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Summary of LHC MD 398: Verification of the dependence of the BCTF measurements on beam position and bunch length

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Summary

The main aim of the MD was to study the dependency of bunch-by-bunch intensity measurements to beam position and bunch length variations. Large beam position offsets in IR4 and varying bunch length were introduced to compare the performance of the presently installed Fast Beam Current Transformers with the new Integrating Current Transformer and the new Wall Current Transformer. This note explains all the procedures of the LHC MD 398, which took place on 20/07/2015, and presents the obtained results.

1. Introduction and motivation

During the LHC Run 1 the bunch-by-bunch intensity measurements obtained with the Fast Beam Current Transformers (FBCT) were observed to be sensitive to the beam position offset as well as to the bunch length variations [1]. During Long Shutdown 1 two new monitors designed to address those issues were installed. The Integrating Current Transformer (ICT) [2], developed in collaboration with Bergoz Instrumentation, was installed on Ring 1 (BCTFR.B6R4.B1). The Wall Current Transformer (WCT), developed internally at CERN, was installed on Ring 2 (BCTFR.B6R4.B2). The two new monitors replaced the so-called "System B" FBCTs. The "System A" FBCTs (BCTFR.A6R4.B1 and BCTFR.A6R4.B2) which provide operational data for many users have been left in place to allow thorough comparison of the three different technologies.

The output signals of all the monitors are integrated in order to obtain bunch intensity information. Currently, this process is performed by the Digital Acquisition Boards (DAB), each equipped with two LHCB2002B analogue integrators originally developed for the LHCb experiment preshower detector front-end electronics [3]. The integration window spans over about 23 ns and is followed by a dead zone of about 2 ns where the signals coming from the monitors are discarded. The two integrators are interleaved and switched every 25 ns such that one of them sees only the odd multiples of 25 ns slots while the other sees only the even multiples. The total beam intensity is calculated as the sum of all valid bunch integrals (i.e. the integrals which are over a programmed threshold) averaged over a few hundred turns. The total beam intensity is logged at the rate of 1 Hz.

The LHC MD 398 described in the present note took place during LHC Fill 4022 on 20/07/2015 between 21:00 and 22:30. It aimed at qualifying the behaviour of the three bunch-by-bunch intensity monitors with large beam position offsets and varying bunch length. Transverse beam offsets were introduced at the location of the monitors in IR4 in both rings to perform a 2-dimensional scan of the beam position. Bunch length was changed by adjusting the voltage applied to the RF cavities.

The first 50 minutes of the MD were spent on injecting the requested beams and, in parallel, adjusting settings of the acquisition electronics to fit most of the output signals of the monitors in the integration window of the DABs. The beam position scan took about 20 minutes and the bunch length scan about 10 minutes.

Throughout the MD the total beam intensity of the following monitors was recorded for further analysis:

- BCTDC.A6R4.B1 (DCCT) located at DCUM 10150 m
- BCTDC.B6R4.B1 (DCCT) located at DCUM 10151 m
- BCTDC.A6R4.B2 (DCCT) located at DCUM 10152 m
- BCTDC.B6R4.B2 (DCCT) located at DCUM 10153 m
- BCTFR.A6R4.B2 (FBCT) located at DCUM 10154 m
- BCTFR.B6R4.B2 (WCT) located at DCUM 10155 m
- BCTFR.A6R4.B1 (FBCT) located at DCUM 10156 m
- BCTFR.B6R4.B1 (ICT) located at DCUM 10157 m

The transverse beam position at the location of the intensity monitors listed above was interpolated from the data recorded by the nearest Beam Position Monitors (BPM) on each side of the intensity monitors:

- BPMYA.5R4.B2 located at DCUM 10132 m
- BPMYB.5R4.B1 located at DCUM 10132 m
- BPMYA.6R4.B1 located at DCUM 10164 m
- BPMYB.6R4.B2 located at DCUM 10164 m

The mean bunch length of both beams was recorded by the Beam Quality Monitor (BQM).

