BEAM POSITION MONITOR FOR CIRCULAR PROTON ACCELERATORS

M. Znidarcic, E. Janezic, Instrumentation Technologies, Solkan, Slovenia
K. Lang, GSI, Darmstadt, Germany

Abstract

Position monitoring, tune calculation and subsequent optimization of hadron circular accelerators require specific instrumentation. Libera Hadron is the newly developed instrument intended for data acquisition and post processing of signals from shoe-box or button type pickups. Development, initial measurements and verification of the instrument performance were conducted in the Instrumentation Technologies' laboratories, followed by the characterization measurements of the unit carried out at Facility for Anti-proton and Ion Research (FAIR) facility. This article discusses the new BPM electronics concept, the tests performed and the performance obtained.

INTRODUCTION

With FAIR project collaboration between GSI - FAIR and Instrumentation Technologies started. The driver for the new Hadron BPM is large SIS-100 synchrotron machine (see Fig. 1).

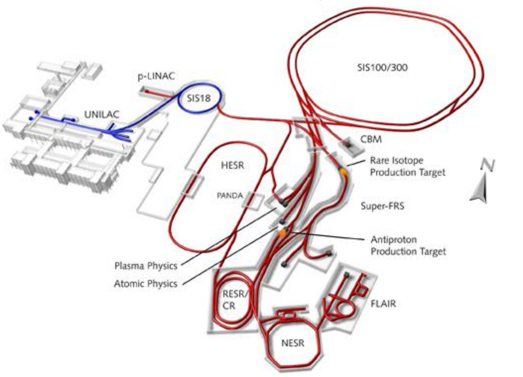

Figure 1: FAIR complex

Below are listed just some of starting points for building the new BPM system. A high accuracy in the order of 100 µm rms of beam position reading is required for the determination of the closed orbit, fast position readout in bunch-by-bunch manner is mandatory especially in cases when bunch manipulations will be performed, beam position data path has to be available for the closed-orbit feedback system etc.

LIBERA HADRON

Libera Hadron system (see Fig. 2) is based on uTCA modular technologies with IPMI platform management. The system is therefore developed on multiple AMC modules, with each module covering different functionalities.

Figure 2: Libera Hadron

The user can access the functions implemented in the Libera Hadron unit through a control system interface, called the Measurement and Control Interface (MCI). This interface was developed to facilitate the integration of Libera Hadron into the accelerator's control system software.

DATA PROCESSING

Libera Hadron has a capability of processing signals from shoe-box sensors or button pickups, with various signal intensities, bunch repetition rates and bunch lengths [3]. Three stand alone algorithms are implemented for this purpose:

- Narrow Band analysis: Superheterodyne SDR receiver for processing bunch signals at extremely low bunch charges.
- Bunch-by-bunch for Shoe-box sensors: Bunch detection algorithm with baseline restorer for processing of unipolar signals.
- Bunch-by-bunch for button sensors: Bunch detection algorithm for processing of bipolar pulses.

Libera Hadron provides four main data paths presented on Fig. 3 (raw ADC data, Bunch-by-bunch, Fast Acquisition and Slow Acquisition). Fast Acquisition data is available over SFP connector on the GDX module (optional).

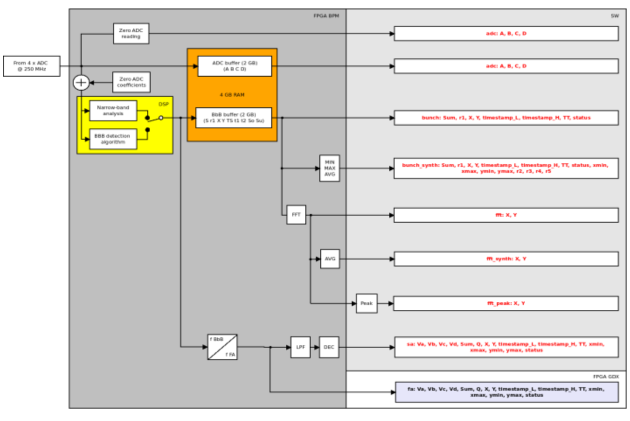

Figure 3: Data paths

Fast Acquisition (10 kHz) and Slow Acquisition (10 Hz) are stream type while other data paths are data on demand type. The complete data processing and data storing in buffers is initiated by the external trigger event signal. The data is stored in two 2 GB buffers which can be read out on users' request:

