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COMMISSIONING RESULTS OF THE NEW BPM ELECTRONICS OF THE ESRF BOOSTER SYNCHROTRON*

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Abstract

The 75 BPM stations of the Booster Synchrotron of the ESRF have been equipped with new RF electronics from December 2014. This new BPM system is based on the commercial Libera Spark system and now provides beam position data at various output rates, and with a possible time resolution even below that of the orbit-turn time (1 us). All modules are situated inside the Booster tunnel and powered by an Ethernet cable. This implies that the RF cables from the BPM blocks are less then 3m and only a single trigger signal in daisy chain is sufficient to keep the 75 stations in turn-by-turn phase over the full energy ramping (200 MeV to 6 GeV) time of typically 50 ms. The high sensitivity of the system yields excellent performance at very low beam currents down to 10uA. Full results of the system, including the application as a high quality betatron tune monitor, will be presented.

INTRODUCTION

This paper presents the measurements achieved during the commissioning of the new BPM electronics readout system for the ESRF booster synchrotron. The advantages of installing of the electronics in the tunnel and their integration in the control system are also described.

The ESRF booster ring accelerates the electron beam coming from the 200 MeV linear pre-injector up to the extraction energy of 6 GeV in a 50 ms period, with 10 Hz cycling frequency. In case of “long-pulse” operation mode, 352 bunches with a maximum current of 5 mA are injected in the storage ring, which operates with 200 mA current. Other operation modes enable multi-single bunch configurations with 1 to 5 bunches and currents up to 0.5 mA. The 300 m ring contains 75 BPM blocks with 60 mm diameter and four buttons with a diameter of 10 mm [1].

The 25 years old BPM electronics are now replaced with the Libera Spark system provided by Instrumentation Technologies. The instrument is a cost-effective network attached device which digitizes and buffers the 4 RF signals from the BPM with 14-bit 125 MHz ADCs. The raw data is later processed in the FPGA delivering position, sum, I&Q and strength signals at Turn-By-Turn rate (1 MSa/s) [2]. This enables the study of the beam properties over the full acceleration cycle, with optional time-domain processing for single-bunch fill pattern [3].

INSTALLATION IN THE TUNNEL

The decision to install all 75 units inside the Booster tunnel was taken after a series of radiation dosimetry, that showed globally low radiation doses as expected. The units are located underneath the girders of the dipoles by means of a simple support. At only a few locations, where radiation doses are stronger (i.e. injection & extraction zones) the unit will be protected against radiation damage by a (slightly) different position and additional Lead shielding. The RF cables (RG-223) are only 3 m long between BPM block and the unit. This installation inside the tunnel yielded a significant cost reduction for this RF cabling, and also an important increase of the sensitivity and resolution of the BPM system since the attenuation of otherwise long (typically 50 m) RF cables is avoided. The installation of cables and units was carried out in 2 weeks, according with the time slots when the tunnel was accessible and during the weekly machine stops.

Data acquisition from all 75 stations is triggered with a daisy-chained signal which travels around the machine in less than 2 µs. To align all the data acquisitions at the same ADC sample a delay setting in the FPGA is used. No machine reference signal is provided to the device since the short acceleration cycle doesn't call for a PLL to control the ADCs sampling rate over time. This simplifies the interface making the instrument affordable without compromising the TBT performance.

CONTROL SYSTEM INTEGRATION

Libera Spark can be accessed through a SCPI-like interface over Ethernet (100 MbE and 1 GbE). Every unit is integrated in the TANGO control system through individual Device Servers (DS) running on a dedicate server. On top of them a “grouping” server collects data from all the stations providing global attributes both for parameters and signals – see Fig. 1. GUIs and Matlab functions enable the end user to control the system.

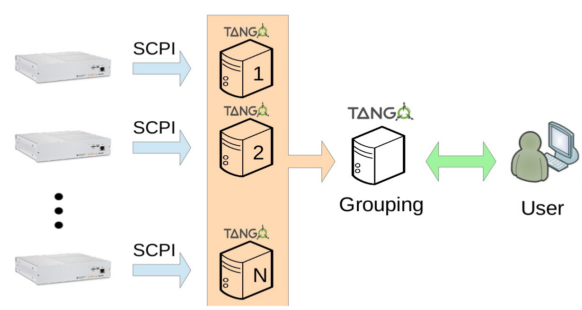

Figure 1: Control System integration architecture.

COMMISSIONING RESULTS

This chapter presents the data acquired from the ESRF booster ring with the new BPM electronics. Since 2 BPM blocks were dedicated to other measurements, only the acquisitions from 73 stations will be presented.

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Time-Adjustment with the Beam Arrival

In order to synchronize all the stations with the beam arrival, each *trigger delay* setting is adjusted to align the data from all the ADC buffers. In each unit, the first bunch is detected via a threshold applied on the mean of the four electrode signals, after filtering them. Later on, the delay can be set to align the first bunch to the desired ADC buffer sample (with a 9.25 ns time accuracy). Figure 2 shows the result with single-bunch beam mode.

