EXPERIMENTAL OBSERVATIONS FROM THE LHC DYNAMIC APERTURE MACHINE DEVELOPMENT STUDY IN 2012

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Abstract

In view of improving the understanding of the behaviour of the dynamic aperture and to benchmark the numerical simulations performed so far, two experimental sessions have been scheduled at the LHC. The observations of the first sessions have been reported elsewhere, while in this paper the latest observations in terms of beam currents, local losses and beam sizes will be described. The octupolar spool pieces have been used to artificially reduce the dynamic aperture and then induced slow beam losses. Alternating signs have been used in order to probe different configurations. Finally, scans over the strength of the decapolar spool pieces have been performed too.

MEASUREMENTS AT BEAM 1

The experimental study repeated and extended similar measurements performed in 2011 [1] to probe the dynamic aperture by observing the bunch current decay after the bunch is blown up so that a certain fraction of particles experiences non-linear motion. The underlying principle is based on a relation between the intensity evolution and dynamic aperture [2] that is derived from an inverse logarithm scaling law for dynamic aperture [3, 4].

So far the LHC shows extremely good lifetime at injection (between ten to hundred hours), thus indicating that the dynamic aperture should be comparable to the mechanical one. This suggests that an effective strategy to measure the dynamic aperture at injection consists of reducing it by acting on some of the non-linear circuits available in the ring. In addition, the injected beam needs to be blown up in order to have enough particles probing high amplitudes and hence experiencing non-linear effects, as diffusive effects have been measured to be very slow in the LHC [5]. This is certainly not the only technique to measure the dynamic aperture (see Ref. [6]).

The strategy used for the machine study has been as follows:

- The machine for Beam 1 is prepared in a configuration similar to the operational one. Contrary to 2011, the Landau octupoles were set to nominal values. All collimators were put in parking position with only the horizontal and vertical primary devices set to 12 σ[1] in order to shadow the machine aperture that was measured to be larger than about 13 σ (the triplet's aperture being larger than 14 σ).
- A pilot bunch with operational normalised emittance, i.e., ≈ 2 μm, and $1.4 - 1.7 \times 10^{10}$ p is injected.
- During this study the transverse damper (ADT) has been used to blow up the beam size until beam losses at the primary collimators are observed. This method, deployed in 2012, relies on exciting the beam with white noise [7]. This had the advantage of creating a well-reproducible Gaussian shape of the transverse beam distribution after blow up. The ADT excitation was obtained by using 3 excitations and 9 excitations of 1 s, each at 10% of strength in the horizontal and vertical plane, respectively. The result of the excitation is a transverse normalised emittance of about $11.5, 13.8$ μm for H- and V-plane, respectively. During the measurements, information about the evolution of beam size and emittance using the synchrotron light monitor (BSRT) has been recorded.
- The beam losses and bunch intensities are recorded and analysed off-line for studying the time-dependence as a result of the change of the current in the spool pieces.

The described experimental procedure has been repeated by changing the settings of the octupolar (MCOs) and decapolar (MCDs) spool pieces with the aim of reducing artificially the dynamic aperture. In the first test [1] the scan over the strength of the octupolar spool pieces was performed by keeping a constant sign for all circuits. This, of course, had an impact not only on the detuning, but also on non-linear chromaticity, which was observed as a reduction in bunch length during the periods with beam losses. To overcome this and to have a cleaner experimental configuration, alternating signs for the octupolar spool pieces have been considered [8] as this allows reducing first order effects.

The overall results of the measurements' programme are summarised in Fig. 1 (upper plot) in which bunch intensity and spool pieces settings are plotted as a function of time. It is worth mentioning that the circuit RCO.A12B1 was not operational, which spoilt the perfect cancellation of first order effects due to the alternating sign.

Several current values and sign configurations have been tested, namely

a) 5 values of current for the MCO circuits with polarities[2] $0 + + + \;\; + + ++$;

[1] It is customary to refer to a normalised emittance of 3.5 μm for computing the collimators' aperture.

[2] The list of polarities starts from arc 1-2 to 8-1. The zero stands for the unavailable circuit.