The MD beams consisted of five sparsely spaced nominal bunches (about 1.1e11 ppb) and a pilot bunch (about 8e9 ppb) in each Ring. The injected 4σ bunch length was approximately 1.3 ns. The study was conducted at injection energy of 450 GeV with regular optics.

2. Beam offset scan

2.1 Procedure

The beam offset in IR4 was introduced by applying a 3-corrector bump for the sector 6R4. Due to optics limitations it was not possible to create bumps of equal amplitudes in both planes for all monitors. The created displacement were in the order of 1.5–3 mm. The orbit bumps were introduced in eight steps:

- positive horizontal
- negative horizontal
- positive vertical
- negative vertical
- positive horizontal with positive vertical (diagonal)

- negative horizontal with positive vertical (diagonal)
- positive horizontal with negative vertical (diagonal)
- negative horizontal with negative vertical (diagonal)

Each beam position offsets was maintained for approximately one minute to obtain enough measurement points for statistical purposes. Between each of the above steps the beam was returned to the reference orbit to normalise the individual steps.

2.2 Data analysis

The exact beam offset at the location of each of the monitors of interest was interpolated from the nearest available position data on either side of the monitor. The closest BPMs for all the monitors were located 22-25 m to the left and 7-10 m to the right. Linear interpolation was used.

For clarity purposes, the logged beam intensity of the monitors installed on the same LHC Ring was equalised by adjusting the System B (ICT and WCT) intensities to match those of System A (FBCTs). This was achieved by introducing an artificial proportionality factor in the order of 1.01–1.02.

The relative change of intensity due to beam displacement was calculated as the ratio of beam intensity during the offset step to beam intensity during the previous zero-offset step and normalised to the unit of mm^{-1}.

2.3 Results

The results obtained during the transverse beam position scan are shown in Figures 1, for Ring 1, and 2, for Ring 2. Beam intensity plots in both figures show only the last 5% of the full scale. The results are also summarised in Table 1 presenting the calculated upper bound of the dependency Both FBCTs suffered from a significant sensitivity to beam displacement - up to $0.7\%\cdot mm^{-1}$ depending on the angle of the displacement. The ICT showed a slight sensitivity to horizontal beam offsets – in the order of $0.02\%\cdot mm^{-1}$. No dependence could be measured for the WCT with the measurement relative accuracy of 0.005%.

The asymmetrical sensitivity of the FBCTs and the ICT is believed to originate from an asymmetry of the monitors themselves. Both detectors incorporate a large magnetic core wound with a wire connected to a single output connector which is located to the outer side of the monitor. Such an arrangement makes both monitors “oriented” in a certain manner and prone to beam position dependence.

Table 1: Measured beam position dependence of FBCT, ICT and WCT

Intensity monitor	**Beam position sensitivity, upper bound (ΔI/I)**
BCTFR.A6R4.B1 (FBCT Ring 1)	$7\cdot 10^{-3}\cdot mm^{-1}$
BCTFR.B6R4.B1 (ICT)	$2\cdot 10^{-4}\cdot mm^{-1}$
BCTFR.A6R4.B2 (FBCT Ring 2)	$7\cdot 10^{-3}\cdot mm^{-1}$
BCTFR.B6R4.B2 (WCT)	$< 5\cdot 10^{-5}\cdot mm^{-1}$ (unmeasurable)

