THE LHC BEAM POSITION SYSTEM: PERFORMANCE DURING 2010 AND OUTLOOK FOR 2011

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Abstract

This paper presents the performance of the LHC Beam Position System during 2010. The system proved to meet most specifications, it was highly reliable and it continuously provided 25 Hz real-time orbit data with micron level resolution to the automatic global orbit feedback system. However, several issues were observed and they will be discussed in detail, such as the dependence on bunch intensity and the effect of surface electronics temperature variations on the measured position.

INTRODUCTION

The LHC Beam Position System is one of the largest beam instrumentation systems at CERN. It consists of 2140 measurement channels that depend on an extensive acquisition chain of 1070 monitors, 3820 electronic cards distributed along the LHC underground tunnel and about 1070 additional digital post-processing cards located in surface buildings. The performance of the system during the 2010 run was very good, with an average of 97% of these channels providing reliable data throughout the year.

The first part of this paper presents the resolution of the different orbit modes implemented, while the second part discusses bunch intensity and temperature dependence issues and the means implemented for mitigating their impact.

ORBIT MODES AND RESOLUTIONS

This paper does not provide a complete description of the LHC BPM system since the reader can find this information in [1, 2, 3]. However, the authors consider it convenient to stress here three of its main particularities:

- Acquisitions are auto-triggered every time the amplitude of the induced pick-up signal is above a pre-defined threshold. This feature facilitated the commissioning of the system during the early days of the LHC as there was no reliance on external timing, providing robustness with respect to RF frequency changes or timing problems. On the other hand, it makes the system more sensitive to spurious noise and complicates the post processing implemented in the Digital Acquisition Boards (DABs) where a re-synchronization with the bunch clock is required for bunch by bunch studies.

- The front-end electronics measure each individual bunch. This design choice relaxes the dynamic range requirements of the system by almost 69dB. In addition, it provides great flexibility allowing many ways of post processing the data.

- Two electronic sensitivities are employed to cover the total bunch intensity range of the LHC; high sensitivity from 2e9 to 5e10 p^+/bunch and low sensitivity from 5e10 to 2e11 p^+/bunch.

The default closed orbit mode used during 2010 was the “asynchronous orbit”. The position data from each incoming bunch enters a digital exponential moving average filter providing an update of the average orbit over the last few thousand bunch positions every 40ms. Typical resolutions of about ~5um were obtained on the average position at each monitor. Fig. 1 shows the position measurement RMS of each BPM along the LHC ring. Notice that several channels exhibit significantly higher values. These are concentrated in two particular regions, where the electronics suffer from larger temperature variations. Each of the 8 LHC long straight sections also exhibit several monitors with larger RMS noise due to the larger aperture of the pick-ups in these locations.

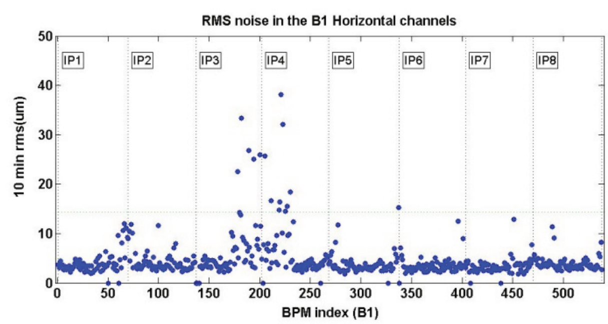

Figure 1: Resolution of each monitor along the ring.

The system also has a “synchronous orbit” mode where a re-synchronisation of the input data with beam synchronous timing allows a particular set of bunches to be selected for analysis. In this case, the orbit is calculated by the arithmetic average over a configurable number of turns (usually 225 in order to reject 50Hz ripple). This is mainly used for the measurements from the directional couplers surrounding the interaction points. These monitors are used where the beams share the same vacuum chamber to allow the measurement of each beam independently. However, their directivity is limited to about 20dB, while the dynamic range of the electronics is ~35dB in each of its 2 possible sensitivities. This means that for bunches with intensities towards the high end of each sensitivity Beam 1 bunches can trigger Beam 2 channels and vice versa. Using the synchronous orbit minimizes the impact of this crosstalk between beams, as it allows the acquisition to be performed only on those bunches which do not see a parasitic crossing in

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the pick-up. However, a knowledge of the beam filling pattern is required in this case.

In order to further evaluate systematic electronic drifts the LHC orbit system was compared to a new high-resolution orbit system prototype based on diode peak detectors [4]. Both systems were connected to two different pick-ups at the same location. Figure 2 shows the results obtained during a physics fill. Over the 15 hour measurement time both systems measured the same position to within 10um. Several RF cavity trips during this time also led to large bunch length variations, which did not affect either of the systems.

