PERFORMANCE OF GLOBAL DIAGNOSTICS SYSTEMS DURING THE COMMISSIONING OF DIAMOND

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Abstract

This paper summarises data acquired with beam diagnostics systems distributed globally through Diamond's Linac, transfer paths, booster and storage ring. It shows results from the electron beam position monitors using their capabilities to monitor transient events, the booster ramp as well as stored beam. The performance derived from real beam measurements is compared to measurements obtained in the lab using signal and pulse generators. Other systems of widespread use are screens and synchrotron light monitors. Their performance and control system integration based on IEEE1394 camera technology is presented. Finally, first results from the fast and slow beam loss monitoring systems are described.

OVERVIEW

A total of 204 electron beam position monitors (EBPM) on stripline and button pickups, 24 cameras on screens and synchrotron light monitors (SLM), as well as 245 beam loss monitors (BLM) of various designs are to be used in the Diamond injector and storage ring. Table 1 show the status of installation, starting at the 100 MeV linear accelerator (LINAC) through the transfer path (LTB) into the booster (BST) and continuing through the booster to storage ring transfer line (BTS) to the 3 GeV storage ring (SR).

	LINAC	LTB	BST	BTS	SR
EBPM	-	7	22	7	168
OTR/YAG	4	4	3	5	2
SLM	-	2	1	2	1
PMT BLM	15	15	-	(15)	-
PIN BLM	-	-	8(32)	-	(168)

Table 1: Installed distributed diagnostics systems (figures in brackets indicate final numbers to be installed)

ELECTRON BEAM POSITION MONITORS

In all locations "Libera Electron" BPMs from Instrumentation Technologies[1] have been used to process the signals from striplines and buttons and to provide the position data in various forms to the control system (EPICS). By implementing the EPICS driver to run on the Libera internal ARM powered single board computer and allowing concurrent access to all data sources a maximum of flexibility has been realised. Most of the data sources are triggered synchronously with the injector, which is running at 5 Hz.

Libera provides digitised data at a wide range of rates which are all created by filtering and decimation of the 4 ADCs at the input where the signals are sampled at 117 MHz. Data at this rate is available through a triggered 1024 sample buffer, which allows precise gating in time. We thus use this data to measure transient beam as in the transfer path or to measure individual turns in the booster or storage ring. However, the 'raw' ADC samples have to be processed as the 500 MHz input has been transformed to a 31 MHz intermediate frequency signal by the undersampling at 117 MHz.

Next, envelope waveforms of 256 points of 34 ns spacing are computed and an adjustable window with programmable width integrates over the length of the bunch train to retrieve the beam position. This process is illustrated on data from the booster (revolution period 528 ns) in Fig. 1.

In adjusting the position of this window the delay of the beam and the timing signal travelling around the storage ring has to be taken into account, so the offset between the earliest and the latest arrival on a storage ring BPM was 62 points on the waveform equalling 2.1 μs. The EPICS channel FT (First Turn) provides the calculated value of the beam position and intensity as well as the ADC waveforms and envelopes for every trigger.

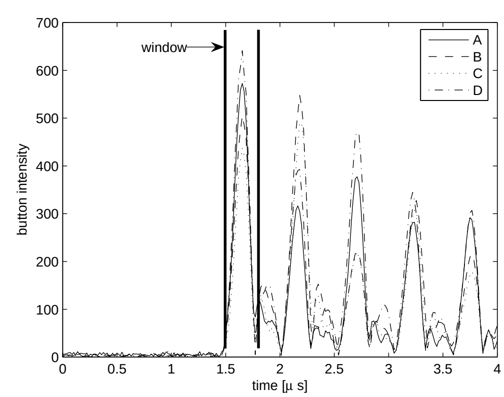

Figure 1: Five turns after injection in the booster

With these windows set the overall trigger delay for the BPM system can now be adjusted to precisely measure the orbit of virtually any turn. It has to be emphasised that the data from the turn-by-turn buffer (see below) is only partially capable to produce precise positions for individual turns, as some 'smearing' between positions of adjacent turns is unavoidable due to the required filtering.

This display of individual orbits is particularly useful in

[1] www.i-tech.si/products-libera-electron.html

establishing the closure of the injection bump in the storage ring to observe not only the first turn (after passing through through two of four kickers on injection) but also the second turn (passing through all four kickers during their decay) or even the turn before the first turn (of the stored beam, passing through all four kickers during switch-on).

