ADT AND OBSBOX IN 2016

D. Valuch, W. Höfle, G. Kotzian, M. Jaussi, S. Rains, M. Ojeda-Sandonís, M.E. Söderén, CERN, Geneva, Switzerland

Abstract

A performant transverse feedback is vital for accelerators like LHC. The LHC transverse feedback (ADT) provides a lot of important data and functionality outside of the "damping envelope". The contribution summarizes the ADT performance in 2016, and presents the newly implemented and commissioned features. Among those is the most awaited online instability detection system, but also new excitation modes allowing to perform precision beam measurements like the tune shift along the batch, excitation for automatic coupling correction or single jaw collimator impedance.

ADT PERFORMANCE IN 2016

Similar to previous years, operation of the ADT was very smooth in 2016. Thanks to multiple redundancy of the low-level RF (LLRF) system and the power system it is very rare that a blocking failure occurs. In total three events were recorded for 2016. A digital to analogue converter (DAC) was hanging after a major power cut in the surface building SR4, where the LLRF system is installed. The signal processing chain produced a feedback signal, but no analogue drive was outputted from the DAC. Consequently, the feedback experienced a longer damping time, which under presence of strong transverse activity dumped the beam. The second recorded fault was a gigabit link failure. The beam position modules send bunch by bunch, normalized transverse position data to the digital signal processing unit by means of gigabit serial links, using both metallic and optical media. The signals are split in the optical domain to feed also the observation system (ADTObsBox [1]). During the year one of the serdes transceivers on the beam position module failed, hence received data for one pickup were corrupted. As a result the optical distribution for this pickup was reconfigured at a cost of loss of redundancy. Finally, the third LLRF system failure has happened after maintenance works on the LHC master oscillator. Thereby the missing clock caused loss of synchronization and ADT lost position of bunch 1. The issue was solved by a power cycle of the digital logic. There was no downtime, but the problem prevented doing loss maps.

Failures of the power system are much less apparent to the operation, as the power system is quadruple redundant. Thus a trip of one amplifier causes 25% loss of loop gain (or 33% longer damping time). The ADT power team keeps a cold-spare power amplifier in the RF zone, making the response time in case of a failure very short.

Eight power tetrodes (RS2048) reached their designated operating time of 20'000 hours and were preventively replaced during TS2 to provide constant and uniform amplifier gain. The average tetrode operating time is 14'000 hours.

NEW DEVELOPMENTS FOR 2017 RUN

ADT is a vital system for LHC. It does not only combat the coupled bunch transverse instabilities, or selectively excites the beam, but it is also commonly used as a very valuable instrument for various machine development studies, or special transverse beam manipulations. The majority of developments every year are invested in all kinds of new functionality. More bunch by bunch diagnostics is always requested, more sophisticated excitation schemes and signals are required, or a close collaboration with other instruments all over the ring is desired. Additionally, certain effort is also invested into system performance improvements.

New generation Anode resistor

The power amplifier delivers the final ~37 dB of gain, providing 10 kV of kick voltage. A push-pull, class AB amplifier is equipped by two tetrodes and two 900 Ohm anode resistors. The resistors are one of the most delicate and challenging components in the signal chain, as they have to withstand high voltage (15 kV), dissipate high power (25 kW) and have a flat frequency response up to higher 10's of MHz. Figure 1 shows the currently used resistors which were custom developed for CERN by industry. As during the years it became increasingly difficult to obtain spare parts, the BE/RF/PM section launched a development program to design and manufacture a replacement in house. The first samples were successfully tested in the laboratory and the first amplifier populated by new resistors should be installed in LHC in the summer of 2017.

Figure 1: The currently used anode resistor (right) and the newly developed replacement resistor (left).

Online instability detection system

One of the most awaited instruments in LHC is a robust transverse instability detection tool/system. The ADT has the bunch by bunch, turn by turn beam transverse position information available within its digital signal processing system. This information was made available for users external to the feedback by means of a so called Observation Box. The transverse box, also known as ADTObsBox (see Fig. 2), is a very powerful computer system, which receives data from up to four pickups (a 1 Gb/s data stream per pickup). The observation system was designed to record and publish the data for offline analysis, but also perform the computationally intensive online analysis.

