

# TURN-BY-TURN DATA ACQUISITION AND POST-PROCESSING FOR THE DIAMOND BOOSTER AND STORAGE RING

R. Bartolini, M. Abbott, I.P.S. Martin, G. Rehm, J. Rowland  
 Diamond Light Source, Oxfordshire, UK.

## Abstract

The Diamond booster and storage ring are equipped with Libera Electron Beam Position Processors with turn-by-turn capabilities. We describe here the turn-by-turn data acquisition system and the software used for post-processing the beam data. The signals from the Libera boxes are acquired and controlled with EPICS and then transferred to the MATLAB environment via the MATLAB Channel Access or LabCA. Here they are post-processed using MATLAB capabilities and dedicated software linked to MATLAB. Examples of data acquired and measurements performed during Diamond booster and storage ring commissioning are reported.

## INTRODUCTION

The Diamond booster commissioning started in December 2005[1,2] followed by the Storage Ring commissioning start in May 2006[3]. The Libera Electron Beam Position Processors[4] were operational since day one and controlled the beam signals from 22 four-buttons BPMs in the Booster and 168 four-buttons BPMs in the storage ring.

Commissioning activity has relied heavily on the “first turn” and turn-by-turn capabilities of the BPMs. While the “first turn” helped in threading the beam around the first few turns in both Booster and Storage Ring, the turn-by-turn capability has been crucial in characterizing and correcting the ramp of the booster and in the preliminary analysis of the linear optics of the storage ring.

Particular effort was spent in the generation of software for the post-processing of the BPM data. Following the general strategy adopted at Diamond[5] the high-level applications have been built in the MATLAB environment and using MATLAB computational and graphical capabilities, together with a link to external software, namely the SUSSIX code[6], dedicated to the frequency analysis of the betatron motion.

Many of the measurement foreseen for the remaining part of the commissioning of the two accelerators will be based on the turn-by-turn capabilities, namely in the characterization of the linear and non-linear optics and the establishment of an on-line model of the two rings.

## EPICS CHANNELS FOR BPM DATA

The 22 BPMs in the Booster and the 168 BPMs in the storage ring share the same electronics and software and provide a wealth of information on the beam position on largely different time scales. In Fig. 1 we describe schematically the type of data produced by the Libera and

the generated EPICS output available to any high-level application.

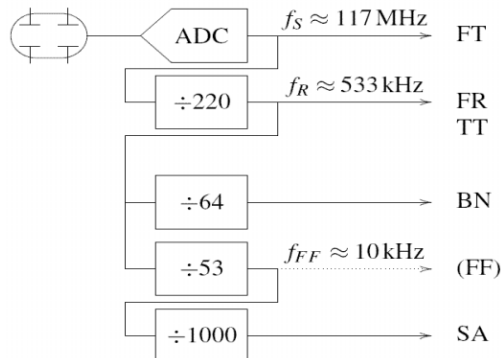


Fig.1: Overview of the processing chain within Libera and generated EPICS output. See text for explanation.

The EPICS channel “FT” (for First Turn) provides the value of the beam position and intensity at the first turn by processing the digitalized signal from the four buttons sampled at 117 MHz [4]. The “FT” channel can also retrieve the beam position at other turns such as the second, or even the zero-th or the “-1th”. This feature was particularly useful for the establishing the closure of the injection bump in the storage ring.

The EPICS channel “FR” (for Free Running) returns a vector of 2048 values with the beam position and intensity, updated after every LINAC gun trigger. It gives information on the early evolution of the beam.

The EPICS channel “TT” (for long Turn-by-Turn captures) can deliver up 100 ms turn-by-turn data, corresponding to the entire booster ramp of 200,000 turns. It is used to analyze the beam position and intensity on a longer scale.

The remaining EPICS channels are do not provide turn-by-turn but decimated waveforms, with different decimation ratio N, containing the beam position and intensity averaged over N turns. These EPICS channels are used for closed orbit measurements (“BN”) and fast and slow orbit feedback (“FF” and “SA” respectively).

## MATLAB POST-PROCESSING

All the data available as EPICS PV can be transferred into the MATLAB environment using MATLAB Channel Access[7] (MCA) or LabCA[8]. Commissioning was started with MCA but the faster connection speed and simplified API of LabCA made it the preferred tool for new work. Once loaded in the MATLAB workspace the turn-by-turn data can be analyzed using MATLAB computation and graphical capabilities.

Turn-by-turn data are directly accessible with the LabCA call `lcaget`, however a special effort was made to integrate these EPICS channel with the turn-by-turn data into Middlelayer[9]. In this way the data can be conveniently accessed without the detailed knowledge of the cumbersome EPICS name. The MiddleLayer structure usually containing the BPM data from closed orbit measurements has been extended to support new fields created for the EPICS channel. As an example, for the horizontal BPM signals, the field `ao.BPMx.Monitor` has been complemented with the subfields

<code>ao.BPMx.Monitor</code>	→	FT data
<code>ao.BPMx.Turns</code>	→	TT data
<code>ao.BPMx.FR</code>	→	FR turns
<code>ao.BPMx.SWF</code>	→	BN ( $\div 64$ )
<code>ao.BPMx.BNWF</code>	→	BN ( $\div 1204$ )
<code>ao.BPMx.Intensity</code>	→	intensity

The data in these fields are accessible with the usual Middlelayer calls, `getam`, `getpv` and `getx`. The default channel `ao.BPMx.Monitor` has been set to read the first turn data (FT) since that choice was convenient in the early stage of booster commissioning.

