ORBIT FEEDBACK AND BEAM STABILITY AT THE AUSTRALIAN SYNCHROTRON

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Abstract

The Australian Synchrotron (AS) is a 3rd generation light source which has been in operation since 2006. Measurement of the storage ring's beam position is provided by 98 beam position monitors, and corrections can be applied using 42 horizontal and 56 vertical slow corrector magnets, and 42 horizontal and 42 vertical fast corrector magnets.

This paper/poster provides a background describing the feedback strategies adopted at the AS leading to the current integrated orbit feedback system together with a description of the beam position analyse techniques currently in use. It will also high-light some of the issues encountered with the system and how they were overcome.

The paper also describes planned improvements including the enhanced orbit diagnostics functionality we are intending to introduce in the next 12 months.

SLOW ORBIT FEEDBACK

From the start of operation to 2017, the feedback system employed at the AS was a Slow Orbit Feedback (SOFB) system. This was a MatLab program that communicated with the Libera Electron beam position monitors and the slow horizontal and vertical corrector power supply controllers using EPICS Channel Access. This operated with a cycle period of 4 seconds. The process is outlined below.

The horizontal and vertical response matrix for the storage ring are derived from the Storage Ring model. These are a 42x98 horizontal response matrix and a 98x56 vertical response matrix; note feedback is essentially independent for the horizontal and vertical planes.

These matrices were read by the SOFB program which used Singular Value Decomposition (SVD) to calculate the inverse response matrices. On each cycle, the SOFB would read the beam position and calculate the deviations from the reference orbit. The required corrections were then calculated by multiplying the inverse response matrix by the deviation vector. Finally the correctors' current setpoints were incremented/decremented by the calculated correction.

FAST ORBIT FEEDBACK

In 2010, we initiated a project to develop an FPGA based Fast Orbit Feedback (FOFB) system that became operational at the start of 2017. It has a bandwidth of up to 300 Hz, with the aim to damp the RMS transverse beam position motion to less than 10% of one sigma of the transverse beamsize, up to a frequency of 100 Hz.

The FOFB system comprises: 98 Libera BPM units, the central FPGA processor, fast corrector power supply controllers and coils, a number of EPICS support modules, and GUI control and monitoring screens. The system is also supported by diagnostic tools to provide a spectrum analysis of the beam positions – see below.

The BPMs were initially Libera Electron BPM units purchased in 2006. However, by the start of 2018, we upgraded to the Libera Brilliance+ units. From an FOFB point of view, this upgrade was quite straight forward. The main issue was a slight change to the message format (two fields swapped) and setting the group size to 99 to accommodate the non-existent unit 0 (our units are identified 1 to 98).

The FOFB FPGA is a Xilinx Vertix 6, it receives the Fast Acquisition group data directly from the Libera BPMs at a rate of approximately 10 kHz. The data is transferred in a UDP packet that contains the x and y beam position together with the frame counter, identity and status information for each BPM. The FPGA calculates the orbit deviation from the reference orbit and multiplies this by the inverse response matrix to form a set of 42 correction values in each plane. These corrections are then subject to a PI filter and three notch filters at 50, 100 and 300 Hz to remove AC mains interference. These values are then transmitted by 20 MHz optical fibre to the fast corrector power supply controllers.

There are 14 fast corrector power supply controllers, one per sector. Each controller powers 6 coils: three for the horizontal plane and three for the vertical plane. The coils were located on the poles of the existing sextupole magnets.

A single EPICS IOC provides both control and monitoring of the FPGA unit and the 14 fast corrector controllers. The power supply controllers are a Detect776 controller manufactured by a local supplier. The protocol is a simple SCPI-like ASCII protocol, and as such a regular EPICS ASYN port driver was developed to provide control and monitoring. For the FPGA interface we developed a simple UDP based binary protocol. This is characterised by:

- Standard 8 byte message header: type, sub-type, sequence number, payload length and pad.
- Fixed size messages (for a given message type).
- All numeric values are integer or fixed point.
- No unsolicited messages from the FPGA.
- Every command/request from the IOC gets a response.

The main data send to the FPGA is the reference orbit (2), the inverse response matrices (2), the P and I values and the system mode. The main data received from the FPGA is status and the running average of the applied corrector values.

The inverse response matrices are calculated from the corresponding response matrix by an EPICS aSub record that performs a SVD operation using the Eigen3 library. The response matrix is defined in a waveform record set by

the accelerator physists. The EPICS IOC also provides the means to snap-shot the current orbit, which can then be used as the reference orbit.

BPM DATA ANALYSIS

The Fast Acquisition group from data the Libera BPMs is also directed to a virtual EPICS IOC that performs BPM Data Analysis. This consists of three major parts.

Monitoring the Frequency Spectrum

This is a high frequency and low frequency Fast Fourier Transform (FFT) on the horizontal and vertical positions of each BPM.

The high frequency FFT is applied to 8192 samples at 10 kHz which provides a spectra from 0 to 5 kHz, at a resolution of 1.22 Hz.

