EVALUATION OF NEW GENERATION HEAVY PARTICLE BEAM DIAGNOSTICS INSTRUMENTATION

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Abstract

This paper presents the achievements in the field of heavy particle beam diagnostics instrumentation. Two different instruments are presented: Libera Single Pass H and Libera Hadron, designed for linear and circular heavy particle beam diagnostics applications respectively. Beside the classical beam position application the paper presents accurate beam arrival time measurements, high resolution single bunch measurements, beam current and fill pattern measurements. The beam signal processing devices are evaluated through extensive laboratory measurements on the real beam and on stepper-motor driven test-benches. The presented instruments are network attached devices, developed on uTCA based platform, that enables the integration of many instruments in the control system network and a simplified implementation of custom signal processing algorithms.

INTRODUCTION

The paper first describes two beam diagnostics instruments developed to full fill the requirements of heavy particle accelerators: Libera Hadron and Libera Single Pass H. In the following sections, the results from extensive laboratory and beam measurements are presented.

The two instruments are both based on the modular uTCA technologies adopted also by other instruments like Libera Brilliance+ and Libera LLRF, that integrates up to 4 beam signal processors in a 19" 2U chassis. Both the instruments adopt the established combination of analog and digital signal processing deeply integrated in the accelerator control system through the Libera BASE (Basic Application Support Environment) software bridging infrastructure. Libera BASE puts the described beam instrumentation devices into a new, modern and completely different perspective. The instruments, besides the flexibility and proclaimed and confirmed principle of 'instruments working together' have a great potential for mutual sharing of development DSP algorithms which calls for the redefinition of this type of beam instrumentation.

Furthermore the two instruments have been developed in order to meet the stringent requirements of future accelerator projects like FAIR, IFMIF Eveda, LANSCE-R and others.

LIBERA HADRON

Libera Hadron is the hadron beam position processing device developed for position measurements on circular heavy particle machines. The system provides the suitable analog and digital processing in order to extract the beam information from individual bunches and track the bunches through the turns during the acceleration cycles.

Optionally the system has the capability to measure the stored charge and characterize the beam position also longitudinally. The available Libera Hadron functionality includes:

- Single Pass – High Resolution, Single Bunch Transversal Beam position measurement: provides for each bunch the 4 electrode amplitudes and the position in the horizontal and vertical plane. The four electrode amplitude information can be calibrated in order to produce an absolute charge measurement.
- Turn by Turn high resolution, turn averaged beam position and charge measurements. The Single Bunch measurement stream is processed by a tracking algorithm that identifies the buckets each turn, even with fast acceleration of the beam, even in the case of losses in some bunches. The algorithm therefore enables the separation of the buckets between turns in order to calculate correctly the turn averaged position and charge.
- Slow acquisition: a slow stream typically used for monitoring purposes.

In addition, the Libera Hadron system can offer the following advanced functionality:

- Single Pass – High Resolution, Individual Bunch Arrival Time measurement: The bunch arrival time is resolved down to few tens of pico-seconds by means of input signal phase measurement.
- Fast acquisition – Very High Resolution Beam Position measurement streaming at 10 kHz rate on dedicated output for Fast Feedback purposes.
- Bunch Map and Bunch Fill Pattern measurements: The Single Bunch informations like Individual Bunch Arrival Time, Charge and Position is organised in turns and buckets in order to observe the behaviour of the individual bunches in the longitudinal and transversal plane during the acceleration cycles.

Figure 1: Libera Hadron in a modular uTCA based 19" 2U rack-mount chassis.

LIBERA HADRON EVALUATION

The Libera Hadron system has been evaluated at Brookhaven National Laboratory at RHIC yellow ring. Figure 2 shows the acquired raw signals produced by the beam during 3 turns.