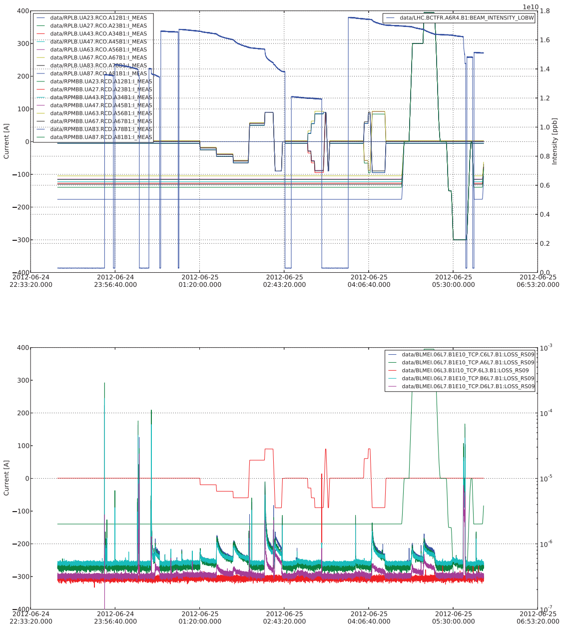

Figure 1: Spool pieces currents and bunch intensity (upper) and BLM signals at TCP locations (lower) as a function of time during the study. The various periods corresponding to different machine configurations are visible.

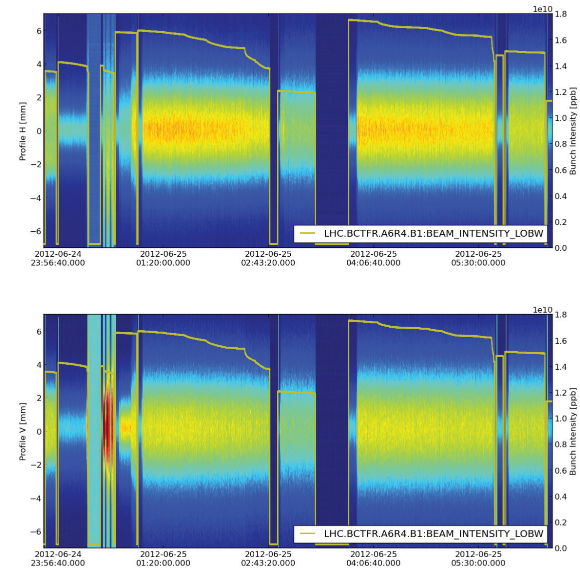

Figure 2: Time evolution of the beam profiles as measured by the BSRT during the study (horizontal, upper, vertical, lower). The time evolution of the bunch intensity is superimposed to identify the relevant events. The width of the beam distribution is rather constant during the MD, apart from one period during which strong losses were observed.

b) 3 values of current for the MCO circuits with polarities $0 - + -\quad + - + -$;

c) 3 values of current for the MCO circuits with polarities $0 - + +\quad - - + +$;

d) 4 values of current for the MCD circuits with polarities $+ + + +\quad + + + +$;

In Fig. 1 the signal from beam loss monitors (BLM) close to the primary collimators (TCP) (lower plot), feature a good correlation with the scan over the spool pieces' strength, at least for cases a), c), and d). For the case b) the losses on the TCPs are much smaller than in the other cases.

The beam size is estimated by fitting the profiles measured by the BSRT, calibrated against the BWS data and the information from the complete set of beam profiles is reported in Fig. 2 including the re-calibration of the data.

No clear trend of σ_{BSRT} has been observed during the measurements, which indicates that the beam size was rather constant apart during the short period of very high beam losses.

The bunch length did not vary during the tests and the peak amplitude of the longitudinal profile follows naturally the same evolution of the bunch charge as seen in Fig. 3. This is an interesting difference with respect to what observed in [1] where the bunch length featured a decreasing trend. This could be related with the different non-linear chromaticity for the two experimental sessions and it could indicate that in the second experiment the losses were more induced by non-linear effects acting on the transverse beam dynamics.

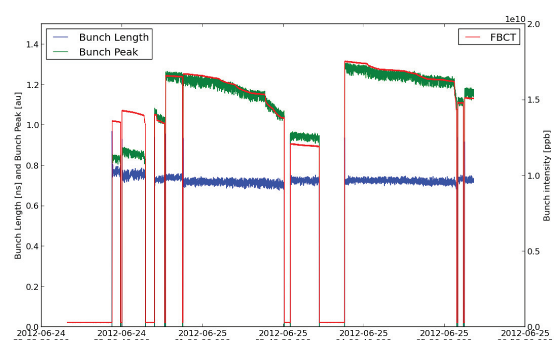

Figure 3: Bunch length and peak amplitude of the longitudinal profile as measured during the study. The evolution of the bunch intensity is also shown. The good correlation between the peak amplitude of the longitudinal profile and the beam intensity is visible.

