USAGE OF THE TRANSVERSE DAMPER OBSERVATION BOX FOR HIGH SAMPLING RATE TRANSVERSE POSITION DATA IN THE LHC

L.R. Carver, X. Buffat, A. Butterworth, W. Höfle, G. Iadarola, G. Kotzian, K. Li,
E. Métral, M. Ojeda-Sandonís, M.E. Söderén, D. Valuch, CERN, Geneva, Switzerland

Abstract

The transverse damper observation box (ADTObsBox) is a device that makes accessible the bunch-by-bunch turn-by-turn data recorded from the pickups of the LHC transverse damper. This device can provide online transient analysis of different beam dynamics effects (tunes and damping times at injection, for example), while also under development is an online coherent instability triggering system. This paper will provide an overview of the current setup and plans for future upgrades, as well as detailing how it deals with the large volume of data being generated. The results of some analysis that rely on the ADTObsBox will also be shown.

INTRODUCTION

In 2012 there were many instabilities at the end of the squeeze that could not be fully explained using the available diagnostics [1]. To try and improve this situation for operation in run II, an intense effort was made to improve the instability diagnostics for the LHC at both injection energy (450 GeV) and top energy (6.5 TeV) [2]. A large part of this effort was to make available the bunch-by-bunch turn-by-turn transverse positions that are measured in the pickups for the transverse feedback system (ADT) [3]. The device that allows this information to be available to the users outside of the ADT system is called the ADT Observation Box (ADTObsBox). The data are accessible through the CERN Front End Software Architecture (FESA) [4].

The ADTObsBox has been used for a wide variety of studies and purposes and has proved to be a vital diagnostic tool. Using this, we are able to probe different stages of the machine cycle when instabilities are present to try and learn about the relevant mechanisms involved and better optimise the machine performance.

This paper will provide a brief overview of the setup and operation of the ADTObsBox, together with some notable examples of studies performed during run II that relied upon the ADTObsBox.

ADTOBSBOX SETUP

The LHC transverse damper is a feedback system, which is designed to actively suppress the oscillatory part of the bunch transverse motion. Analogue signals from stripline pickups are processed and digitized by a dedicated Beam Position Module for the horizontal and vertical planes. Each 25 ns, the module calculates an intensity independent, normalized position for every bunch, which are then fed by means of a digital link into two digital signal processing units (mDSPU). Here the position signal from multiple pickups is combined and the correction kick signal is computed. The amplified, high-voltage kick is applied to the beam by means of electrostatic kickers. This is shown graphically in Fig. 1.

The ADTObsBox is a very powerful computer system [5] that was designed to receive a copy of the digital bunch-by-bunch transverse position data stream, analyze it online or offline, make it available to users outside of the ADT system, or to store it. After reception, the pickup data is stored in a very long rolling buffer (currently 6 million turns). A set of shorter buffers of pre-determined length (typically 4096, 32768, 65536 turns referred to as 4k, 32k, or 64k buffers respectively) is made available to the users or other FESA classes. These buffers can be each independently frozen by triggers with an arbitrary delay. Typical use cases are injection oscillations (first 4k turns after the trigger), post mortem buffer (last 64k turns before the trigger), or a long instability buffer (30 s before the trigger and 30 s after the trigger). The triggers can come from any source; either a manual push of a button, an automatic signal timed with a machine event (for example injection or dump) or from other instability triggers based on other diagnostics. The triggers are managed by the LHC Instability Trigger Network (LIST) [6].

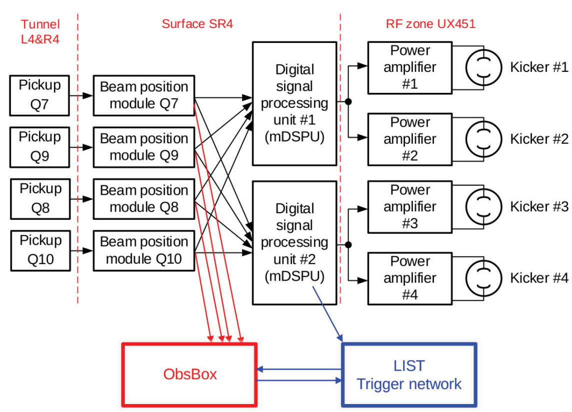

Figure 1: An overview of the LHC transverse feedback system (ADT).