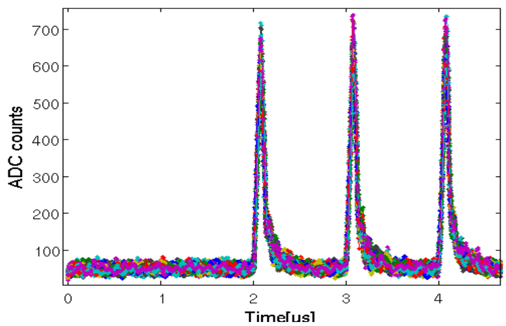

Figure 2: ADC processed data used to synchronize all the units with the beam arrival.

Turn-by-Turn Measurements and Tune Monitor

Turn-by-Turn data available from all the stations now allows beam lattice measurements. Beam position and sum signals are yielded during the whole (50 ms) acceleration cycle, at the 1 μs T-b-T rate.

From every station it is possible to calculate the betatron tune through a frequency analysis of X and Z positions. Figure 3 shows an example of the vertical tune, where an FFT is calculated on data slices of 500 μs (500 turns). In order to better excite the beam oscillations in the Z plane, a vertical shaker is used. With the new electronics, a tune monitor application which combines the data from all the stations can be integrated among the other control system tools.

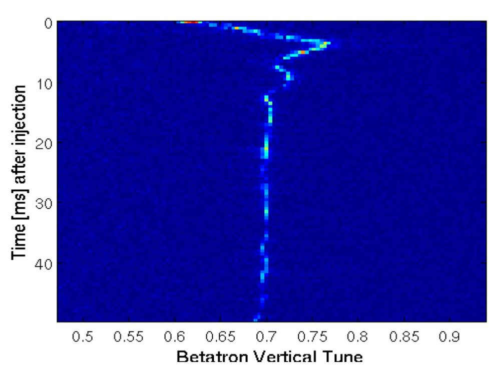

Figure 3: Vertical Tune measurements.

TbT Position Resolution vs Beam Current

In case of long pulse operation mode, the booster operates with a nominal current of 2.5 mA and can be lowered to tens of μA. In the measures here described, the current was decreased in steps from the nominal value down to fractions of it. The SUM signal was used to evaluate the current level of each step in relation to the nominal value – see Fig. 4.a. The X and Z position resolution of the BPMs was very roughly assessed by calculating the RMS in a window of 1000 turns, taken 9 ms after the injection when the beam motion itself is relatively small (i.e. all perturbations from the injection process have fully damped down). Figure 4.b presents the average result from all the BPM stations.

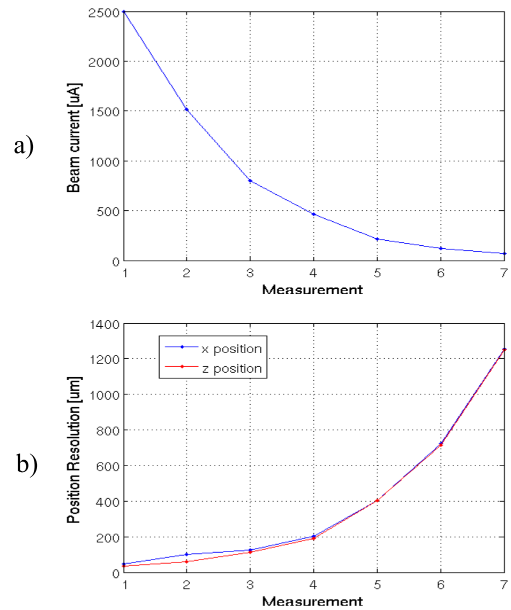

Figure 4.a: current measurements with the SUM signal; Figure 4.b: X and Z position resolution Vs current.

Beam Position and Orbit with Decimated Data

Libera Spark provides the decimated version of each of its Turn-by-Turn signals, averaging them by a factor of 64. This decimated data is useful for at least two reasons:

1. it reduces the signal bandwidth, lowering the noise contribution and increasing the resolution;
2. it drastically reduces the amount of data which needs to be transferred over the network, so signals can be observed for longer periods.

Beam position can be then monitored from the injection to extraction. This is shown in Fig. 5, where the position offset from each BPM signal is removed.

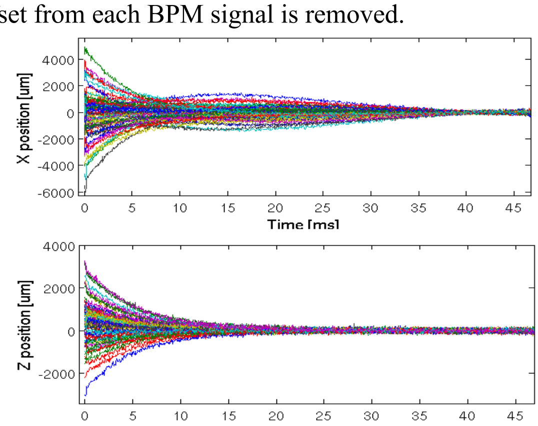

Figure 5: Beam position from all the BPMs.