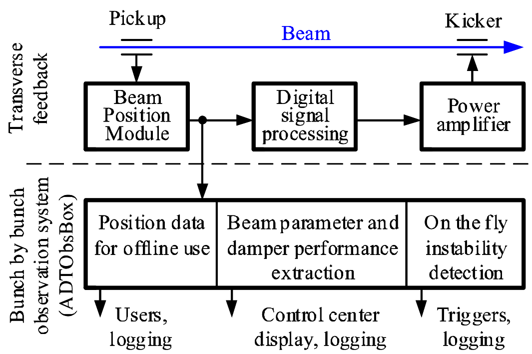

Figure 2: Integration of the ADTObsBox into the transverse feedback system.

The very first true online analysis application for the observation system is the online transverse instability detection. Data from each pickup are published in chunks of 4096 turns by the ObsBoxBuffer FESA class running in the ADTObsBox. The online analysis system is implemented also as a FESA class, called ALLADTCopra [2], running in the very same computer. It subscribes (at the time of writing) to the Q7 buffer of both beams and both planes and receives a data array of 4096 turns by 3564 bunches. By means of digital signal processing [3] the instantaneous transverse oscillation amplitude is extracted from the data stream and the trend is analysed with three different time constants (256, 1024 and 4096 turns) to search for the onset of a coherent activity (see Fig. 4). In case a positive trend and predefined conditions are met, a trigger is sent to the LHC instability trigger network LIST [4].

The major leap this instability detection system brings is the transverse activity analysed for the first time bunch by bunch and for all bunches. When the activity is detected the information about which bunches became unstable and an indication of time constant is available already at the very moment when the trigger is being sent. This greatly simplifies the search for activity, as other observation instruments can already know "where to look". Consequently this avoids a need to continuously blindly trigger and download long data buffers and offline search for transverse activity. The analysis results and information are properly logged. A side product of the instability detection system is an online transverse activity monitor – a fixed display will be made available in the CCC, which shows the oscillation amplitude (calibrated in mm) of every bunch in real time.

Damper performance analysis tool

Most concerns expressed by the operation group concerning the ADT in the past years were if the feedback operates correctly. Another analysis tool, named ALLADTDiag [5], also running in the ADTObsBox was prepared in 2016. The tool subscribes to the injection oscillation buffer (for both beams and both planes) and after every injection it calculates the bunch by bunch damping time and bunch by bunch fractional tune. The curves are presented in the CCC in a form of an ADT diagnostics fixed display (see Fig. 3). Data from as few as 15 turns are required to calculate the tune – the tune value is available to the operator even before the RF capture – this makes the tool very valuable e.g. at accelerator restart after a long stop.

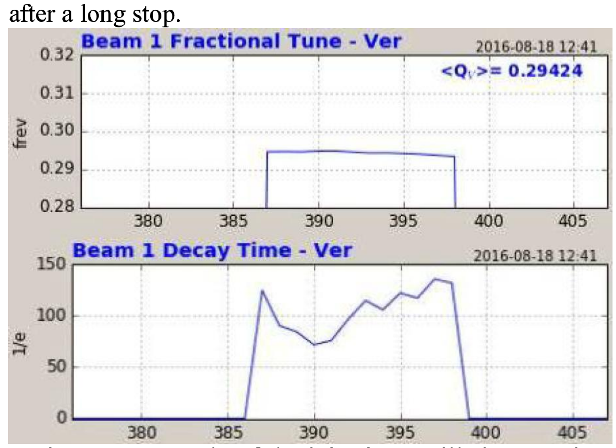

Figure 3: Example of the injection oscillation transient analysis by the ALLADTDiag FESA class. The plots are available to the operator as part of a fixed display.