Currently under development is a trigger that is based on a continuous stream of bunch-by-bunch turn-by-turn data which will be able to perform high-speed analysis and detect the onset of coherent activity of each bunch. This trigger will be fundamental for instability diagnostics as it will allow the freezing of the ADTObsBox buffers as well as other instability diagnostics for automatic data acquisition. For more information on the development of this trigger, see [7].

ISBN 978-3-95450-182-3

DATA STORAGE

The ADTObsBox generates a large volume of very valuable data that users desire to be stored. There are 3564 available bunch slots in the LHC and in 2016 more than 2000 bunch slots were routinely filled (from both scrubbing and physics operation). For the 64k buffer this amounts to approximately 530 MB of data per acquisition (for a single pickup out of eight). During times when the ADTObsBox was frequently triggered, this can quickly amount to volumes of data on the order of 100's of GB in a short period. This data is all stored using the new CERN EOS storage service making all the data accessible over the network [8].

However, it is challenging to present this data in a useful and coherent way. Work and effort are currently ongoing in order to tag and pre-analyse the ADTObsBox acquisitions to calculate meta data based on both an analysis of the data and the machine conditions at the time they were acquired. This meta data can then easily be filtered to allow the user to search through the large volume of data. This will also allow the removal of uninteresting data or bad acquisitions which can save on storage space.

USAGE IN THE LHC

We will now give some examples of studies that have been performed since the beginning of run II that rely on the ADTObsBox.

Scrubbing

In the past, some data was available from the pickups of the ADT, but it was for a maximum of 8 bunches and only for offline analysis. No online analysis tool was operational.

The evolution of the observation system has been critical for fast instability diagnostics during the LHC scrubbing run. The 32k turn buffer of the ADTObsBox was set to be frozen at every injection into the LHC. A Python tool was developed that can relatively quickly (within approximately 10s) extract, save and plot the data. This tool was a vital diagnostic as it allowed a rapid determination on whether the injection was clean (free from instabilities) or if there were large coherent oscillations. Figure 2 shows a typical plot that was produced which reveals strong instabilities of several bunches within the newly injected bunch train. The beam shown in this example was dumped after 11,900 turns due to the losses caused by these strong transverse instabilities.

Now a real-time instability detection system has been put into operation. It will be used as an online tool which will be capable of detecting bunch-by-bunch coherent activity within a delay of approximately 1000 turns and send information about the unstable bunches together with a trigger to other diagnostic instruments in the machine (for example the headtail monitor [6]).

Currently the ADTObsBox is being used mainly for offline analysis which involves either manually freezing the buffers or using synchronised triggers with machine events, but with the new accelerator logging system and the instability trigger, the project is moving towards more online analysis that would, in this case, only save data when coherent activity is detected.

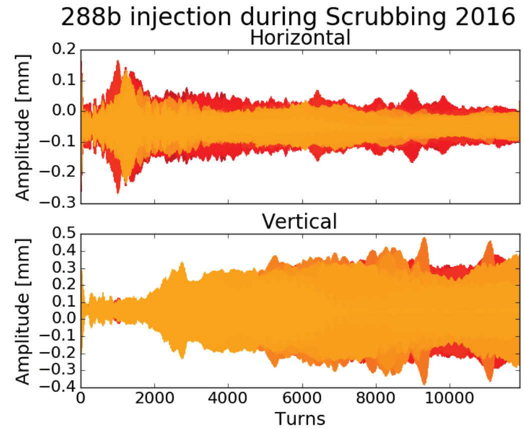

Figure 2: Injection oscillations from the only 288 bunch injection into the LHC in 2016. This injection triggered a beam dump due to transverse instabilities arising from the interaction with the electron cloud. The colour spectrum represents bunches at the beginning of the train (darker) towards bunches at the end of the train (lighter).

