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APERTURE MEASUREMENTS WITH AC DIPOLE AT THE LARGE HADRON COLLIDER

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Abstract

Global aperture measurements are crucial for a safe operation and to push the performance of the LHC. In particular, the knowledge of the global aperture at top energy allows pushing the optics to reduce the colliding beam sizes. The standard method used in the LHC commissioning requires using several low-intensity bunches for one measurement and makes bunches un-usable for other activities. This paper presents first global aperture measurements performed at injection with a new method using the AC dipole. This method consists in exciting large coherent oscillations of the beam without spoiling its emittance. A gentle control of the oscillation amplitude enables re-using the beams for several measurements. These measurements are compared with aperture measurements performed using the standard method based on destructive blow-up of bunches. Possible benefits, for example for optics measurements, at top energy with squeezed optics, are elaborated.

INTRODUCTION

Aperture measurements are a very important part of the standard LHC commissioning and one of the key parameters for the definition of the entire collimation system settings. These measurements need to be done to verify that the minimum aperture in the machine is protected by the collimation system. In addition, the detailed knowledge of the available aperture at top energy determines the performance reach in terms of smallest achievable colliding beam size [1].

At top energy, the standard method for LHC aperture measurements consists in performing a gentle blow-up of one pilot bunch using the transverse damper (ADT) until the aperture is touched by the beam envelope and losses are observed by the LHC Beam Loss Monitor (BLM) system. This identifies the longitudinal location of the aperture bottleneck. In these conditions, an automated beam-based alignment of the collimator used for the measurements is performed. When the BLM next to the collimator gives a loss spike, it is touching the envelope and its opening is the same as the envelope. The aperture of the collimator in units of σ, minus a small overshoot from the applied steps of the collimator movement, corresponds to the aperture of the bottleneck [2]. This method requires using several pilot bunches for a single measurement, as the ADT blow-up increases the emittance, and makes the bunches un-usable for other activities. At top energy, this is often not efficient.

A new method based on the AC dipole, used for optics measurements in the LHC [3–5], has been tested for the first time for aperture measurements. This method consists in exciting large coherent beam oscillations without blowing up its emittance [6], allowing thus to explore large transverse amplitudes. The ultimate goal of this study would be that the aperture measurements at top energy could be combined with optics measurements or with any other beam activity requiring individual low-intensity bunches saving commissioning time. In addition, the optics measurements can be performed with the largest possible amplitude of the AC dipole kicks without causing losses on the aperture, thus making the measurements more precise.

We present in this paper the analysis and comparison of the global aperture measurements performed for Beam 1 (B1) on the 15th of September (MD1) and on the 29th of November (MD2) 2017 at injection energy of 450 GeV with pilot bunches of 1×10^{10}. In addition, aperture measurements were performed during the MD1 using a collimator to mimic the machine bottleneck to have a reference value for the comparison between the methods. Details of the measurements and analysis can be found in [7].

MEASUREMENTS PROCEDURE AND ANALYSIS

For both aperture measurement methods a similar experimental procedure and analysis is followed. First of all, all collimators are retracted. Then, the beam is excited either the AC dipole or the ADT, respectively, such that losses are measured at the aperture bottleneck with the BLM system. The extension of the beam envelope is measured by performing an aperture scan using typically a primary collimator (TCP). The TCP is closed towards the beam in steps of 0.5 σ until the losses move from the bottleneck to the TCP. Once we ensure that both jaws have touched the beam, the gap of the collimator in units of σ can be translated into the aperture of the bottleneck.

In Fig. 1 an overview of the evolution of the key observables during the AC dipole aperture measurements performed in MD2 with B1 is shown. In this plot, we have the TCP half gap in units of σ (green line), the AC dipole kick (blue dots), the ADT blow-up trigger (black stars) and the losses observed in IP2/6/7 in Gy/s. The AC dipole amplitude in mm corresponds to the peak to peak β−function horizontal oscillations in the arc where the nominal β−function is expected to be about 180 m. In addition, the losses in IR7 generated by B2 have been added (black) to monitor the activity of the parallel measurements, which generated

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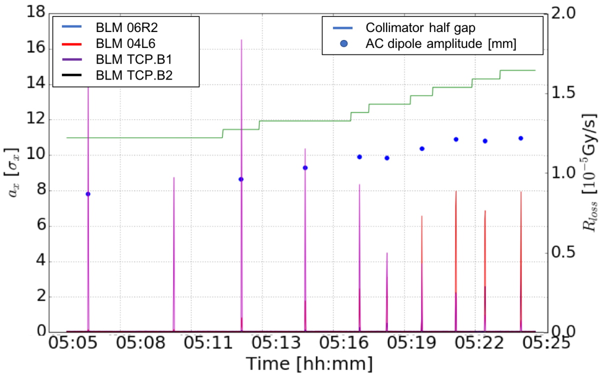

Figure 1: Collimator gap (left axis) and beam losses (right axis) versus time from the dipole measurements in MD2.

losses and could interfere on the aperture measurements being performed in B1.