Several applications have been written in MATLAB to perform routine tasks during Booster commissioning such as displaying turn-by-turn data, compute and display their FFT spectrum, measure the betatron tunes at injection and tracking them during the ramp. Two examples are described in what follows.

Using the turn-by-turn data available from a BPM for the whole ramp cycle, the MATLAB script `showtunemove` has been written to acquire and post-process the data and display the amplitude of the FFT spectrum as tune signals as a function of time. The BPM signal is cut in slices of 512 turns and for each slice the FFT amplitude spectrum is computed. The results for all slices are then merged together and displayed as a MATLAB colormap during the ramp. The Hanning filter can be selected if needed to generate more visible peaks in the amplitude spectrum, albeit at the expenses of a reduced frequency resolution. An example plot of the FFT amplitude spectrum during the ramp taken during the booster commissioning is shown in Fig. 2. The betatron oscillations in both planes of motion are generated by two striplines excited with white noise. The betatron tunes in the horizontal and vertical planes are clearly identifiable as the highest peak in the spectrum, i.e. the brightest curve in the colormap. The constant lines corresponding to a tune value of 0.18 are given by a spurious 340 kHz frequency (0.18 w.r.t. the booster revolution frequency) which is an artefact of the BPM electronics and will be removed in a future hardware upgrade.

Similar to this, the MATLAB script `brgettune` has been developed to extract the tune signals from the turn-by-turn data along the ramp. For each slice of turn-by-turn data, the script looks for the highest peak in the amplitude

spectrum. A precise determination of the betatron tune is then performed using an interpolated FFT algorithm around the highest peak in the FFT amplitude spectrum following Asseo's technique [10]. An example plot of the booster tunes during the ramp is reported in Fig. 3.

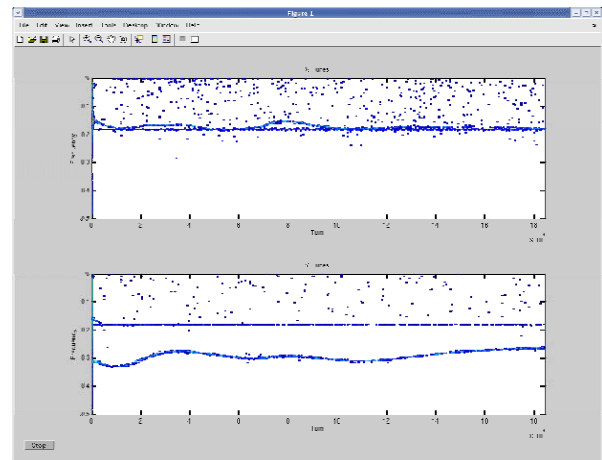


Fig 2: Amplitude of the FFT spectrum during the ramp in horizontal plane (top) and vertical plane (bottom).

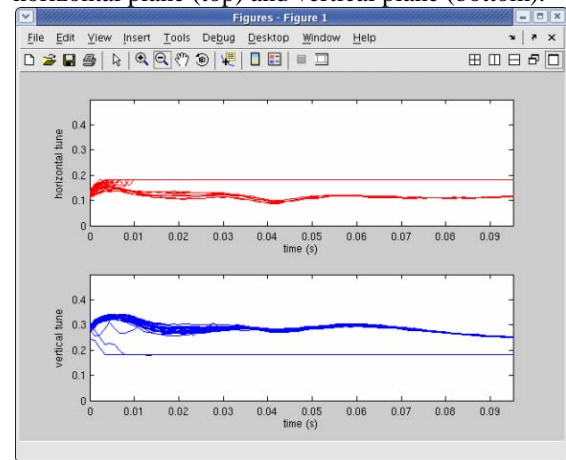


Fig 3: Fractional tunes during the ramp in horizontal plane (top) and vertical plane (bottom).

The signals were acquired during several booster ramps and clearly show the variation of the betatron tunes both along the ramp and within each shot, especially at low current quadrupoles excitation. Again the spurious 340 kHz frequency appears to mislead the peak search algorithm at times.

## SPECTRAL LINE ANALYSIS

Turn-by-turn data can be post-processed to obtain useful beam dynamic information and to build an on-line machine model. They can provide complementary information to the LOCO package[11] to reconstruct the linear part of the machine model and also give insight into the non-linear part of the model by means of the determination of the non linear resonance driving terms[12].