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In the same way, using the data from all the stations it is possible to picture the machine beam orbit at a given time (e.g. 20 ms after injection). From Fig. 6, a clear pattern which reflects the nearly periodic booster lattice structure can be seen.

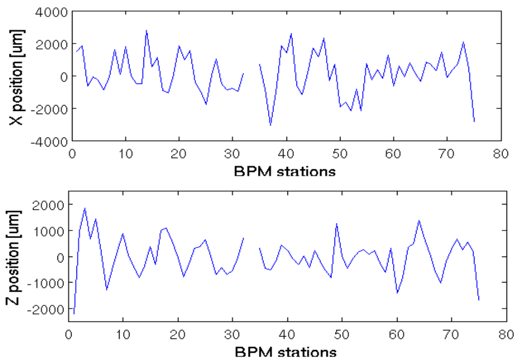

Figure 6: Beam orbit measurements.

Beam Extraction and Injection

The extraction of the beam from the Booster into the Transfer Line is first prepared by a slow local horizontal bump, produced by three bumpers, that starts about 1.5 ms before the extraction moment. This bump can be seen by two BPM stations (QD39 and QF1) that are inside this bump (see Fig. 7b). This bump moves the beam a few mm closer to the septum blade of the extraction septum magnet, and at the exact moment (turn) of extraction a fast 1 µs kicker then deflects the beam to the external side of that septum blade. This fast kick (i.e. position displacement) is also seen on the same BPMs on the last recorded turn.

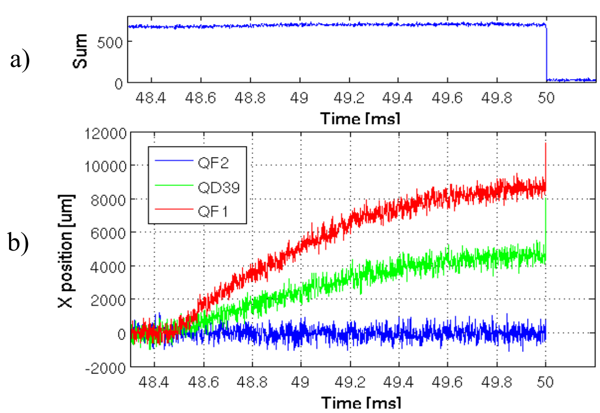

Figure 7.a: SUM signal during the extraction; Figure 7.b: X position signals during the extraction.

Using the ADC data an interesting analysis of the beam trajectory of the injected beam is possible when the Linac is operated in so-called long-pulse. The latter is roughly 1.6 µs long which means that at least 0.6 µs of it is lost in the very first turn since the Booster can only accommodate 1 µs. The injection kicker provides a flat horizontal kick of 5 mrad deflection strength and 1 µs duration to put the injected beam on axis and centered in the Booster vacuum chamber. The 0.6 µs of beam that is outside this flat kick window will get an insufficient kick and therefore crash into the vacuum chamber wall, after about 20 meters, and so it is still detected by the first 3 or 4 BPMs after the injection zone. Figure 8 shows the filtered Sum data of the 4 ADCs (i.e. beam intensity) of all BPMs.

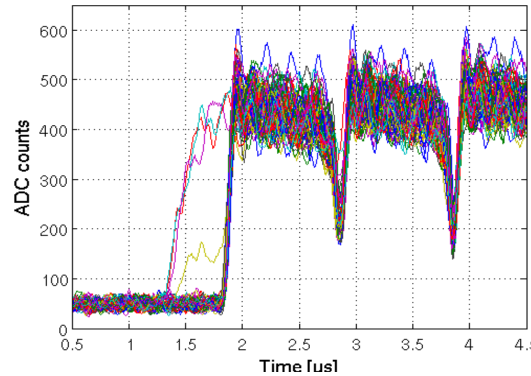

Figure 8: ADC data from the beam injection.

DATA-THROUGHPUT LIMITATIONS

Together with the installation of the new BPM electronics, also the reliability of first implementation of the TANGO DS infrastructure was evaluated. The request of large amount of data, or the acquisition at high trigger rates crashed the system regularly. The presence of a grouping server between each unit DS and the GUIs simplifies the access to the data, but it also introduces some uncertainty on which part could limit the overall system throughput. Therefore more investigations will be done in order to improve the sustainable trigger rates and the acquirable amount of data.

CONCLUSIONS

The ESRF booster ring is now equipped with 75 new BPM electronics. The installation of the units in the booster tunnel was done in two weeks, with a significant cost reduction for the RF cabling. All the Libera Spark units are powered on with an Ethernet cable and boot using the same network image.

The instrument delivers data with different time resolutions (ADC, TbT, decimated TbT) and processing techniques (Digital Down Conversion and Time Domain Processing). The instruments provided extremely valuable data both for the accelerator standard operations and for the understanding of some machine non-ideal behaviours.

Future work will try to assess the full potential of the different signal processing techniques according with the operation mode, as well as the system long term stability.

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