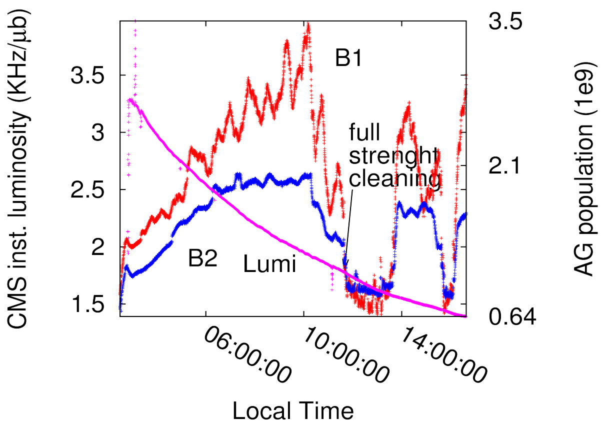


Figure 5: CMS luminosity (magenta), B1 (red) and B2 (blue) AG population during October 13 experiment. The luminosity run started around 3h00, AG cleaning (with various settings) at 10h17.

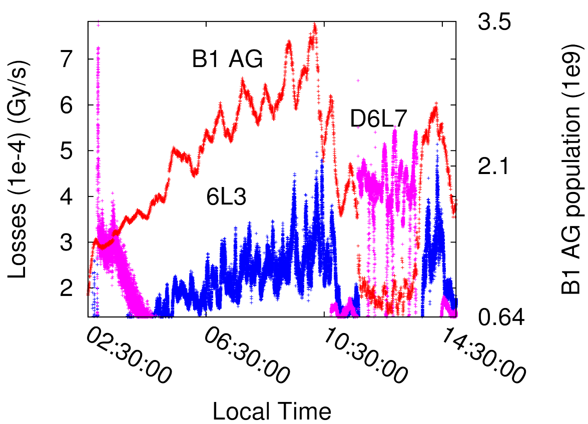


Figure 6: B1 AG population (red), losses at betatron collimator TCP.D6L7.B1 (magenta) and momentum collimator TCP.6L3.B1 (blue).

The largest cleaning efficiency is obtained with full kicker length and higher voltage (11h38). A careful inspection of the data allows to notice the effect of the cleaning on the luminosity. The luminosity data have been linearly fitted right after each step. As the decay is non-linear, the fit was performed using only the first 10 minutes after each change of AG cleaning settings. Unfortunately, the TIMBER [1] data with low sampling rate (1 per minute) were used and therefore the fit quality is not optimal. The detrimental effect on luminosity is proportional to the cleaning window and kicker strength.

We tried to estimate the loss of integrated luminosity due to the cleaning procedure. The luminosity reduction observed during the October 13 experiment has been applied to the fitted instantaneous CMS luminosity measured on October 16, under the assumption that the effect does not depend on time. The worst case, namely cleaning turned on at 100 % of nominal power and with long kicker pulse, leads to a reduction of the integrated luminosity by 13 % on a 8 hours run (Fig. 7), while the estimated reduction for the second worst case (50 % power, long pulse) is 5 %. As mentioned above, the fit quality is rather poor and the results are very qualitative.

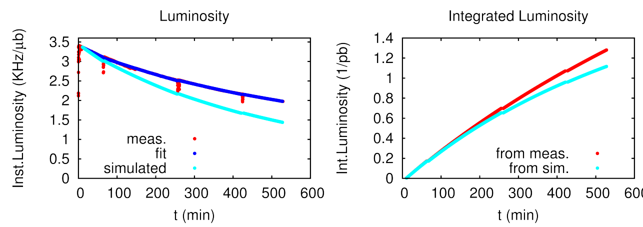


Figure 7: On the left, the instantaneous luminosity actually measured on October 16 by CMS is shown (red) together with the luminosity obtained after applying the largest reduction observed during the October 13 experiment (cyan). The corresponding integrals are shown on the right.

## SUMMARY AND OUTLOOK

Results of LHC AG cleaning tests at 3.5 TeV during luminosity operation were reported. With respect to 2009, a great improvement has been achieved after a filter was installed for correcting dispersion in the transverse damper system cables connecting the surface to the underground tunnel. However, a non negligible effect on luminosity was still observed.

Further improvements of the hardware are planned for the long shutdown next year.

A procedure for abort gap cleaning has been defined and used in 2012 during 4 TeV luminosity operation. The procedure includes the observation of the abort gap population and the beam losses at the collimators. Abort gap cleaning is to be started if the total abort gap population exceeds $5\times10^9$ protons.

## ACKNOWLEDGMENTS

The work of E. Montesinos and his team has been essential to ensure the proper functioning of the powering of the LHC transverse damper system. The operation crews are also thanked for their assistance during system commissioning and beam measurements.

## REFERENCES

[1] W. Höfle, Proc. EPAC'04, Lucerne, July 2004, p. 575.
[2] A.S. Fisher, LHC Performance Note-014 (2010).
[3] CERN-ATS-Note-2011-128 PERF.
[4] CERN-ATS-Note-2012-001 PERF.

[1] TIMBER is the data extraction interface of the LHC data logging system.



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