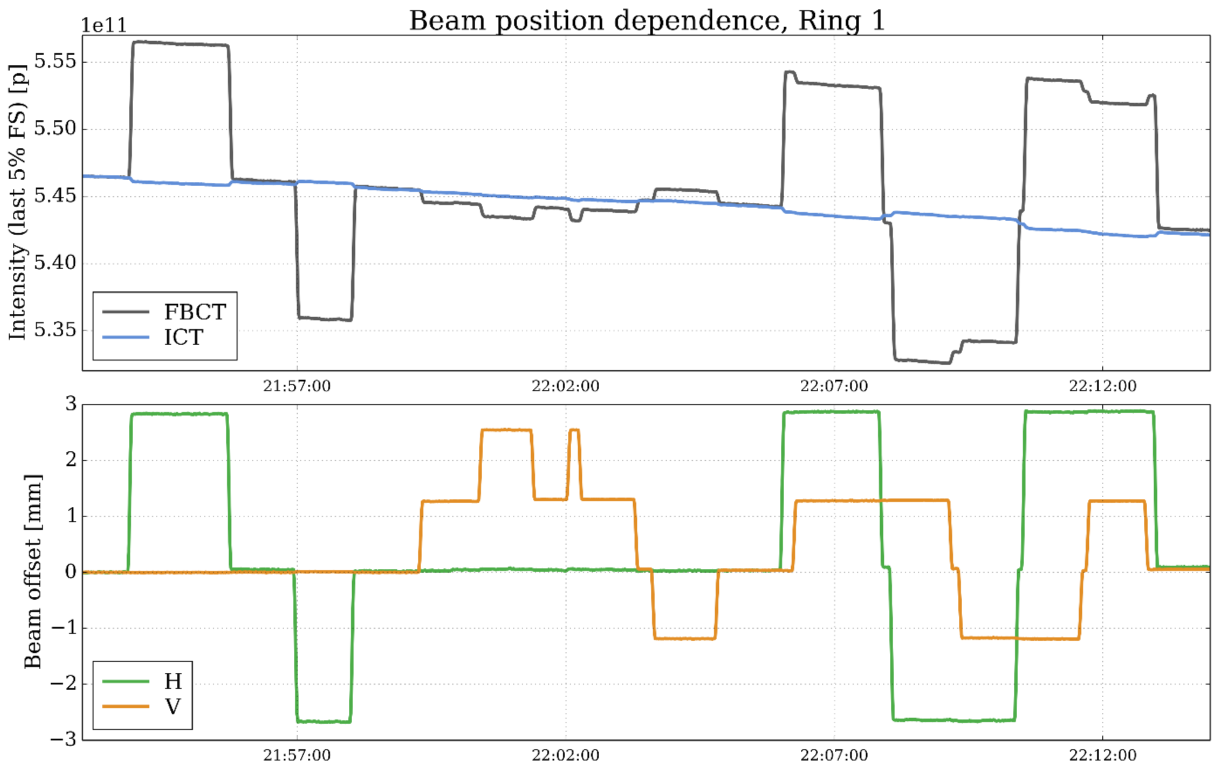

Figure 1: Comparison of beam position dependence for FBCT (black) and ICT (blue) on Ring 1

