TRANSVERSE FEEDBACK: HIGH INTENSITY OPERATION, ABORT GAP CLEANING, INJECTION GAP CLEANING AND LESSONS FOR 2012

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Abstract

The transverse damper system (ADT) plays an important role in the preservation of the beam transverse emittance and for damping of oscillations driven by the coupled bunch instability. An overview of the ADT system will be presented with an emphasis on the important feedback loop parameters as they change from injection through the ramp into collision. The dedicated setting-up procedure required for the different bunch intensities and bunch spacings will be explained. During the 2011 run the injection and abort gap cleaning became operational at injection energy. Preparations for cleaning at 3.5 TeV as well as batch selective transverse blow-up were completed and preliminarily tested. Plans for 2012 include study and potential improvement of the system impulse response to improve the 'selectivity' of the cleaning and blow-up facility. The ADT also provides bunch-by-bunch observation, which was extensively used during the run and MDs, and will be further upgraded during the next year.

INTRODUCTION

The transverse damper, in the LHC referenced as the ADT, is a feedback system which measures the beam transverse oscillation, calculates a correction and applies it back to the beam via electrostatic kickers.

The beam position is measured by means of two stripline pickups per beam and plane located close to the Q7 and Q9 magnets around the LHC point 4. The Sum and Delta signals from the pickups are digitized by the Beam Position (Bpos) modules. A normalized, intensity independent value representing the bunch position is then sent to the Digital Signal Processing Units (DSPU) at a rate of one sample per bunch per turn (i.e. 40 MHz rate).

The DSPU receives the bunch position data from the two pickups, aligns them in time (time of flight and cable delay compensation) and calculates the correction kick. The numerical value is then converted back into the analogue domain and sent to the power amplifiers feeding the kickers [1].

Apart of the transverse feedback and injection oscillation damping function the ADT system can also excite beam oscillation which is also a very useful feature for the machine operation.

ADT AND THE BEAM PARAMETERS

In order to conserve the best ADT performance it is necessary to optimize certain system settings to match the actual beam parameters. A set of settings was prepared during the 2010-2011 operation to optimally cope with bunch intensities from 5e9 to 3e11 charges per bunch and bunch spacings from a single separately injected bunch in the machine down to 25 ns.

Beam Position module

The Beam Position module calculates a bunch by bunch, intensity independent, normalized bunch position. The RF front-end electronics uses very sensitive wide band precision analogue IQ demodulators. The amplitude of the analogue Sum and Delta signals should be carefully mapped into the dynamic range of the demodulators to achieve optimal operating conditions and at the same time protect them from damage caused by signals induced by intense beams.

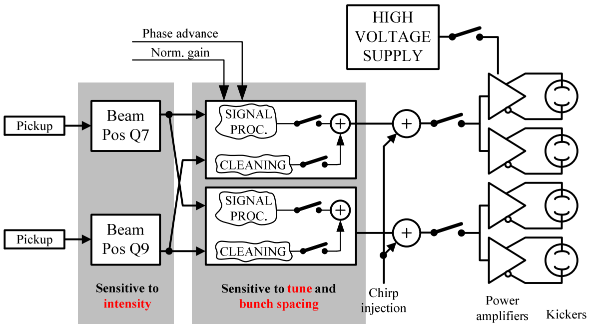

Figure 1: ADT layout as seen from the CCC.

The currently used strategy is to map both input signals to about 80% of the module's ADC full scale at a given bunch intensity and 2 mm position deviation from the pickup center. Measurements indicate that the noise floor is of the order of 2µm rms [2]. The setting-up procedure was considerably automated in 2011, now requiring only 30 minutes per beam and per plane. Due to continuous increasing bunch intensity expected in 2012 it is necessary to prepare new sets of settings for 1.3-1.5-1.7e11 ppb right at the start-up.

The RF front end gain is currently kept constant to operate with nominal beam intensity, using a threshold to block the functioning on pilot and probe intensity bunches. The gain is changed by the experts when needed, e.g. for low intensity operation with ions or high pile-up MDs. An automatic sequence is being prepared to allow observation of the injection transients also for the pilot injection within the nominal sequence (see the "Tune measurement using ADT data" later).

