SYNCHRONOUS MEASUREMENT OF STABILITY OF ELECTRON BEAM, X-RAY BEAM, GROUND AND CAVITY VOLTAGE

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Abstract

We have developed hardware and software that allows continuous and synchronous recording of electron and X-ray beam position as well as cavity voltage and ground vibrations at a rate of about 10 kS/s for periods of many days. To this end, additional nodes have been added to our existing fast network that feeds the Fast Orbit Feedback System, namely tungsten vane type front end XBPMs, RF cavity pickups and accelerometers. The synchronous nature of these measurements shows the correlation between electron beam motion through an insertion device and observed X-ray beam motion in the frontend or orbit distortions caused by fluctuations of the RF cavity voltage. While the additional channels currently are only observed, the potential of including these in the fast orbit feedback will be discussed.

INTRODUCTION

Orbit stability is paramount at synchrotron light sources. To this end, the use of a fast orbit feedback (FOFB) system based on the data from a multitude of electron beam position monitors (EBPMs) is regarded as standard these days. As Diamond Light Source, we have been operating successfully with a FOFB for several years now [1].

The FOFB design uses an in house developed 'Communication Controller' to allow the fast and redundant distribution of the individual beam position readings between the EBPMs and computational nodes [2]. The Communication Controller provides fast RocketIO communication links and packet forwarding based on firmware residing in a Virtex FPGA. While originally designed to operate exclusively in the Libera Electron EBPM units that are in use at Diamond, this firmware has since been ported to other devices and has thus enabled adding additional nodes to the Fast Acquisition (FA) network.

The data from these additional nodes is firstly available for simultaneous recording with the beam orbit, but could also be used for corrective action should it be found useful. We have so far added the following:

- An archiver node which retrieves all data from the fast network and stores it to disk.
- Libera Electron units with modified FPGA firmware to monitor RF cavity voltages.
- Libera Photon units which allow direct connection to tungsten vane type X-ray beam position monitors (XBPMs).
- In-house developed baseband digitiser units capable of recording 2 times 4 analogue inputs at 10kS/s.

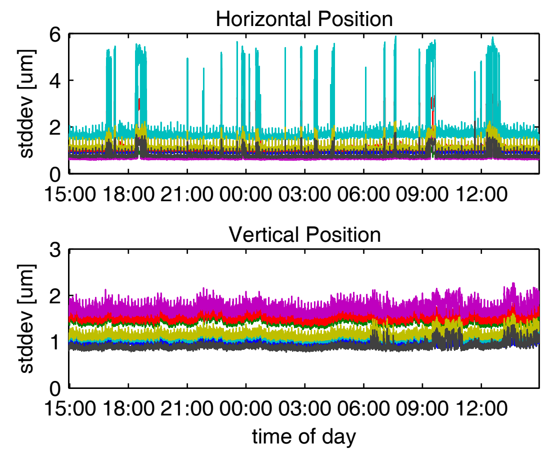

Figure 1: Standard deviation of EBPM position readings over a 24 h period. Colours represent 7 EBPMs in one cell.

All of these will be discussed in the remainder of this paper and example measurements will be provided to illustrate their capabilities.

ARCHIVER NODE

Data on the FA network arrives at an update rate of 10kS/s; the total aggregate data rate from 172 EBPMs and a few additional pickup nodes is around 15MB/s. Data is received from the FA network via an FPGA PCIe Virtex 5 development board managed by a Linux device driver, with both the FPGA firmware and driver developed in house.

The FA Archiver captures the entire data stream to disk in real time, re-broadcasts selected subsets of the live stream to interested clients, and allows rapid access to any part of the saved data. The archive is saved into a rolling buffer allowing retrieval of detailed beam position and additional data from any time in the last four days.

A simple socket based interface to the FA Archiver software allows easy access to both the stored and live data from a variety of clients. Clients include a graphical viewer for visualising the motion or spectrum of a single BPM in real time, a command line tool for retrieving any part of the stored data by time of day, and MATLAB® scripts for exploring the data set, helped by the storage of decimated min, max, and mean data (see Fig. 1).

ADDITIONAL SENSOR NODES

To date, we have added two Libera Electron units to monitor the RF cavity and forward waveguide voltages, two Libera Photon units to record fast X-ray beam motion directly on two XBPMs, and one prototype in-house digitiser with various uses described below.