AC dipole-like excitation

The ADT was already equipped by signal synthesisers to excite and clean the beam in the abort gap and the injection gap. With a well controlled impulse response of the entire ADT signal chain it became apparent that a more demanding excitation schemes can be implemented and safely executed through the whole LHC cycle. The most recent addition is an AC-dipole like excitation, called "ADT-AC dipole" for clarity. Unlike the real AC dipole magnet, the ADT-AC dipole excitation strength is much lower, providing a maximum of 2 μrad @ 450 GeV. This constraint is well compensated by a full freedom and flexibility of the number of targeted bunches to be excited anywhere in the ring, the excitation frequency starting already at DC (i.e. a dipolar kick), the unlimited number of excitation turns, or a possibility to excite only every n-th turn. The rise and fall times of the excitation waveform are also fully programmable.

The presented features make the ADT-AC dipole an invaluable complementary tool to the "real" AC dipole for precision, or automatic measurements. The first measurements have been already performed in 2016. It was demonstrated, that a single bunch within a 25 ns train can be excited, or selected bunches can be excited for 10's of thousands of turns without noticeable emittance blow-up for coupling measurements. The new excitation functionality was immediately used in various studies (e.g. [6] [7] [8]).

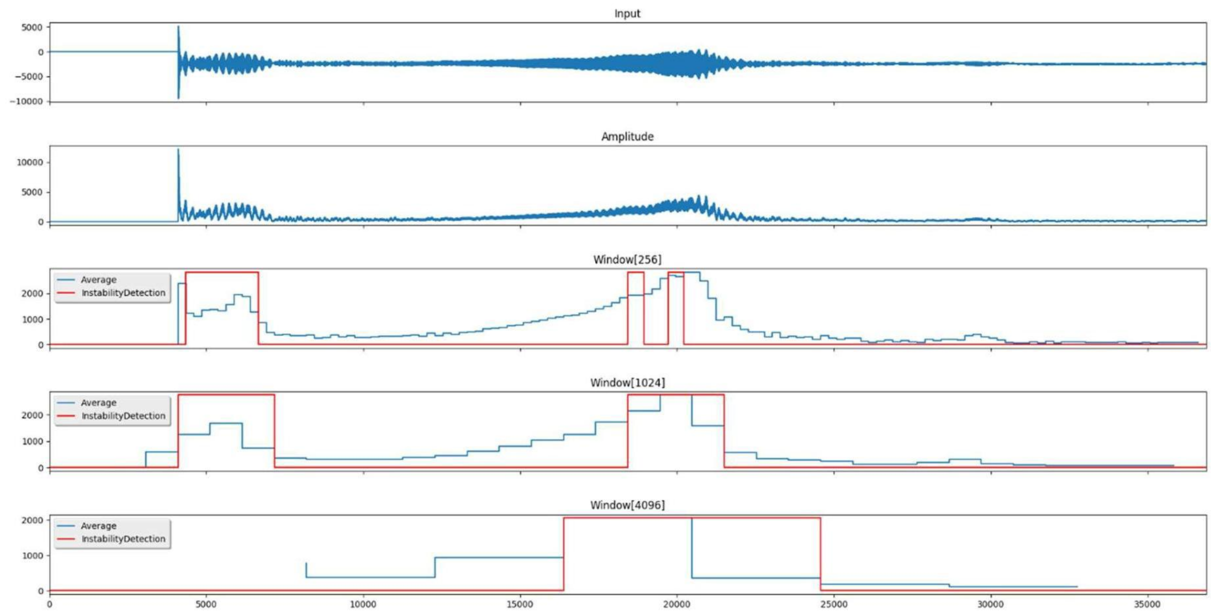

Figure 4: Demonstration of the instability detection process. The top plot shows the input pickup position data after injection. The second plot shows the oscillation amplitude, followed by three activity detection windows of 256, 1024 and 4096 turn length. The red curve represents the "bunch unstable" flag.

PRECISION MEASUREMENTS WITH ADT

The ADT is a complex system involving multiple devices, which are interconnected and synchronized. This opens endless possibilities in performing sophisticated measurements. For example the beam can be passively observed by the ADTObsBox, data stored, or immediately analysed in the box, including analysis of various transients. This functionality was already discussed in the previous chapter. A very powerful tool is to use the ADT as an exciter and observe the beam behaviour by the ADTObsBox. Some results will be shown here.