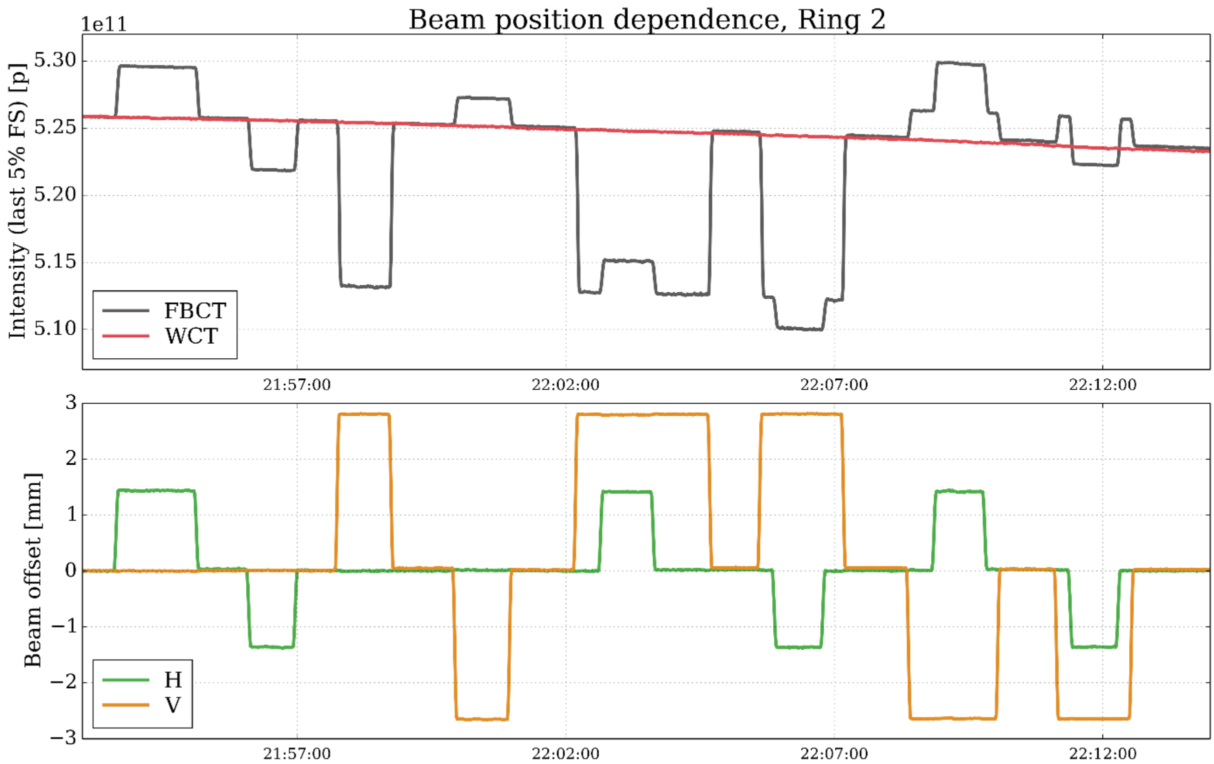

Figure 2: Comparison of beam position dependence for FBCT (black) and WCT (red) on Ring 2

3. Beam length scan

2.1 Procedure

The bunch length sweep was performed by adjusting the voltage of the RF cavities for both beams in the range of 3-14 MV. The scan began with the initial RF voltage of 6 MV translating to the average 4σ bunch length of about 1.32 ns. The RF voltage was then increased in steps of 1 MV (equivalent to shortening the bunch length by about 50 ps per step) up to 14 MV when 1.05 ns bunch length was reached. The RF voltage was reverted to the initial value of 6 MV in 4 steps of 2 MV and subsequently decreased in steps of 1 MV (elongating the bunch by about 50 ps per step) until the beams were dumped at 3 MV (about 1.5 ns bunch length).

2.2 Data analysis

Similarly to the beam position dependency analysis, the logged beam intensity of System B was adjusted to match System A. This was achieved by introducing an artificial proportionality factor in the order of 1.01–1.02.

The relative change of intensity due to bunch length was calculated as the ratio of beam intensity during the bunch length sweep step to beam intensity during the initial 1.3 ns/4σ bunch length and normalised to the unit of $(ns/4\sigma)^{-1}$. Due to the very low bunch length sensitivity of all the tested monitors, the calculated results are determined with limited accuracy.

2.3 Results

The results obtained during the bunch length scan are shown in Figures 3, for Ring 1, and 4, for Ring 2. Beam intensity plots in both figures show only the last 0.1% of the full scale. The results are also summarised in Table 2 presenting the calculated upper bound of the dependency. The FBCTs and the ICT were observed to have very little sensitivity to bunch length, below $0.2\%\cdot(ns/4\sigma)^{-1}$. The WCT displayed higher dependence on the bunch length on the level of $0.5\%\cdot(ns/4\sigma)^{-1}$. The source of this sensitivity is currently not fully understood but it is suspected to originate from the electronics chain and not the monitor itself. Further study is currently being conducted to recognise the mechanism and find a possible solution to minimise bunch length dependence of the WCT.

In the operational scenario of a 300 ps 4σ bunch length shortening for long physics fills the intensity measurement accuracy of the FBCT and ICT would be better than 0.06% and better than 0.15% for the WCT.