Tune Measurements

Characterisation of the machine impedance as well as impedance contributions from individual collimators is very important for current operation of the machine as well as for future upgrades (for example HL-LHC) and running configurations for the near future. To measure the impedance contribution from a single collimator, the tune shift incurred when moving the collimator from parking position to close to the beam can be measured. In order to make this measurement, an excitation is used (either with the ADT itself or with a tune kicker) with a simultaneous trigger being sent to freeze the ADTObsBox buffers. The kick provided sufficient amplitude to accurately calculate the tune, and many excitations were used with the collimator at tight and loose settings.

Dedicated measurements were made to calculate the tune shift for one of the secondary collimators (D4L7) at interaction region 7 (IR7). The high resolution data extracted from the ADTObsBox allowed, with high accuracy, a tune shift to be measured: $\Delta Q_V = (3.94361 \pm 1.4)\text{x}10^{-5}$. Using the available data, consistent results were achieved when using different algorithms for the tune calculation [9, 10]. This measurement shows the level of sensitivity in the data that can be acquired. This methodology will be used in 2017 to measure the impedance contribution of a new low impedance collimator prototype (TCSPM).

The synchronisation between different systems, i.e. triggering of buffers being well timed with the initialisation of the kick, shows the versatility of the ADTObsBox and its infrastructure. There is also significant effort ongoing to measure the tune shift along the batch from electron cloud using active excitation by the ADT. This was first tested in 2016 and will be expanded upon and improved in 2017 [11].

Observations During Operation

There was a period in 2016 when, during the injection process, individual bunches were observed to have undergone emittance blowup in the vertical plane. In order to try and understand what was happening, the ADTObsBox 64k buffers were set to be frozen by a manual trigger which was applied regularly during the expected time of the instability.

A bunch by bunch analysis of this vast sum of data was able to reveal individual bunches undergoing small coherent oscillations that were approximately timed with their emittance blowup. Figure 3 shows an example of an oscillation captured by the ADTObsBox. The top plot is the full unfiltered trace which includes all orbit drifts and corrections. The middle plot shows the filtered trace, where all low frequency contributions are removed and only frequencies close to the tune are considered. The lower plot shows the FFT of the full signal in the tune region. It can be seen that the bunch undergoes a coherent oscillation with a rise time on the order of several thousands of turns, before decohering back to the stable point. It is this decoherence that causes the emittance blowup and it can be seen that it occurs over approximately 20,000-30,000 turns.

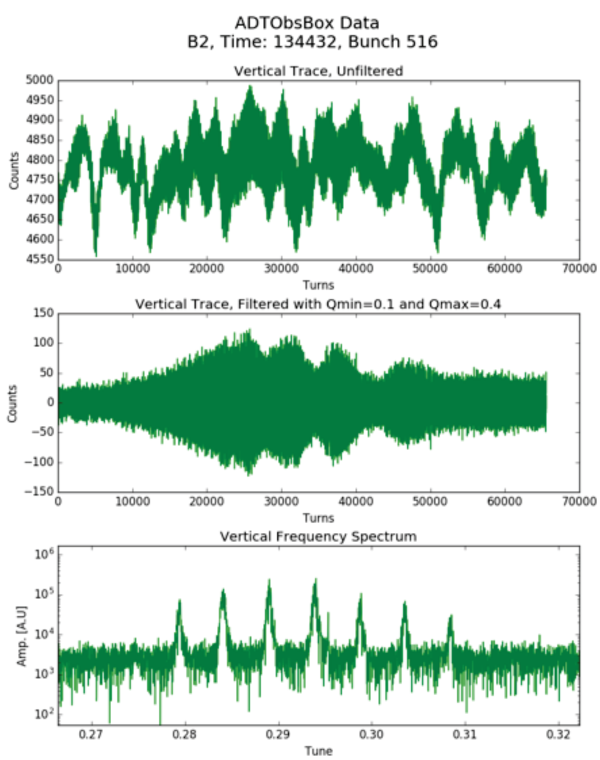

Figure 3: Single bunch coherent oscillation captured by manually triggering the ADTObsBox during the injection process. The top plot shows the unfiltered trace, the middle plot shows only the tune frequencies contribution to the signal with the FFT shown in the lowest plot.