Digital Signal Processing Unit

The DSPU receives the normalized bunch position from two Beam Position modules and calculates the correction kick. The output signal is pre-distorted by means of digital filters to compensate for the first order low pass characteristics of the power amplifier with the electrostatic kickers. Currently only the phase response is compensated leaving about 600 ns rise/fall time for the kicker to reach the full available kick amplitude as illustrated in the Figure 2.

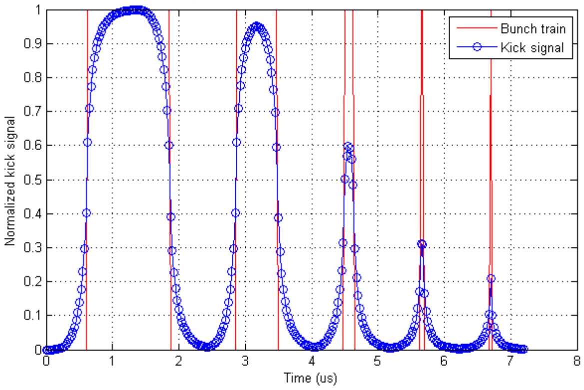

Figure 2: Available kick strength as a function of the bunch spacing. Red trace bunch train, blue trace normalized kick voltage. From left to right 1250-625-150-50-25 ns scenario.

However, bandwidth of the signal processing chain can be optimized for beams with longer than nominal 25 ns bunch spacing to profit from the larger kick strength by stretching the impulse response. Several sets of settings were prepared in 2011 to provide optimal system performance with different beam types. The parameters are loaded upon request from the operations group by the ADT experts.

ADT OPERATION THROUGH THE LHC CYCLE

The ADT was originally designed to preserve the beam transverse emittance by damping the injection oscillations and to damp oscillations driven by the coupled bunch instability during the filling and ramping. Experience in 2010 showed that thanks to a good noise performance of the ADT's low-level RF electronics it is possible to keep the ADT active also during the stable beams periods which was originally not the default mode of operation [3]. Keeping the transverse damper active during the physics fills helps to stabilize some beam-beam induced effects and can keep the impact of external perturbations on the beam emittance small.

A summary of the ADT activity through a nominal LHC cycle is shown in the Figure 3.

Currently, during injection of the probe beam the transverse damper feedback loop is not active (intensity threshold) to provide clear signal for the tune diagnostic system required to set up the machine before injection of the nominal intensity bunches. The power system is however kept active allowing various beam measurements during the machine setting-up (chirp, transverse excitation).

Change of the beam mode from “injection probe beam” to “injection physics beam” activates the cleaning process (see the section “Abort Gap and Injection Gap Cleaning” for details). The damper feedback loop activates automatically with injection of the first nominal intensity bunch damping the injection oscillations. The gain of the feedback loop is set relatively high to provide a damping time of a few tens of turns and preserve the transverse emittance at flat bottom.

Due to compatibility reasons with the tune feedback, the damper gain is significantly reduced to obtain a damping time of about 500 turns on the transition from the “injection of physics beam” to “prepare ramp” beam mode. The gain is kept low during the first part of ramp where the tune feedback activity is the largest. The damper electronic gain is then ramped together with the energy and stays at a level that provides damping time of about 100 turns.

Feedback loop parameters (phase shifts) are changed during the squeeze to follow the tune change. From then on the damper is kept on with static parameters during the entire duration of “stable beams”.

In 2011 a new mode of operation – abort gap cleaning at flat top was prepared and commissioned [4].

ABORT GAP AND INJECTION GAP CLEANING

Already in 2009, beam excitation by a coherent signal in a defined time window was implemented and tested [5]. This excitation is now routinely used in the operation for the Abort Gap cleaning (AGC) [6]. The time position of the excitation window is fixed within a machine turn, located in the left part and covering about one third of the abort gap. The abort gap cleaning signal is applied to the beam in the vertical plane.

A new cleaning mode, injection gap cleaning (IGC), was introduced in 2011 in order to help to keep the injection of the high intensity and long bunch train beam cleaner. ADT excites the uncaptured beam in the gap where the next train is going to be injected including the length needed for the rise and fall time of the injection kicker. Together with other measures, abort gap and injection gap cleaning helped to keep the injection losses of high intensity beams sufficiently low [6].

In case of the injection cleaning, the cleaning slot is advanced through the turn as it is programmed on the fly by the injection sequencer before every injection at the moment when the beam starts to be prepared in the SPS (10-15 seconds of cleaning). The injection gap cleaning signal is applied to the beam in the horizontal plane.