A number of further EPICS channels (FR, TT, BN, PM) draw their data from a Libera internal circular buffer of button intensities at turn-by-turn rate. This data is continuously created by digital down conversion and decimation and stored into the buffer which holds several seconds of data. While it would have been desirable to make the whole contents of this buffer available through EPICS, limitations of the available memory for buffering and the available network bandwidth for transferring required a more differentiated approach detailed below:

- FR (Free Running) returns a vector of 2048 values with the beam position and intensity, updated on every trigger. This information is useful to display the early evolution of the beam after injection and real-time updated tune spectra by applying an FFT.
- TT (long Turn-by-Turn) can deliver up to 100 ms turn-by-turn data, corresponding to the entire booster ramp of 190,000 turns. It is also triggered but needs to be enabled externally for a single shot acquisition. Once the acquisition is armed, the data are acquired always from the same starting point with respect to the LINAC gun trigger, e.g. in the Booster, at the beginning of the ramp. Transfer of this long buffer is realised using blocks of 16384 points to reduce the amount of memory consumed by this function. This long buffer is particularly interesting for accelerator physics applications [1].
- PM (Post-Mortem) returns the past 16384 turns (pre-trigger) and is triggered by a dedicated PM input on beam loss and used to review the events leading up to beam losses.
- BN (Beam-Normal) returns a further decimated waveform, containing the beam position and intensity averaged over 64 turns. The length of the vector covers 100 ms and is continuously triggered. For display purposes these waveforms are also available with an additional decimation of 16 thus giving the average of 1024 turns. These data are used for a booster closed orbit display as shown in Fig. 2.

Finally, there is an EPICS channel SA (slow acquisition) which gives stored beam position updates at 10 Hz. A further data source at 10 kHz update rate will not be available through EPICS but is directly connected to the FOFB network through a custom communication controller implemented on the FPGA [2]. It should be noted that only the 10 Hz and the 10 kHz data sources will fully benefit from the channel multiplexing scheme of Libera, as only these data paths will be routed through the whole chain of filters required to remove the artifacts of the input switching.

Table 2 summarises first results on the achieved performances in various operational conditions which so far are in good agreement with earlier lab measurements [3]. The performance in FT mode is significantly better in the transfer path as the striplines used as pickups there deliver about 100 times larger signal amplitudes than the buttons used in the booster.

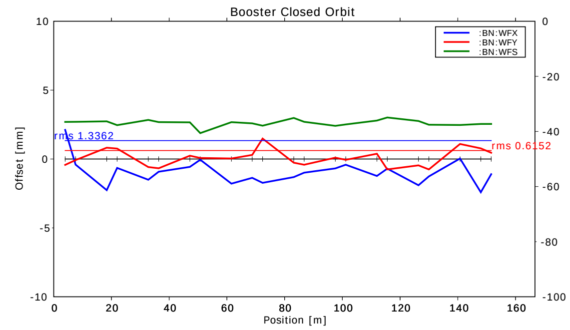

Figure 2: Booster closed orbit display

location	mode	charge/current	total noise
LTB	FT	1.7 nC	60 μm
BST	FT	1.6 nC	170 μm
BST	TT	1 mA	60 μm
BST	BN	1 mA	10 μm

Table 2: Preliminary EBPM performance data from commissioning measurements

SCREENS AND SYNCHROTRON LIGHT MONITORS

Throughout the injector, screens and synchrotron light monitors (SLM) are installed to image the electron beam. We use PointGrey[2] Flea IEEE1394 cameras in combination with Unibrain[3] repeaters and SedNet IEEE1394 PMC boards[4] as the acquisition system. Up to 8 cameras are connected to a single IEEE1394 interface card and thus share the bandwidth on the bus. However, this is hardly a limitation as 30 fps at full camera resolution (1024x768) could be transmitted, whereas each camera takes only 5 fps (due to the synchronisation to the injection trigger). Additionally, the beam can only be intercepted by one screen at any time, so the need for parallel observation of images from several cameras does only arise with SLMs.