This case really highlights the power of the ADTObsBox, as it shows that even when more than 2000 bunches are present in the machine, small coherent oscillations happening to individual bunches are able to be detected with high sensitivity.

FUTURE WORK

The project is moving towards online analysis using the ADTObsBox, with new tools being developed that will include a new online vibration measurement device, and the aforementioned instability trigger based on the bunch-by-bunch coherent motion. There is also ongoing activity to develop new lower noise beam position front ends which will allow more sensitive observations.

CONCLUSION

The ADTObsBox was developed in response to a need for the high resolution data from the ADT pickups for instability detection and analysis. The system has shown that it is very flexible and has been set up such that it can be triggered by machine events or by manual triggering. This will soon be extended to include automatic triggering based on coherent oscillations near the natural tune.

REFERENCES

[1] T. Pieloni *et al.*, "Observations of Two-Beam Instabilities During the 2012 LHC Physics Run", presented at the 4th Int. Particle Accelerator Conf. (IPAC'13), Shanghai, China, May 2013, paper TUPFI034, pp 1418-1420.

[2] T. Levens, K. Lasocha, T. Lefevre, "Recent Developments for Instability Monitoring at the LHC", presented at the International Beam Instrumentation Conference (IBIC) 2016, Barcelona, Spain, September 2016, paper THAL02, pp. 852-855.

[3] A. Butterworth P. Baudrenghien, D. Valuch, "RF and ADT Upgrades After LS1", presented at the Chamonix Workshop on LHC Performance, Chamonix, France, 2014, CERN-2015-002, pp. 60-64.

[4] M. Arruat *et al.*, "Front-End Software Architecture", presented at the International Conference on Accelerator and Large Experimental Control Systems 2007 (ICALEPCS07), Knoxville, Tennessee, USA, 2007, paper WOPA04, pp. 310-312.

[5] M. Ojeda *et al.*, "Processing High-Bandwidth Bunch-by-bunch Observation Data from the rf and Transverse Damper Systems of the LHC", presented at the International Conference on Accelerator and Large Experimental Control Systems 2015 (ICALEPCS15), Melbourne, Australia, 2015, paper WEPGF062, pp. 841-844.

[6] T. Levens *et al.*, "Instability Diagnostics", Proceedings of the 6th Evian Workshop on LHC Operation, Evian, France, December 2015, CERN-ACC-2015-376, pp. 137-141.

[7] M. Soderen, *et al.*, "Online bunch by bunch transverse instability detection in LHC", presented at the 8th Int. Particle Accelerator Conf. (IPAC'17), Copenhagen, Denmark, May 2017, paper MOPAB117, this conference.

ISBN 978-3-95450-182-3

[8] A.J Peters, E.A Sindrilaru, G. Adde, "EOS as the present and future solution for data storage at CERN", presented at the 21st Int. Conf. on Computing in High Energy and Nuclear Physics (CHEP), Okinawa, Japan, April 2015, paper 042042.

[9] N. Biancacci, "Collimation Hierarchy MD - impedance measurements", LHC Collimation Working Group No. 207, 22/08/16 (2016), https://indico.cern.ch/event/564394/

[10] D. Valuch *et al.*, "Update on single-collimator impedance measurements", ColUSM Meeting No. 75, 19/08/16 (2016), https://indico.cern.ch/event/562580/

[11] L.R. Carver *et al.*, "MD2013: Tune Shift Along the Batch at Flat Top", CERN-ACC-NOTE-2017-0011, CERN, Geneva, Switzerland, 2017.

ISBN 978-3-95450-182-3