- ADC buffer (Raw ADC data): data coming directly from the ADC converters @ 250 MHz sampling rate. Ca. 270 M samples (> 1 second of 4 channels data) can be stored. Bunch shapes through time can be observed here.
- BbB buffer (Bunch-by-bunch data): 2 GB of RAM memory reserved for this purpose. Ca. 200 M samples (> 66 seconds of data @ 1 MHz bunch repetition rate) can be stored. The position data is registered for each individual bunch so this data can be used for tune determination.

There are four additional data paths [2], offering to the user various options of data representation and post analysis (Closed orbit, trending, trending mean, tune, FFT, etc). Example of FFT vs. time acquisition is presented on Fig. 4.

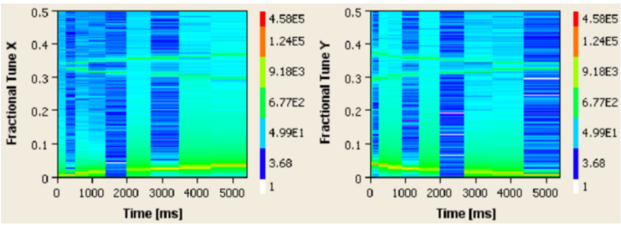

Figure 4: Color coded FFT waterfall diagram vs. time

CONTROL SYSTEM INTEGRATION

On the top layer, Libera Hadron provides the MCI with a development package and Command Line utilities for open interaction in different control systems. On top of the MCI, various adaptors to different control systems can be implemented (EPICS, Tango, FESA etc.). The EPICS interface with the QT based GUI enables full control of the instrument and it is part of the standard software package.

Figure 5: QT based GUI

EVENT RECEPTION

Libera Hadron detects the events announced by the accelerator timing system in order to set the data processing parameters, set external preamplifier value or lock to various external signal clocks. It enables event reception via the optics/wire in the event receiver module (EvRx).

Figure 6: Event receiver module.

The EvRx (see Fig. 6) module receives the optical signal through the SFP transceiver and identifies and extracts the 16-bit event code. Once the code has been extracted, the module decodes the event identification code and triggers specific functions at low latency. EvRx module is compatible with Micro Research Finland (MRF) and White Rabbit timing systems.

TESTING

Measurement performance mostly depends on the Libera Hadron front-end configuration. Its parameters are set in accordance with various accelerator characteristics. The most important are sensor type, beam dynamic range, distance between bunches and bunch length. In the SIS-100 case the typical bunch lengths are 30 ns with maximal repetition rates of 3.3 MHz.

The crucial GSI - FAIR requirement for the RF front end design was flat frequency response in range from 40 kHz up to 55 MHz, considering that -20 dB rejection has to be reached at 125 MHz. The RF front-end frequency response measurement results are presented on Fig. 6. Measurement was performed in the range from 40 kHz to 150 MHz. The signal source was Rohde-Schwarz SMA100A signal generator. Since the generator and test setup are not linear, the test setup was measured with the spectral analyzer prior the test. The measured deviations were considered in the final result (see Fig. 7).

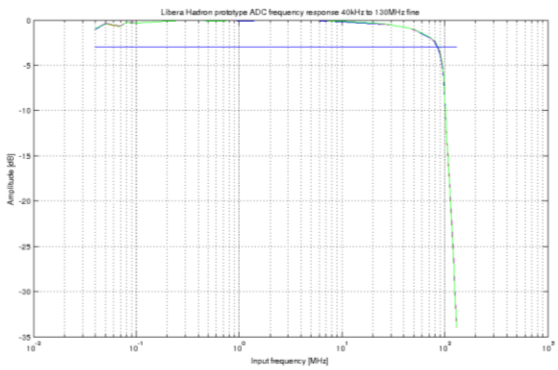

Figure 7: RF front-end frequency response

Position measurement rms requirement for SIS-100 is 100 µm in bunch-by-bunch mode within the 10 dB dynamic range. The full scale of the instrument must be 2V peak.