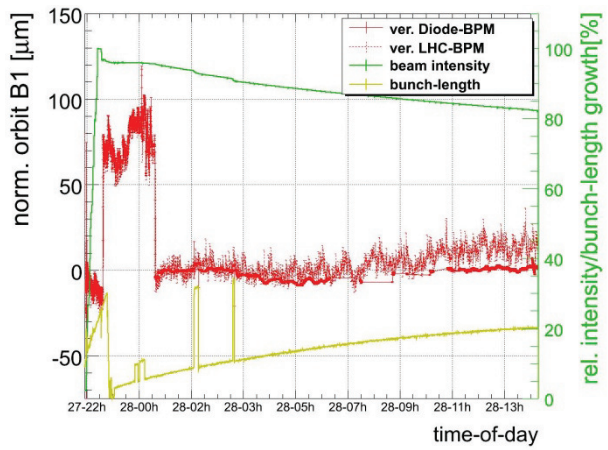

Figure 2: Beam position measurements in the LHC comparing the standard LHC orbit electronics with a new prototype system based on diode peak detectors.

TRAJECTORY RESOLUTION

From the trajectory analysis of 31 injections during the early synchronisation tests for Beam 1, the overall RMS variation in single bunch, single turn position over a timescale of ~10 minutes was generally seen to be between 150-400µm. This order of magnitude is consistent with the electronic noise estimations for bunch intensities in the range 2e9 p$^+$/bunch to 5e9 p$^+$/bunch protons used during these tests [5].

INTENSITY LIMIT

In order to test the lower limit for auto-trigger detection the bunch intensity was varied from below 1e9 p$^+$/bunch to around 3e9 p$^+$/bunch, while counting the number of correctly triggered BPMs. The lower limit for correct BPM functioning was found to be ~1.5e9 p$^+$/bunch [4].

INTENSITY DEPENDENCE

In order to study the beam intensity dependence of the closed orbit measurement, the position of a single bunch with an initial intensity of 1e11p$^+$ was tracked while scraping down the intensity to below the auto-trigger threshold using a primary collimator. During the experiment, the sensitivity mode was switched every ~10 seconds in order to obtain the characterization curve of both sensitivity ranges simultaneously. Fig.3. shows the measured position drift with respect to the initial stable orbit due to the bunch intensity variations for Beam 2. The optimum switching point for changing the sensitivity mode was found to be around 5.2e10p$^+$/bunch. In such conditions the maximum drift was <20um in high sensitivity mode and <40um in low sensitivity, while the "jump" observed due to the switching was ~40um (well within the system specifications). The curves shown are the average response for all arc type beam position monitors.

During a second experiment, this time using Beam 1, the scraping was performed without sensitivity mode switching and repeated to obtain a full set of data for each sensitivity setting. Fig.4 shows the results obtained. Surprisingly this time no optimum switching point was found. With bunch intensities of 4e10 p$^+$/bunch, the difference between sensitivity modes was ~300um, and higher than 800um at 5e10 p$^+$/bunch. Below 3e10 p$^+$/bunch and above 6e10 p$^+$/bunch, the flatness was better than 20um.

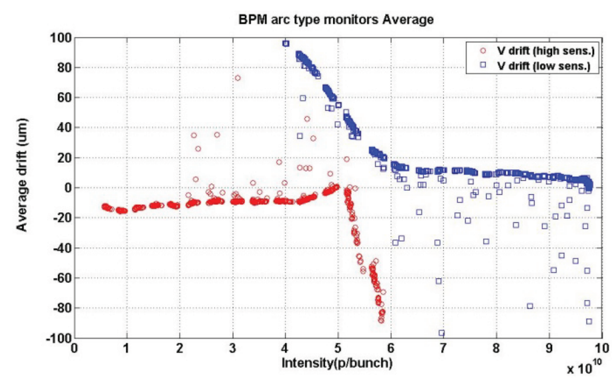

Figure 3: Characterization curve of the BPM system response with the bunch intensity for LHC Beam 2.

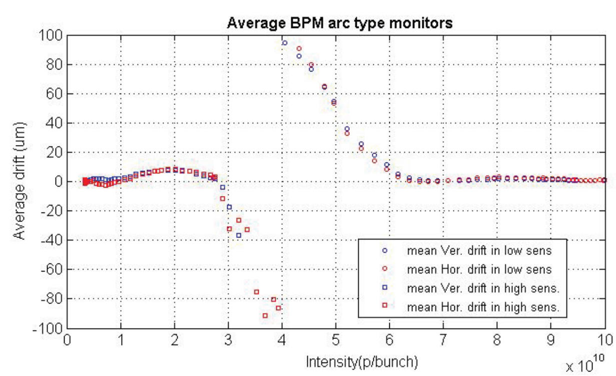

Figure 4: Characterization curve of the BPM system response with the bunch intensity for LHC Beam 1.