RF Voltage Monitoring

For the purpose of recording postmortem data, we already had two Libera Electron units connected to signals of the RF cavities. We record the individual channels (reference, cavity probe, forward and reverse power) as I/Q data in case of a beam loss to determine in what sequence the loss of beam and RF power occurred.

We now modified the input to the Communication Controller logic to be able to select not only the position data (which is calculated as a difference over sum from all four inputs) but also individual channel magnitudes as the data to be sent. In this way, we are able to monitor the cavity voltage and forward power of each of the two currently operational RF cavities and record this together with the orbit data in the FA archiver.

X-Ray Beam Position

We have added two Libera Photon units [4] to read the signals from two XBPMs in one front end and send the resulting position readings to the FA network. These units were delivered with the Communication Controller integrated by the manufacturer and have a control system interface very similar to our Libera Electron EBPMs so that integration was straight forward.

Baseband Digitiser

The baseband digitiser consists of a commercially available Xilinx FPGA development board and an in-house developed ADC board with two four-channel 16-bit ADCs, based on a similar design in use at DELTA [5].

Each ADC samples four signals at 161kS/s achieving 4 samples per channel within a communication controller time frame of 100 μs. Integration of the Communication Controller into the design enables injection of the data into the FA network. To simplify the synchronisation of the data acquisition with the FA network, this unit automatically locks the ADC conversion rate to the network frame pace. Control system interface of the baseband digitiser is handled by running embedded Linux and EPICS on the PowerPC core integrated in the FPGA.

The DSP data path includes, in order, averaging of 4 samples per channel over a time frame, calculating X, Y and SUM values at fast acquisition rate of 10KHz, and decimation of position data down to slow acquisition rate at 10Hz. Through the control interface we can chose to send either X and Y position or the individual channel values.

This enables use of this digitiser for various purposes: Firstly, it can be directly connected to the output of two

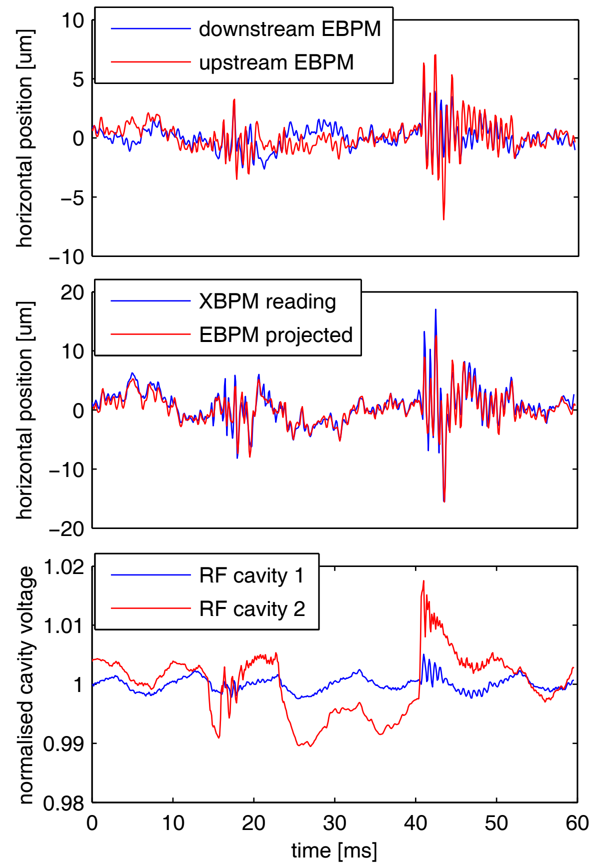

Figure 2: EBPM and XBPM position readings together with records of the RF cavity voltages with step changes.

LoCuM-4 current amplifiers as used in the instrumentation of most of our front end XBPMs. One digitiser unit then provides a cost efficient upgrade to add X-ray beam positions of both XBPMs to the FA network. Secondly, it can be used to digitise any other signal that could be of interest to be recorded and analysed synchronously with the beam orbit, for instance accelerometers or beam position monitors in the beamline.

EXAMPLE MEASUREMENTS

In Fig. 1 periods of distinctly larger standard deviation of the beam position readings can be seen. These increases in orbit motion are particularly strong on EBPMs in regions of the orbit with high dispersion, so a connection with the RF cavities had been suspected.