Table 2: Bunch length dependence of FBCT, ICT and WCT

Intensity monitor	Bunch length sensitivity, upper bound (ΔI/I)
BCTFR.A6R4.B1 (FBCT Ring 1)	$2\cdot 10^{-3}\cdot(ns/4\sigma)^{-1}$
BCTFR.B6R4.B1 (ICT)	$2\cdot 10^{-3}\cdot(ns/4\sigma)^{-1}$
BCTFR.A6R4.B2 (FBCT Ring 2)	$2\cdot 10^{-3}\cdot(ns/4\sigma)^{-1}$
BCTFR.B6R4.B2 (WCT)	$5\cdot 10^{-3}\cdot(ns/4\sigma)^{-1}$

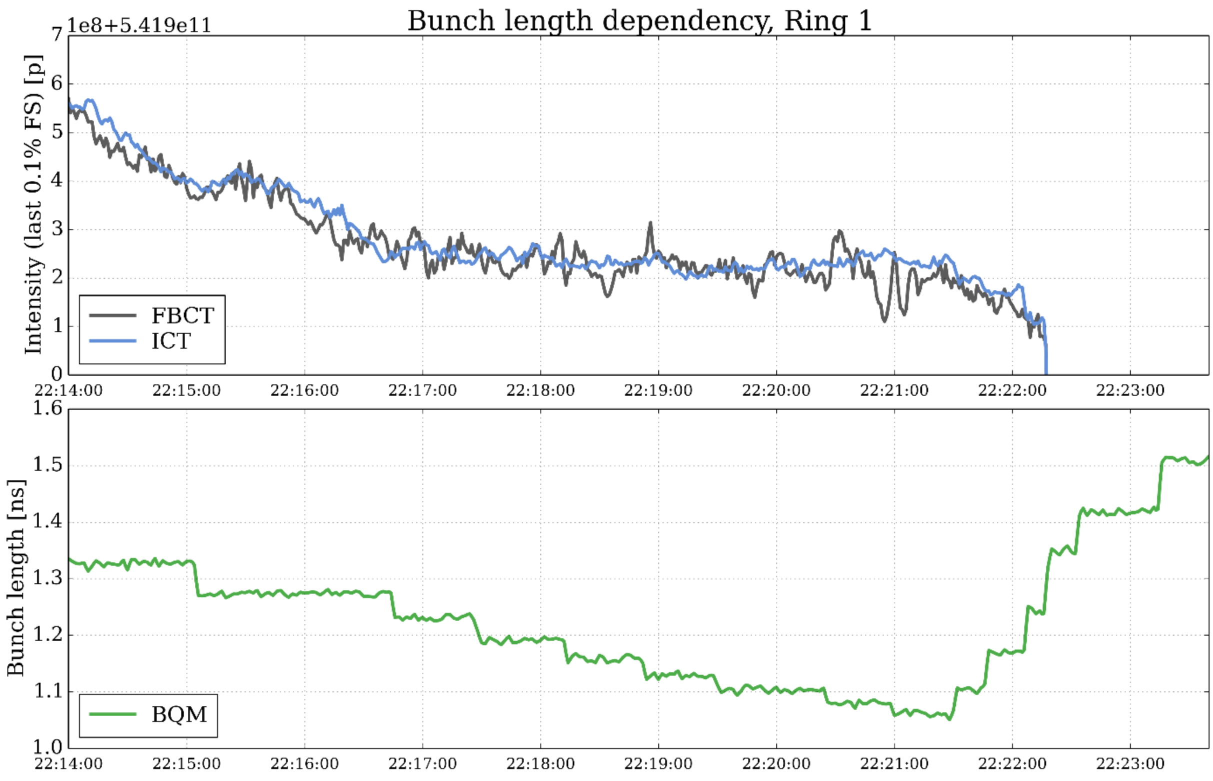

Figure 3: Comparison of bunch length dependence for FBCT (black) and ICT (blue) on Ring 1