The Beam 1 and Beam 2 acquisition chains are identical and all front-end cards were calibrated, measured and qualified for a bunch intensity linearity of <±120um (<±1% of an arc BPM half radius) over their whole working range. The bunch intensity dependence was found to come not from the beam position front-end boards, but from an adjacent card installed in the same crate used to measure the bunch intensity by integrating the sum of the BPM electrode signals from a given beam [6]. A small impedance mismatch in its input stage produces a signal reflection that is sufficient to affect the position measurement of the beam it is selected to measure, which, for the tests performed above was Beam 1. About 700 of these cards are installed in the LHC. For the time being, while the LHC is in physics operation, the short-term solution has consisted in removing these cards and replacing them with termination boards in the most critical locations.

TEMPERATURE DEPENDENCE

Another undesired effect observed is that ambient temperature changes in the surface rack electronics produce a systematic offset in the beam position measurement. This then leads to a real beam offset when the orbit feedback system tries to compensate for it.

The currently implemented solution consists of a software algorithm that removes the drifts based on the measured temperature dependence of each channel. This dependence was obtained by measuring the position during calibration while at the same time using the on-board temperature sensor of each digital acquisition card to measure the temperature. The change in temperature was achieved by remotely changing the fan speed of the VME crates used to house the surface electronics.

During operation with beam, the system periodically measures the temperature of the cards and corrects the digital data accordingly.

The average position change due to temperature before correction was ~50um/ºC. Applying the software correction algorithm reduces this effect to below 20um/ºC. Fig 5 shows the temperature evolution during a period with stable beams phase with the corresponding corrected and non-corrected position from a single BPM channel.

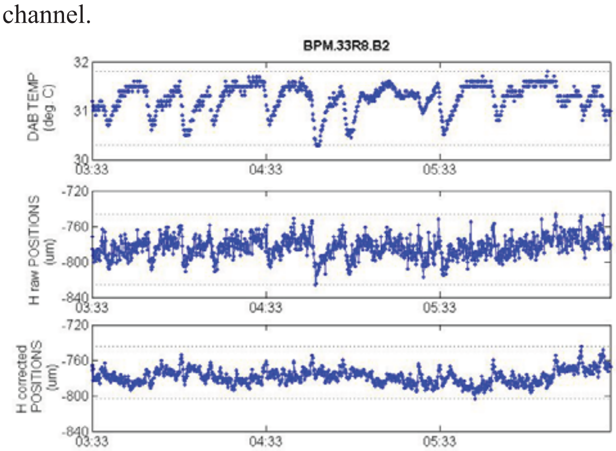

Figure 5: a) Temperature of the DAB mezzanine. b) Uncorrected beam position during stable beams. c) Position of the beam once the temperature drifts have been compensated.

However, this technique has several limitations. The fan speed change only allows the characterization of temperature variations within a range of 5-6ºC, whilst the observed surface building variations can be much larger. In addition, the gradient calculation uses a simple linear fit. Therefore, if the temperature drift observed since the last calibration is larger than a few degrees, the error is no longer negligible. For this reason, the system is now systematically calibrated before each beam injection.

The long-term solution to overcome this problem will consist in placing the surface electronics in temperature stabilised racks, implementation of which is currently foreseen during the long LHC shutdown of 2013.

CONCLUSIONS

The LHC orbit system has performed remarkably well during the LHC 2010 run, allowing to increase the number of bunches and their intensity in a short period. However, a few issues regarding its dependence with the bunch intensity and the temperature in the surface racks were observed. This paper has quantified their impact, and described the means put in place to mitigate their effects.

The 2011 LHC run will still be more demanding for the system, since the number of bunches will still increase significantly and the β* will be reduced. Both facts need smaller apertures at the collimators level and therefore stronger requirements in terms of resolution and long-term stability. Additionally the on-going beam-beam effects and other instabilities studies have tight turn-by-turn and bunch-by-bunch demands.

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REFERENCES

[1] D. Cocq, “The Wide Band Normaliser : a New Circuit to Measure Transverse Bunch Position in Accelerators and Colliders”, Nucl. Instrum. Methods Phys. Res., A 416, 1998.
[2] D. Cocq et al, “First beam tests for the Prototype LHC orbit and trajectory system in the CERN SPS”, DIPAC 2001, ESRF, Grenoble, France.
[3] E. Calvo et al, “The LHC Orbit and Trajectory System”, DIPAC 2003, Mainz, Germany.
[4] M. Gasior, R. J. Steinhagen, “High resolution beam orbit measurement electronics based on compensated diode detectors”, BIW 2010, New Mexico, USA.
[5] R. Jones, “Commissioning and first performance of the LHC beam instrumenation”, BIW 2010, New Mexico, USA.
[6] J.L. Gonzalez et al, “The measurement of bunch intensity using the LHC BPM system”, DIPAC 2009, Basel, Switzerland.