An EPICS driver for the cameras has been written and allows control of the exposure time (20 μs to many seconds) and camera gain (0-30 dB). Additionally, the control screen offers the ability to use digital zoom and pan which looks at a region of interest only and magnifies this on the display. An example of this control is shown in Fig. 3.

[2]www.ptgrey.com/products/flea/
[3]www.unibrain.com/Products/p1394/FR400.htm
[4]www.mindready.com/eng/embedded_boards_2.asp

On most of our camera optics, each pixel represents 30 μm$\times$30 μm on the beam plane, so that this facility is usually sufficient to comfortably observe the beam without the need for an optical zoom. Also, the combination of YAG and OTR screens in conjunction with the adjustable camera gain meant that a remote controlled iris or neutral density filters are not required. The optics required thus only fixed focus lenses (in all but two locations) with one mirror to protect the camera from x-rays created at the screen. One issue in the adoption of IEEE1394 cameras

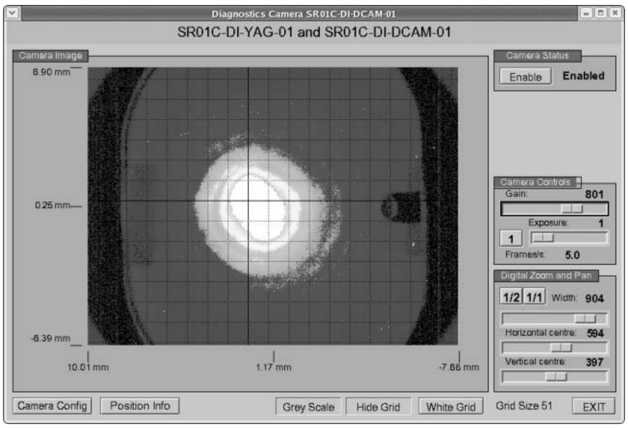

Figure 3: Camera control screen

has been the paucity of knowledge on damage and failure rates in a radiation environment. We had thus tested these cameras under strong radiation [5] and are now keeping a record of hot pixels (pixel which appear white at full gain and 1 s exposure), damaged columns (peak mean column) and overall damage (mean background) seen on each camera with no light. The amount of damage varies depending on the camera location, with the cameras at the low energy end of the LINAC seeing least and the SLM cameras in the LTB seeing most damage so far. Table 3 show the the experienced damages at these two locations over a two month period including one month of SR commissioning with intense injector operation.

Apart from the damaged columns which appear as spurious peaks in profile measurements, these damages have no impact on the operation so far. In particular, the hot pixels, while clearly a permanent damage, are not seen in normal operation with short exposure times. From the minute increase in background compared to the irradiation experiments it can be estimated that these cameras will remain operational for many years.

BEAM LOSS MONITORS

Two types of beam loss monitors [4] have been procured and partially installed in different locations.

The PMT/scintillator type is read with an ADC triggered on injection and shows remarkable dynamic range (>30000) with very small shot-to-shot variations ($\approx$ 5%). This has allowed using it to optimise injection into the booster by fixing two of these BLMs to either side of the injection septum which enabled the beam to be steered through this small vessel with minimum losses.

	06/04/2006		18/06/2006	
	Gun	LTB-SLM	Gun	LTB-SLM
hot pixels	34	5066	64	9698
peak column	2.97	35.12	3.85	41.34
background	2.31	1.68	2.42	2.06

Table 3: Damage to cameras. Between the two dates, the LINAC had operated for ≈500 h, producing ≈1.5 nC per shot or 13.5 mC in total.

The PIN-diode BLMs have been assembled together with a small custom designed circuit which amplifies and stretches their output pulses in order to make them compatible with the the long cables and opto-isolated inputs of counter card which we use. Some of them have been deployed in the booster and give good a good dynamic range of information: the background is about 1 count per second, during a good booster ramp we see about 20-100 counts per second, whereas in the case of beam loss during the ramp we can see >10,000 counts per second. These high count rates are clearly localised and thus provide useful information in optimising the booster.

CONCLUSIONS

The well advanced integration of EBPMs, cameras and BLMs into the control system has enabled their regular use during commissioning and provided a broad range of useful information. Early performance measurements of the EBPM system are in line with earlier lab measurements and the turn-by-turn capabilities in conjunction with the decimated data stream have proven most useful.

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