The BLM response to the amount of beam losses reaching the BLM is in general different at different locations due to the shower development, the local geometry, and the tail populations. In addition, the intensity will depend on the strength of each beam excitation. This introduces an uncertainty on the aperture obtained directly from the collimator settings at which the aperture bottleneck is shadowed by the collimator. For these reasons, the BLMs signal integrated over 1.3 s in Gy/s is normalized to the highest BLM value recorded at the corresponding location during the scan and to the beam intensity drop (number of protons) in each step [8]. The aperture of the bottleneck can be estimated as the interpolated cross-over between the TCP losses and the aperture ones. However, this could also be a possible source of uncertainty, especially if the intensity drops is of the same order of magnitude as the noise of the Fast Beam Current Transformer (FBCT) used to measure the beam intensity. Because of that the AC dipole measurements in MD1 could not be normalized to the beam intensity. In Fig. 2 the intensity along the measurements in MD2 is shown as an example where one could observe the difference in the intensity drops generated in each of the scans.

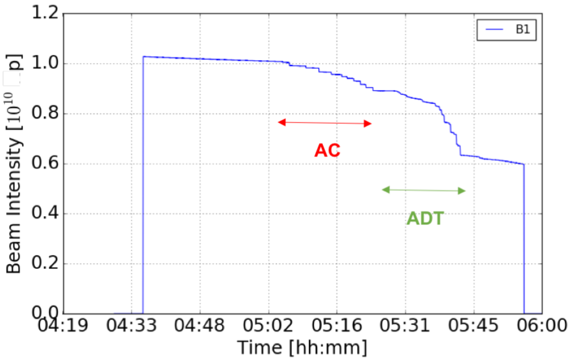

Figure 2: Beam intensity in MD2.

RESULTS

An example of the results obtained in MD2 is shown in Fig. 3 in the form of normalized losses in the TCP (black) and bottlenecks (red and blue), as a function of the TCP half gap in units of σ for the AC dipole (top) and the ADT blow-up (bottom) scans. The measurements are compared between the methods for the two sets of measurements in MD1 and in MD2 in Table 1 and Table 2, respectively. Both lower collimator position in the scan protecting the aperture and the interpolated aperture values are shown. The associated errors have been calculated as the quadratic sum of the 10 % β–beating (5 % of beam size change) [9] and the relative collimator position step on the scan (0.5 σ).

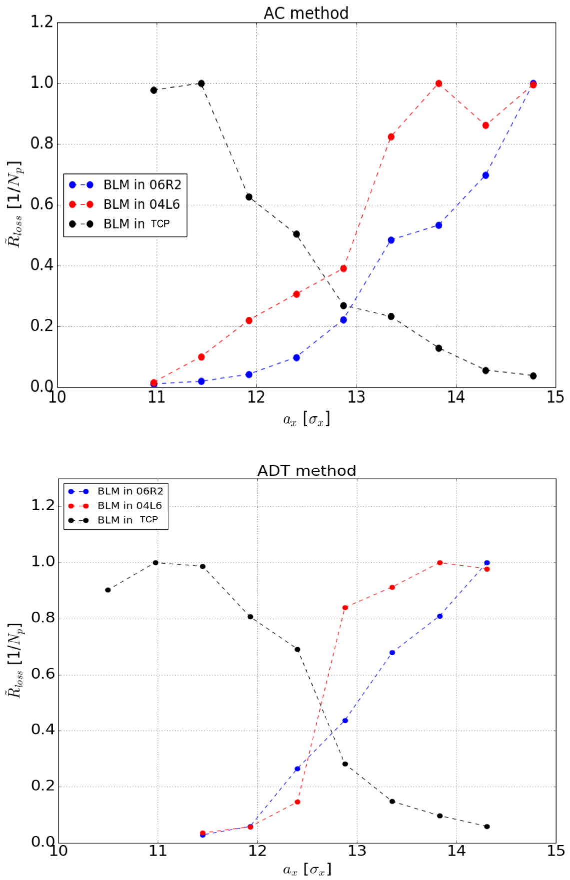

Figure 3: Normalized BLM losses at the bottlenecks and at the TCP as a function of the TCP gap in units of σ for the AC dipole (top) and the ADT (bottom) scans in MD2.

Two global aperture bottlenecks were found for B1 in the horizontal plane using both methods. One in Q6R2, a quadrupole magnet in the Interaction Region (IR) 2, and the other one in TCDSA.04L6, a septum protection collimator in IR6. In Fig. 3 (top) the AC dipole method results from MD2 are shown. A clear decrease of losses in IR2 is observed as we reduce the gap of the TCP while for the bottleneck in IR6 it is not until the 4th point in the scan that we see a decrease of losses as we close the TCP gap. The TCP shadows the aperture of the bottlenecks at 12.9 and

12.4 σ for the Q6R2 and TCDSA.04L6, respectively. The interpolated apertures are 12.9 σ for Q6R2 and 12.7 σ for the TCDSA.04L6 bottleneck.