A MATLAB application *allbpm\_analysis* has been written to acquire the BPM signals from all the BPMs in the ring and to perform comparisons with the machine model available within Middle Layer. The task performed by this application can be summarised in

- BPM data and FFT display
- frequency analysis with SUSSIX[6]
- comparison with ring model

The application uploads all the BPM signals simultaneously in the MATLAB workspace and computes the FFT of all signals. Data and their FFT are then displayed according to the input options specified from the GUI by the user. These options include the selection of a particular BPM, of the plane of motion to analyse, the selection of the starting and ending point in the signal analysis. This feature is quite useful in cases where the beam is kicked and the betatron oscillations experience a significant decoherence due to the non-linearities, to avoid the analysis of irrelevant part of the BPMs signals.

The application is linked internally to the code SUSSIX[6] which performs a complete decomposition of the spectral content of the betatron oscillations at all BPMs. Frequencies, amplitude and phases of all the spectral lines at all BPMs are made available for further MATLAB processing. The frequencies of the spectral lines are also classified as linear combination of the betatron tunes.

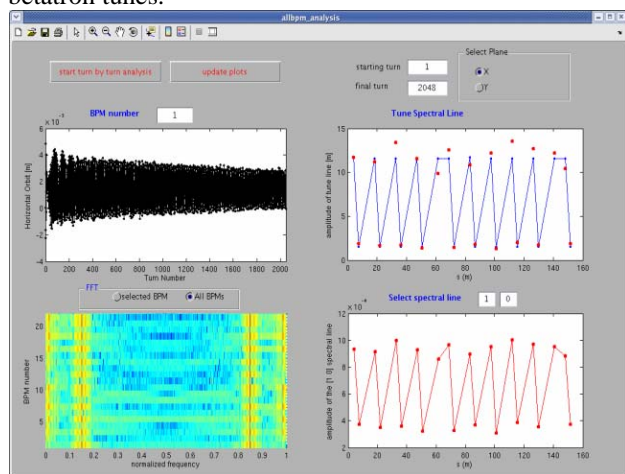


Fig. 4: Screenshot of *allbpm\_analysis* GUI. See text for explanation.

The amplitude and phase of spectral lines at the betatron tunes carries information about the linear optic of the machine: if linear coupling is negligible, the amplitude of the tune line is exactly proportional to the square root of the  $\beta$ -function and the phase coincides with the phase advance once a reference azimuth is fixed in the lattice. In general each spectral line can be put in correspondence with a non-linear resonance driving term[12]. The *allbpm\_analysis* application allows the selection of which spectral line to analyse, to plot its

variation along the azimuth of the ring, at each BPM, and to compare with the corresponding non-linear driving term computed from the model.

A screenshot of the *allbpm\_analysis* is shown in Fig. 4, where turn-by-turn data from the 22 BPMs booster at injection energy were captured and analyzed. The GUI displays the horizontal signal at the first BPM (top left), the colormap of the FFT at all BPMs (bottom left) where the horizontal tune is clearly visible. The top right graph shows the amplitude of the horizontal tune spectral line and its comparison with the horizontal  $\beta$ -functions. A zoom of this graph is reported in Fig. 5 for the vertical turn-by-turn data. Model and measured data agree within 15% in line with analogous results obtain with the LOCO analysis of the booster optic at injection[2]

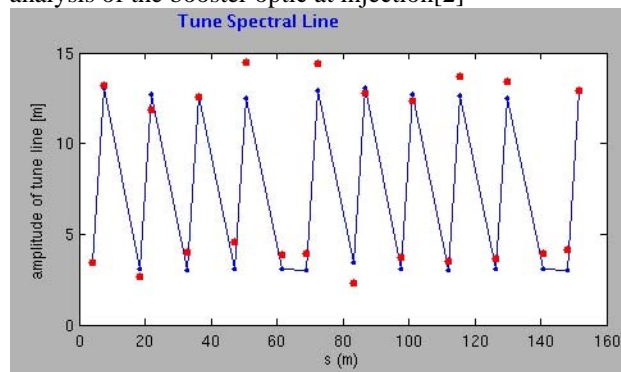


Fig. 5: Zoom of the top left graph in *allbpm\_analysis* GUI. Same data as Fig.4; vertical plane selected.

## CONCLUSION

Diamond high-level software exploits heavily the turn-by-turn capabilities of the Libera Electron Beam Position Processors. The booster commissioning and the initial stage of Diamond storage ring commissioning have been greatly facilitated by the BPM system, available from day one. Work is continuing to refine the high-level applications with the final aim of constructing a full on-line model of the accelerator directly from turn-by-turn BPM data.

## REFERENCES

- [1] V.C. Kempson et al., these proceedings.
- [2] B. Singh et al., these proceedings.
- [3] R.P. Walker, these proceedings.
- [4] G. Rehm, these proceedings and reference therein.
- [5] R. Bartolini et al., these proceedings
- [6] F. Zimmermann et al., these proceedings; R. Bartolini and F. Schmidt, CERN-SL Note **98-017** (AP), (1998).
- [7] A. Terebilo, in ICALEPCS 2001, 543, (2001).
- [8] T. Straumann, SLAC web site.
- [9] G. Portmann et al., PAC05, 4009, (2005).
- [10] R. Bartolini et al., in EPAC96, 1329, (1996) and references therein.
- [11] J. Safranek, EPAC 2002, 1184, (2002).
- [12] R. Bartolini et al., PAC05, 1452, (2005).