The bunch current data has been acquired using two mechanisms from the same hardware device. In one case, the data are generated at 1 Hz, while the second option uses a dedicated software to extract data at the higher resolution of 50 Hz. The latter has a higher level of noise, as can be seen from Fig. 4 (left). For the sake of comparison, a moving average filter using 200 data samples has been applied to the 50 Hz data to suppress the noise. Figure 4 (right) shows a comparison for a subset of data. It is clear that the averaged data is much cleaner than the 50 Hz and of quality comparable to the 1 Hz data.

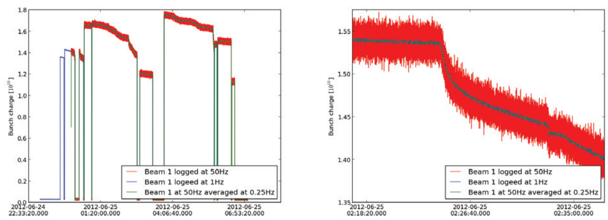

Figure 4: Evolution of the bunch charge as measured at 1 Hz and 50 Hz (left). A zoom in of the first picture is also shown (right) in which an averaged signal derived from the 50 Hz data is shown.

The tunes have been monitored using the BBQ system. The raw data, available as sets of overlapping turn-by-turn acquisitions, have been merged and analysed using a moving-window FFT of 8192 samples which allows isolating the 50 Hz lines and, at the same time, following the time evolution of the frequency spectra. The large width of the tune peak and its low amplitude prevent a precise tune estimate.

It is worth emphasising that some of the lines in the frequency domain of the vertical plane, the one that features the best signal to noise ratio, are moving in time following the change of the strength of the MCOs or MCDs as seen in Fig. 5. The periodograms for both planes are shown for the four configurations considered in the MD study together with the evolution of the current of MCOs or MCDs. The lines also seem to converge to a single frequency value for a particular value of the current. This value is close to the tune derived from the injection oscillation. In the horizontal plane one can glimpse the same effect, but the signal to noise ratio makes it less evident. In the case of the MCDs the behaviour is similar, even if weaker than for the octupoles. These observations are being analysed in more details to provide an explanation.

CONCLUSIONS

A second measurement session has been performed in 2012 to probe the dynamic aperture for different configurations of the octupolar and decapolar spool pieces, including also different sign combinations of the octupolar correctors.

As for the first experiment in 2011, a clear correlation between beam losses and non-linear correctors settings has been observed. Unlike the previous experimental session, no clear variation of the bunch length has been observed, which could indicate the losses are more correlated with transverse effects than non-linear chromaticity.

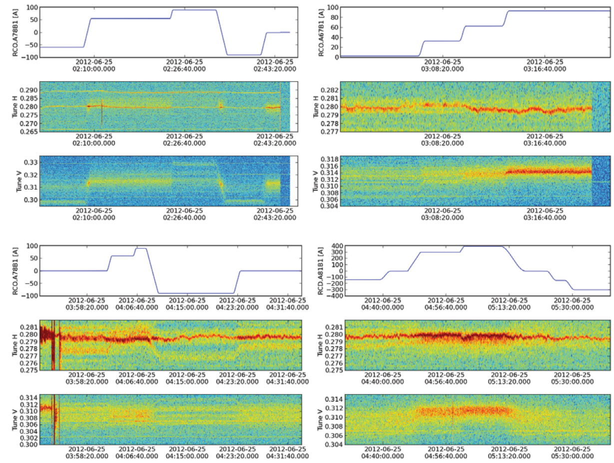

Figure 5: Periodograms around the tune values (current evolution, upper, horizontal tune, middle, vertical tune, lower) derived from the BBQ signals for configuration a) (upper left), b) (upper right), c) (lower left), d) (lower right). Some of the frequency lines move in correlation with the evolution of the spool pieces current. This effect is visible in either horizontal or vertical plane.

The next step will be a quantitative analysis of the collected data using the fit model based on the inverse logarithm decay of the dynamic aperture with time.

ACKNOWLEDGEMENTS

Discussions with S. Fartoukh are warmly acknowledged.

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