Position rms was estimated with four equal signals applied to the Libera Hadron RF inputs. Evaluated signal is presented on Fig. 8. The signal was measured directly at the Libera input. Repetition frequency of the simulated bunches was 3.3 MHz while FWHM of bunch signal was 30 ns.

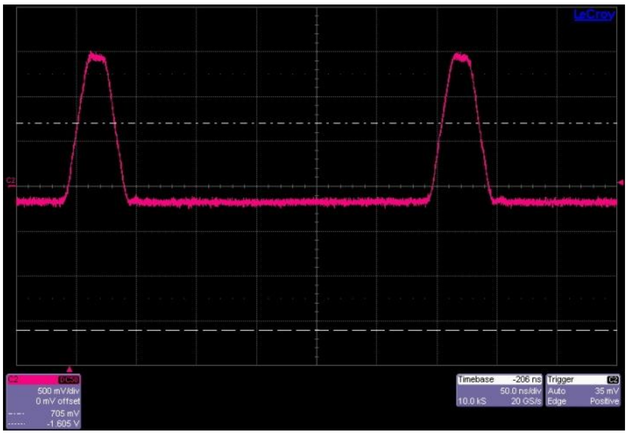

Figure 8: Input signal

Evaluation was done with bunch-by-bunch position results within the dynamic range of 15 dB. The RMS was calculated on the 10000 acquired position samples. Kx and Ky geometrical coefficients were set to 100 mm. Results are presented on Fig. 9.

Figure 9: Position rms (15 dB dynamic range / FWHM=30ns)

Libera Hadron RF front-end hardware configurability enables processing of various signal shapes and intensities. In the case of lower signal intensities, the RF front-end gain can be reconfigured.

In the case of the following test, the full scale of the instrument was set to 70 mV peak. In this case the signal FWHM was 100 ns. Kx and Ky geometrical coefficients were set to 100 mm. Results are presented on figure 10.

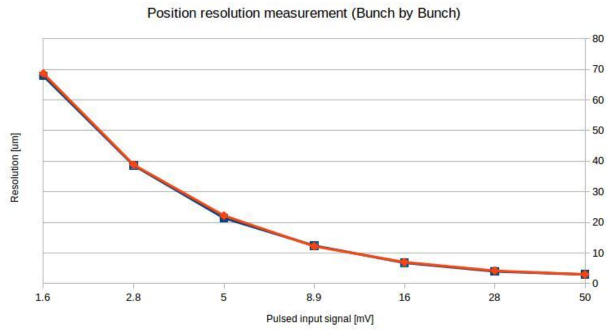

Figure 10: Position rms (30 dB dynamic range / FWHM=100ns)

EXTERNAL PREAMPLIFIER

External module called Amplifier 110 is intended to reduce big dynamic range of signals in order to enable further processing/measuring. Huge 110 dB (-50 dB to 60 dB) beam dynamic in SIS-100 accelerator can not be coupled directly with the Libera Hadron BPM. External preamplifier mounted close to the sensors is in charge to provide high intensity and low noise signals to Libera Hadron unit. Control data are transferred from the Libera Hadron to the Amplifier 110 by using SPI protocol. The Amplifier 110 can be controlled from the accelerator event system through Libera Hadron or directly from the Libera Hadron unit.

CONCLUSION

One of the crucial requirements for the hadron BPM system is the capability of detecting individual bunches within the acceleration cycle and actual bunch-by-bunch measurement rms under specific conditions. Position rms close to 7 μm (FWHM=30 ns) was achieved in the laboratory test setup.

The successful collaboration needs to be emphasized between users (GSI - FAIR) and development & manufacturing of the instrument (Instrumentation Technologies).

REFERENCES

[1] fair-center.eu website: http://www.fair-center.eu/public/what-is-fair/accelerators.html

[2] Instrumentation Technologies, “BPM data acquisition for circular machines”, internal document, Solkan (December 2013)

[3] Instrumentation Technologies, “HBPM project design document”, internal document, Solkan (January 2014)