As the excitation signals are generated by a digital LLRF system, the waveform can be easily pre-distorted in a controlled way to achieve different deflection voltage profiles on the kicker plates. The signal can be prepared such a maximum available deflection strength will be achieved at a price of exciting multiple bunches within few hundred nanosecond window. On the other hand, the signal can be pre-distorted such that only a single bunch of arbitrary position within a 25 ns train will be excited, at the price of lower kick strength. The latter method was used to measure electron cloud induced tune shift along a batch of 25 ns beam [9]. Figure 5 shows the high level of process control, when only bunches 1, 6 and 12 were excited transversally, without noticeable leakage to the neighbouring bunches. Bunches were excited to reach about 100 μm oscillation amplitude, with the oscillation transient recorded by the ADTObsBox and tune calculated offline. It is being considered to perform this kind of measurements with a full machine at flat top.

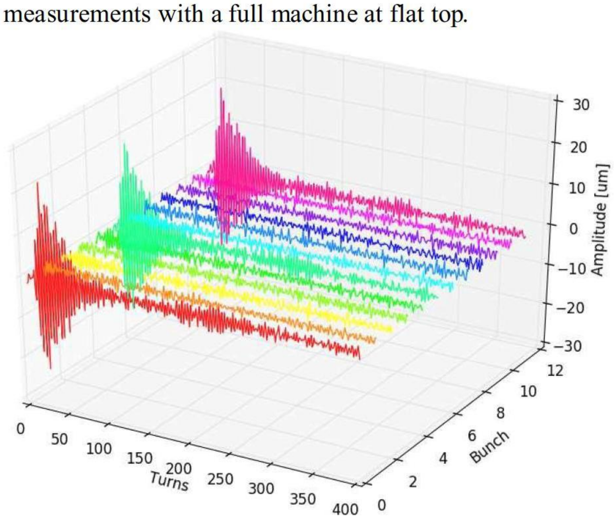

Figure 5: Excitation of individual bunches within a 25 ns bunch train for tune shift measurement (picture courtesy of Lee Carver).

A similar method was proposed to determine a single jaw collimator impedance by means of precision tune shift measurements. The feedback gain was reduced to provide few hundred turns of good quality data, the beam was excited to an amplitude below 100 μm and the damping transient recorded by the ADTObsBox. A tune shift between the two collimator positions in the order of 4e-5 was found, well compatible with the model (see Fig. 6).

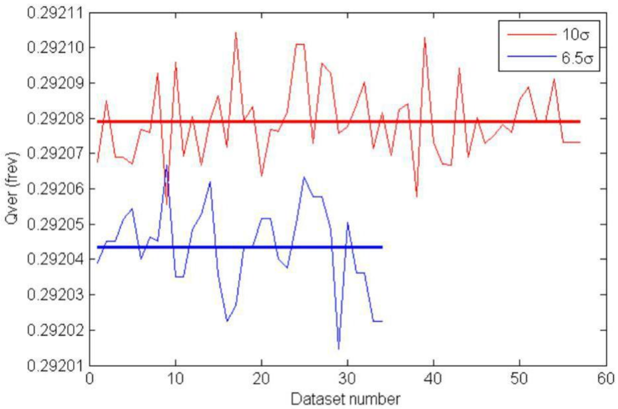

Figure 6: A feasibility of tune shift measurements in the order of 4e-5, with an error bar below 1e-5 using only the ADT data was demonstrated.

CONCLUSIONS

The LHC transverse feedback provides a lot of important data and functionality outside of the "damping envelope". There is a continuous effort to research, implement and operationally use more and more sophisticated and very advanced functions of the system, giving a way to tools like automatic coupling correction, precision tune measurements of individual bunches, beam halo cleaning by couloured noise and many more. There is also an ongoing research in possibilities for computationally very intensive online data processing from the ADTObsBox devices.

ACKNOWLEGEMENTS

The authors would like to thank colleagues from the BE/OP team for a very smooth year, and also colleagues from the BE/BI and BE/ABP groups for many fruitful discussions and pleasant time spent in the control room doing MDs.

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