The cleaning function during filling is demonstrated on the Figure 4 using real acquired data of the fill 1867. The abort gap cleaning is activated in the vertical plane at the transition from “injection probe beam” to “injection physics beam” (1) modes. The signal is present during the entire length of the filling. After the first physics beam batch was injected (2) the sequencer programs the next injection slot and activates the injection gap cleaning in the horizontal plane (3). The injection cleaning slot is advanced through the turn as filling continues (4). Both cleanings are deactivated after the last injection (5,6) before transition to the "prepare ramp" mode.

PICKUP CABLE REPLACEMENT DURING THE TS 2011-2012

Coaxial cables between the pickups in the LHC tunnel and the surface building SR4 were completely replaced for the horizontal, beam 2 system addressing the issue with excessive periodic reflections on the transmission line caused by improper cable installation during the LHC construction. The periodic reflections introduce noise into the beam position measurement degrading the transverse damper system performance mainly for dense bunch spacing filling schemes. A total of four lengths of about 700 m each of a new type 7/8" smooth-wall aluminum coaxial cable were installed. Preliminary reflectometer measurements show a significantly cleaner impulse response than the previous lines.

The new cables will be evaluated with beam and if proven better, all remaining 6 pairs will be replaced during LS1 in 2013.

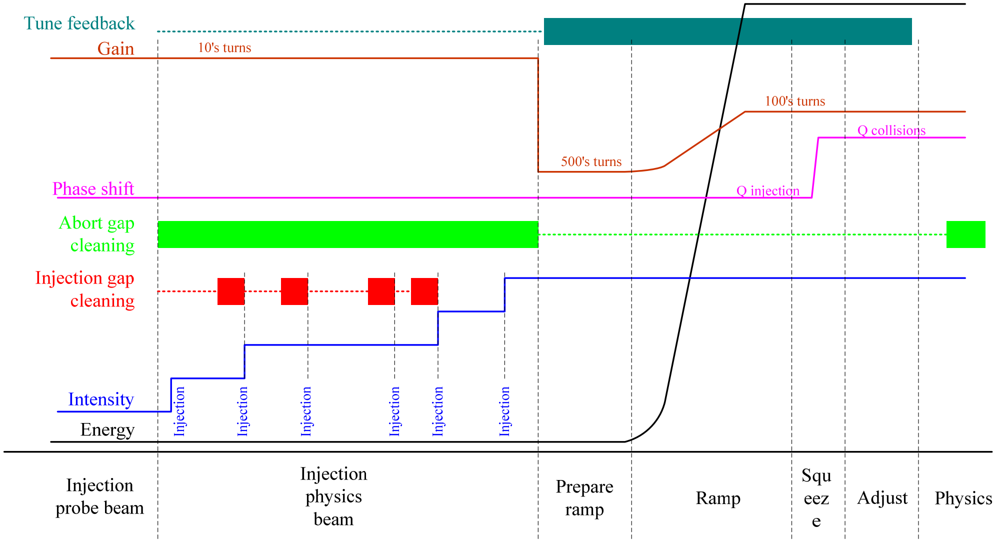

Figure 3: ADT activity through a nominal LHC cycle

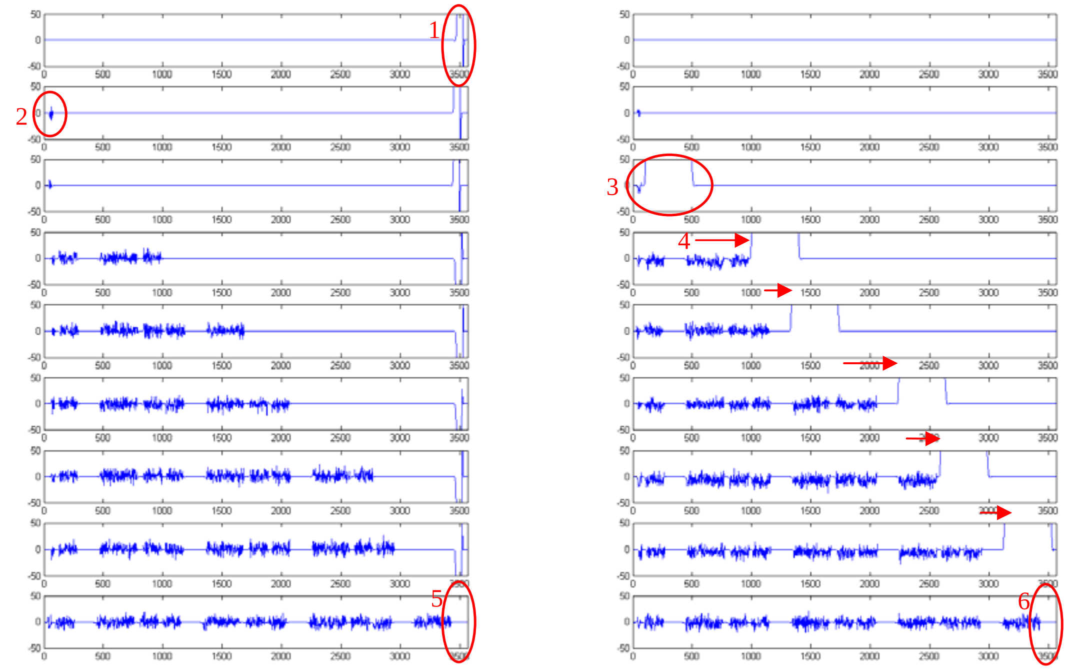

Figure 4: Function of the Abort gap (left) and the Injection gap cleaning (right) captured from the filling of the fill 1867. Horizontal axis 25ns bunch slots, vertical axis digitization steps. Vertical scale is expanded to see the regular ADT activity (noise like) and the cleaning pulses (rectangular pulse).

MDS AND PLANS FOR 2012

A number of improvements and new modes of operation are foreseen for 2012.

Controlled emittance blow up for loss maps

A new excitation method on top of the coherent excitation for the abort gap and injection gap cleaning was implemented and tested in 2011 [7]. A time gated white noise signal was applied to the beam allowing to blow-up the transverse emittance in a controlled way and only for selected segments of beam.

Currently the loss maps and collimation efficiency are measured using the “third order resonance” method [8] which is very time consuming especially at the flat top where one ramp per measurement is needed. The new method using ADT should allow to significantly shorten the time needed to perform the loss maps, as the bunches could be blown up one after the other, each used to measure for example one beam and one plane.