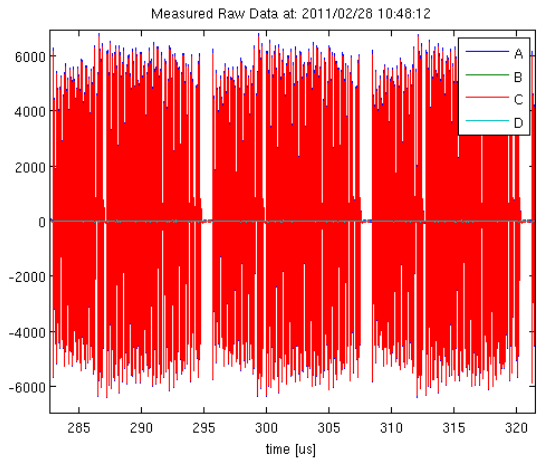

Figure 2: Libera Hadron raw BPM data acquisition during 3 RHIC turns showing the characteristic beam pattern.

The Libera Hadron system provides the Single Bunch data where the contribution of individual bunches is presented.

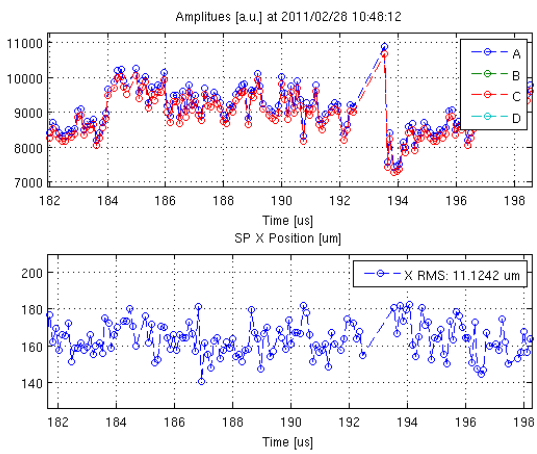

Figure 3: Libera Hadron Single Bunch acquisition: one RHIC turn zoom-in showing the identified bunch amplitude and position represented vs. time. The position standard deviation calculated over 1 ms is 11.2 µm.

The individual bunch measurements are then organised in turns and buckets. A bunch map representation of the organised data is a useful for tracking the beam evolution during several turns. The bunch map of figure 4 represents with a greyscale the normalized bunch charge versus the turns and the buckets.

Libera Hadron has been evaluated also during beam injection. Figure 5 summarizes the measurements during few injection cycles showing the average stored charge per bucket, the position and the number of filled buckets versus time.

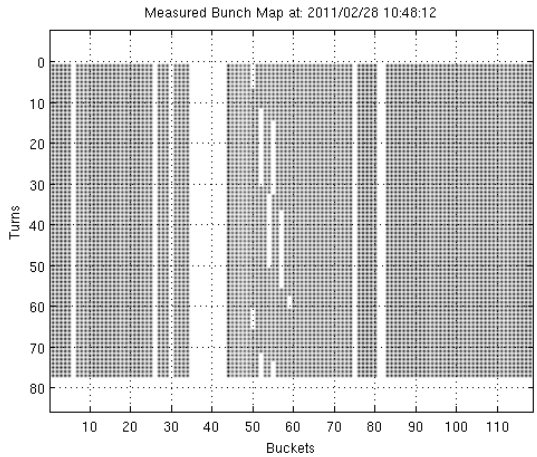

Figure 4: Bunch map of 78 RHIC turns. The greyscale represents the normalized bunch charge. In some turns few bunches went below the defined detection threshold.

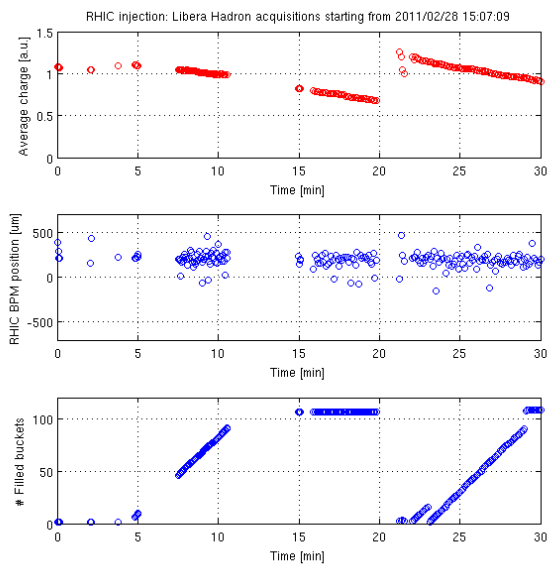

Figure 5: RHIC injections over 30 minutes (normalized charge, beam position and number of bunches)

The Libera Hadron system averages the Single Bunch information over the recognized turns and provides a Turn by Turn stream.