In fact, these turn out to be due to sudden changes in the RF voltage in one of our cavities, which are yet to be understood. Close investigation of the records from EBPMs, XBPM and cavity voltages (Fig. 2) shows step changes by nearly 2% of the RF cavity 2 voltage, which are then followed by synchrotron oscillations visible on both EBPMs and XBPMs.

At the same time, these disturbances illustrate that a sim-

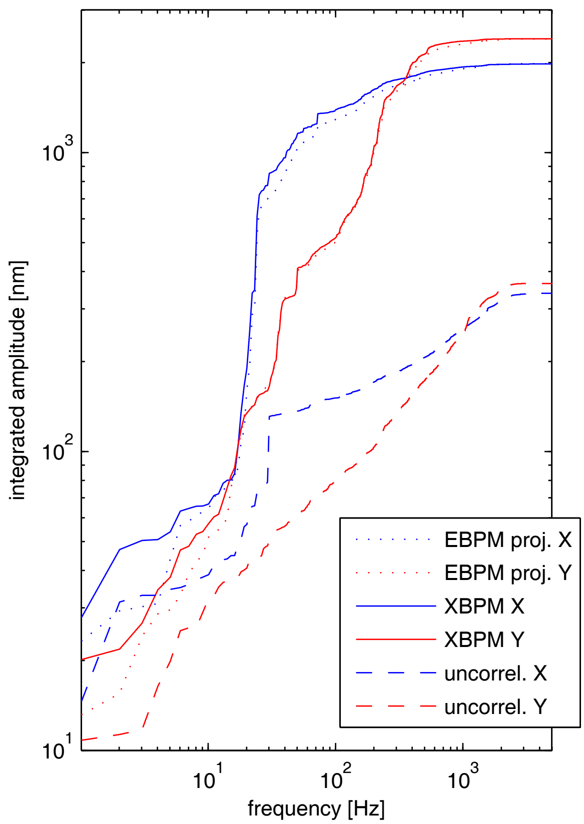

Figure 3: Integrated motion amplitudes of projected EBPM and XBPM positions (at the location of the XBPM), and uncorrelated components.

ple geometrical projection of the upstream and downstream EBPMs (separated by 5.75 m) around an undulator agrees well with the X-ray beam position at the corresponding XBPM (12.25 m downstream of the undulator). It should be noted, that the projected EBPM trace had to be delayed by 2 samples to align with the XBPM recording (here from a Libera Photon). This delay has been found to be due to the ADC used which included over-sampling followed by a filter with a relatively long group delay.

Correlation of EBPM and XBPM Readings

The strong correlation between the projected EBPM and the actual XBPM readings could already be seen in Fig. 2. When the correlations is calculated over a larger number of samples (10072 or 1 s of readings) it is about 95% in both axes. This has been further investigated using a singular value decomposition to separate the correlated and uncorrelated components. The results in Fig. 3 compares the integrated motion amplitude of the projected EBPM and the XBPM reading to the uncorrelated component between the two.

It can be seen that the uncorrelated component, which carries the random error from all three instruments involved, is almost one order of magnitude down for most of the frequencies. Only at frequencies below 10 Hz is the uncorrelated component closer to the actual amplitude, but then it is only a few nm up to these frequencies.

The spectral shape of the uncorrelated component carries one interesting point: While the Y component resembles white noise up to the low pass filter in the EBPMs, the X component exhibits one bump at about 30 Hz, which is present in the XBPM but not the projected EBPM reading. Further investigation is required to clarify where this originates from, however, this line adds only 50 nm to the integrated amplitude.

CONCLUSION

We have presented the capabilities of extensions to our Fast Acquisition network. These enable us to record XBPM positions, RF cavity voltages and other analogue inputs from sensors synchronously together with the beam orbit data from all EBPMs. The ability to keep a record of this data for several days and readily access it allows us to investigate the origins of rare orbit disturbances and assess their impact on the stability of the X-ray beams delivered to beamlines at the same time.

Simultaneous position records of the electron beam through an undulator and the produced X-ray beam show that the EBPMs capture all fast motion appropriately. This shows convincingly that integrating XBPMs with a slow position feedback loop is sufficient and little extra information would be added by integrating them fully in the fast feedback.

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