Due to the very controlled character of the blow up even more advanced measurements could be done, like already proposed checks of the collimation efficiency during the ramp and at the end of a fill [9].

The method will be commissioned and it is foreseen to be routinely used during the 2012 start up and subsequent run.

Gain modulation within the turn and tune measurement using the ADT data

Due to compatibility issues between the transverse damper and the tune measurement system two new methods for tune measurements using the ADT data were proposed.

The first “sacrificial bunch method” uses a set of a few bunches for which the transverse feedback gain will be deliberately lowered in order to permit higher transverse oscillation amplitudes. These bunches will be observed by either the gated BBQ system (if available) or by the damper digital signal processing system. In contrast to the BBQ gating, the ADT observation requires only firmware modifications in the damper signal processing system. The new firmware is foreseen to be implemented during the 2011-2012 winter technical stop.

The second “residual noise method” extracts the tune information from the noise spectrum of the damper in-loop signals. A feasibility study was done in 2011 [2].

Both tune measurement methods require feedback loop gain modulation within the turn, a new feature which will be also implemented during the 2011-2012 winter technical stop.

Extension of the bunch-by-bunch observation capabilities

The signal processing system of the transverse damper measures the beam position bunch-by-bunch creating a continuous stream of very valuable data. The low-level RF VME boards are equipped by sets of 256k samples long buffers which are being used for various beam motion observations.

The ADT currently provide data for the injection oscillation fixed display (first 8192 turns after injection of the first bunch in the train). The multiturn application heavily used for the MDs provides observation of 1, 2, 4, or 8 selectable bunches up to 256k bunch-turns (product of number of observed bunches and number of observed turns). The ADT also sends the content of the post mortem buffer containing the last 70 turns before the dump. It was proved to be very useful diagnostic tool during the first 25 ns MDs in 2011 [10].

The currently prepared tune measurement buffer will provide online information for the selected bunches up to 16k bunch-turns.

Depending on the available resources an implementation of a bunch mask based observation of the transverse beam parameters is foreseen. This would allow to increase the observation capacity to some 1 million bunch-turns (e.g. 1 bunch for 1e6 turns or all 1380 bunches for 760 turns).

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