On the bottom plot of Fig. 3 the results corresponding to the ADT blow-up method are shown. In this case, a clear reduction of losses is observed for both bottlenecks as we reduce the TCP gap. From these scans both bottlenecks are protected when the collimator is closed to 12.4 σ. The interpolated values for the measured apertures are 12.8 σ for the Q6R2 and 12.7 σ for the TCDSA.04L6 bottlenecks.

Table 1: MD1 AC dipole and ADT blow-up global aperture measurements.

Bottleneck	AC dipole a[σ]		ADT blow-up a[σ]	
	Interp.	**Coll. scan**	**Interp.**	**Coll. scan**
Q6R2	12.5±0.8	12.5±0.8	12.7±0.8	12.5±0.7
Q4L6	12.1±0.7	12.0±0.7	12.6±0.8	12.5±0.7

Table 2: MD2 AC dipole and ADT blow-up global aperture measurements.

Bottleneck	AC dipole a[σ]		ADT blow-up a[σ]	
	Interp.	**Coll. scan**	**Interp.**	**Coll. scan**
Q6R2	12.9±0.8	12.9±0.8	12.8±0.8	12.4±0.7
Q4L6	12.7±0.8	12.4±0.7	12.7±0.8	12.4±0.7

Good agreement is found on the location of the bottleneck and the aperture is within the associated error in both sets of measurements. The measurements performed using the ADT blow-up method are consistent with the results of MD1 being the largest difference about 0.1 σ. The AC dipole results are also consistent within the error associated to each method. The largest difference about 0.5 σ is found on the aperture measured in IR6 in MD1 and on the bottleneck in IR2 in MD2 with respect to the ADT results. In order to understand this discrepancy the beam orbit between the scans was investigated. However the orbit shifts observed was up to 100 μm in both bottlenecks and TCP. This could not explain a discrepancy on the aperture measurements higher than 0.1 σ. We have to notice here that the intensity normalization could not be applied to the AC dipole measurements in MD1 because the intensity drops during the scan were smaller than the noise of the FBCT increasing the uncertainty of the measurements. From these measurements we could conclude that for a better intensity normalization and to reduce the uncertainty of the measurements, it is important to generate pronounced loss spikes.

In addition to the aperture measurements in MD1 the emittance of B1 in the horizontal plane was measured using wire scanners as a function of the AC dipole amplitude [10]. The emittance was not changing and we could demonstrate that the new method is non-destructive allowing us to reuse the bunch for other activities.

Concerning the time required by each method, we have to note that the AC dipole method is a bit slower because one minute of cool down is needed by the AC dipole between excitations. However the excitations are independent for each beam and each plane and one can perform measurements in parallel to maximize the efficiency of the measurements.

During MD1 measurements were also performed with a tertiary collimator (TCT) in IR5 (TCTPH.4R5.B1) fixed to 10 σ half gap in order to have a reference value for the comparison between the methods. In this scenario, losses were only observed in the TCT in IR5 (artificial bottleneck) and in the TCT in IR1 (TCTPH.4R1.B1) used to scan the aperture. A summary of the measurements can be found in Table 3. Both lower collimator position in the scan protecting the aperture and the interpolated aperture values are shown.

Table 3: MD1 AC dipole and ADT aperture measurements with 10 σ TCT in IP5 as bottleneck.

Bottleneck	AC dipole a[σ]		ADT blow-up a[σ]	
	Interp.	**Coll. scan**	**Interp.**	**Coll. scan**
TCTH.IR5	10.7±0.7	10.5±0.7	10.8±0.7	10.5±0.7

Good agreement is found between the location and aperture measured by the two methods in both the interpolated and the collimator scan value. In this case a systematic offset is found when comparing to the reference value of 10 σ, which is however within the associated error of each method.

CONCLUSIONS

Global aperture measurements are crucial for a safe operation of the LHC and to push its performance. The possibility of using for aperture measurements a new method based on the AC dipole has been explored for the first time. The new method has been benchmarked against the ADT blow-up method. Both methods identified the same bottlenecks location and the corresponding measured apertures are in good agreement within the estimated errors.

The time required by the AC dipole scan is slightly longer than that needed by the ADT blow-up method for one beam and one plane, however the method is non-destructive and it can be combined with other activities in commissioning reducing the number of beam injections. In particular, it can be combined with optics measurements, thus saving commissioning time and enabling the optics measurements with the highest possible beam orbit amplitude making the optics measurements more precise. The plan is to use this new method at top energy for the 2018 commissioning to fully profit of it.

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