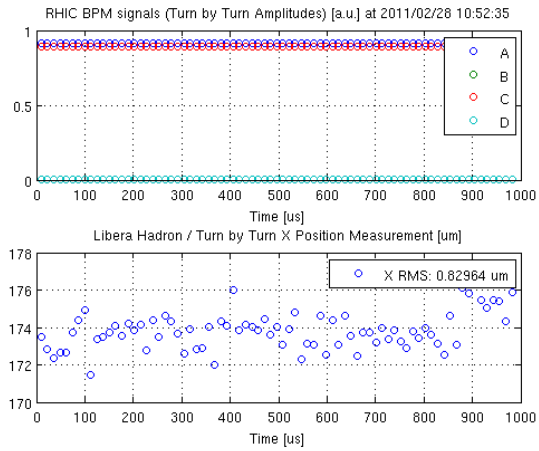

Figure 6: Libera Hadron Turn by Turn data, representing 1 ms, the standard deviation is 0.83 µm.

The Libera Hadron system has been also evaluated by means of extensive laboratory measurements with the RHIC stepper-motor wire test-bench in order to determine the RHIC pickup geometrical factors up to the cubic term to be used for calibration purposes.

Table 1: Libera Hadron Performance Measurement Summary (RHIC Bunch repetition rate approx. 9.3 MHz, revolution frequency approx. 78 kHz)

Measurement	Beam (RHIC)	Laboratory
Single Bunch Position RMS	11.2 µm	3.72 µm
Turn by Turn Position RMS	0.83 µm	0.32 µm

LIBERA SINGLE PASS H

Libera Single Pass H is a single pass phase and position processor specially developed for linear machines accelerating heavy particles. The instrument has the capability of measuring the beam position and arrival time in machines requiring accurate time of flight measurements. The phase measurement is performed with respect to an external MO reference RF signal. The instrument is designed to cover a 60 dB input dynamic range in order to provide accurate measurements at different beam current machine settings.

The system has been evaluated on a stepper-motor controlled button BPM wire test bench at CIEMAT. The signal from an RF generator at 175 MHz has been used to produce a sequence of pulses that were amplified and sent to a wire test-bench. The relatively weak signal, due to the significant test-bench insertion loss, was processed by the Libera Single Pass H unit and averaged over 120 µs, corresponding to the IFMIF macro-pulse length. Here just the most significant measurements are reported. The measured standard deviation was 0.66 µm in the horizontal and 0.96 µm in the vertical plane. The phase measurement standard deviation was 0.026 deg.

Table 2: Libera Single Pass H Performance Specifications (sensitivity coeffs. kx=ky=10 mm, Data Rate = 1 MHz)

Signal Level [dBFS]	Typical Position RMS [µm]	Typical Phase RMS [°]
0	3	0.01
-20	3	0.01
-40	15	0.05
-60	150	0.025

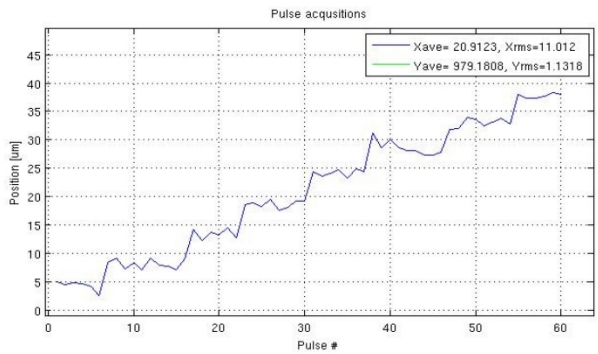

Figure 7: Libera Single Pass H position acquisition: The response to a sequence of 5 µm steps are applied through the CIEMAT stepper-motor wire test-bench.

CONCLUSIONS

Both the instruments provide the functionality necessary to process the non-relativistic beam signal, extract the significant information at high resolution. The flexibility of the uTCA based platform and the Libera Base software structure simplify the integration of the instruments in the accelerator control system and the extension of the basic functionality.

ACKNOWLEDGEMENTS

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REFERENCES

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