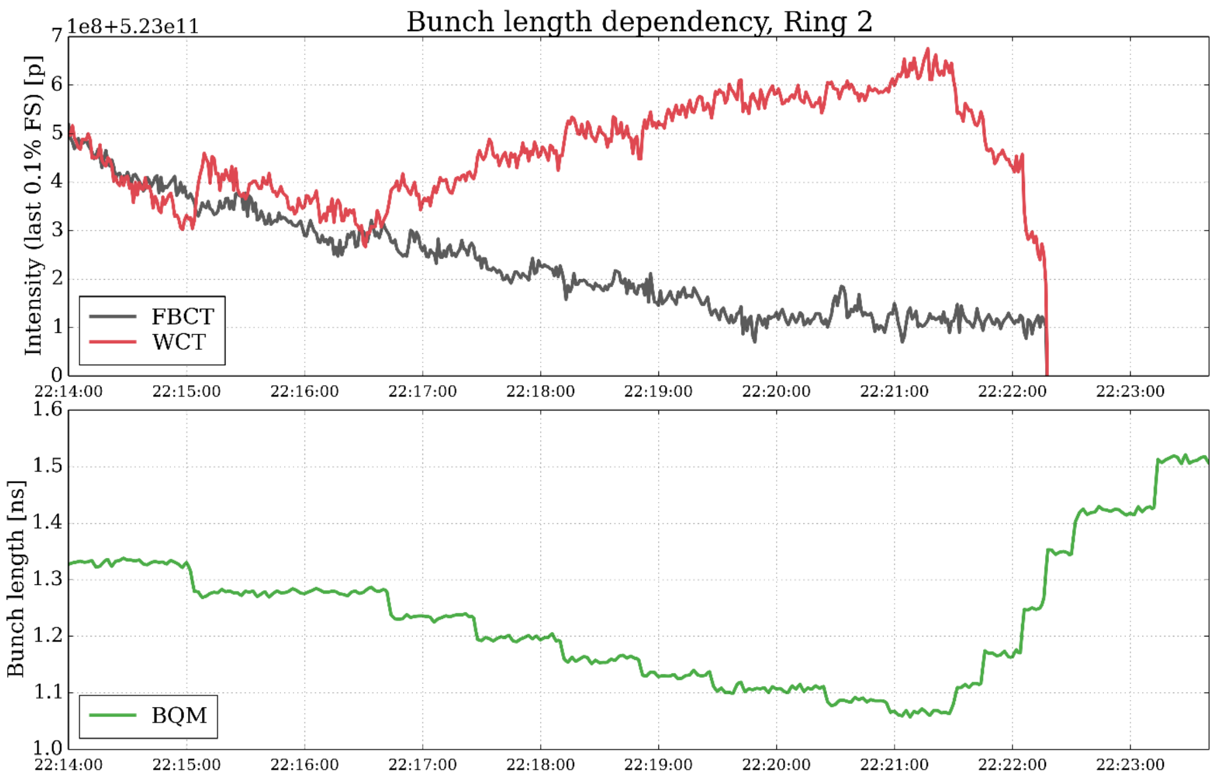

Figure 4: Comparison of bunch length dependence for FBCT (black) and WCT (red) on Ring 2

4. Conclusions

The LHC MD 398 provided very useful data to compare the two new fast beam intensity monitors – the ICT and WCT - to the FBCTs in terms of the monitor sensitivity to beam offset and bunch length. With large beam displacements in IR4 the ICT and WCT showed significantly lower beam position dependence than the FBCT – by more than an order of magnitude for the ICT and more than two orders of magnitude for the WCT. The ICT and FBCT were observed not to be very sensitive to bunch length whereas the WCT showed a little higher dependence which remains to be understood.

References

[1] P. Odier, et al. “Operational Experience and Improvements of the LHC Beam Current Transformers”, in Proceedings of the 10th European Workshop on Beam Diagnostics and Instrumentation for Particle Accelerators (Hamburg, Germany), 2011, p. 467

[2] K. B. Unser, “Design and Preliminary Tests of a Beam Intensity Monitor for LEP”, in Proceedings of the 1989 Particle Accelerator Conference (Piscataway, NJ, USA), 1989, vol. 1, p. 71

[3] G. Bohner, et al. “Very front-end electronics for the LHCb preshower”, Note LHCb 2000-047, CERN, Geneva, Switzerland, 2000