The low frequency FFT is applied to 8192 samples at 625 Hz which provides spectra from 0 to 312 Hz, at a resolution of 0.076 Hz. The 625 Hz data is generated by decimating the 10 kHz data using a low pass bi-quad filter [1].

Each spectra is updated once per second. An example of a slow horizontal FFT spectra is shown in Fig.1.
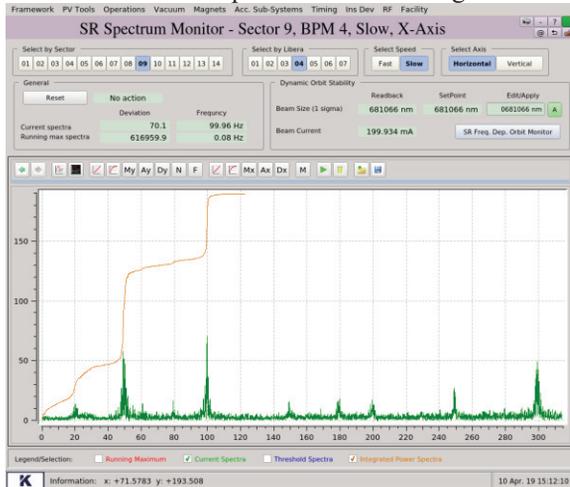
Figure 1: Example of BPM position spectra.

Dynamic Orbit Stability

For the low frequency spectra, an integrated amplitude up to 110 Hz is be calculated for each BPM in both x and y. The integrated powers are normalised by dividing by the x or y sigma beamsize at the BPM location. This results in two vectors for x and y showing the integrated beam motion normalised to the local beamsize.

Orbit Pattern at a Specified Frequency

The system allows the user to nominate a centre frequency (f_0), frequency half span and the number of frequency points (N, typically 10). See Fig.2. Using these parameters, a frequency spectrum is calculated using the correlation method for each of the N frequencies, and these are summed to create a single 1 x 98 vector of complex values for the x plane and the y plane.
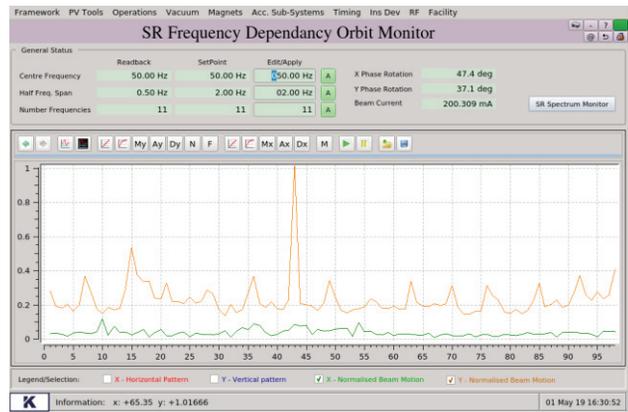
Figure 2: Example of BPM position spectra.

The complex elements of each vector are then rotated by an angle which is chosen to maximise the RMS of the real component of the rotated vector. This is the peak closed orbit distortion created by the perturbation at frequency f_0.

INTEGRATED ORBIT FEEDBACK

In 2017, we introduced integrated orbit feedback. This is a C++ program that replaces the previous MatLab Slow Orbit Feedback, but is also cognisant of the Fast Orbit Feedback system.

The main user interface is shown in Fig.3.

Figure 3: Main Orbit Feedback Control Screen.

This program uses the Eigan3 library and SVD to calculate inverse response matrices from the response matrices. The calculation of the inverse response matrices also uses the Tikhonov regularization method, and does not use truncated singular values [2-3]. The α parameter is user selectable, typically set to 2000 A/nm (horizontal) and 45000 A/nm (vertical).

As well as the slow horizontal and vertical response matrices, the program also uses a 98x1 Radio Frequency (RF) response matrix and adjust the Storage Ring master oscillator frequency in addition to the slow horizontal and slow vertical correctors.

The orbit feedback program has two modes of operation.

Standalone Operations

When FOFB is not running, the orbit feedback typically runs every second – this period is selectable by the operator in the range 0.1 to 120 seconds. The mode of operation is essentially the same as the previously used MatLab SOFB program.

The orbit error is simply the measured orbit less the reference orbit:

$$x_{err} = x - x_{ref}$$
$$y_{err} = y - y_{ref}$$

Where x_{err} and y_{err} are the orbit errors, x_{ref} and y_{ref} are the horizontal and vertical reference obits.

Coupled Operations

When the FOFB is running, the orbit feedback typically runs every 4 seconds – this period is also selectable by the operator in the range 0.1 to 120 seconds.

However for this mode of operation, the orbit error calculation takes into account the mean of the fact corrections being applied by the FOFB system. This FOFB calculates the running average of the corrections it applies and this is made available, via an EPICS PV, at a rate of 10 Hz.

In this case, the orbit error is:

$$x_{err} = x - x_{ref} - Rx_{fast} * HFC_{mean}$$
$$y_{err} = y - y_{ref} - Ry_{fast} * VFC_{mean}$$

Where Rx_{fast} and Ry_{fast} are the response matrices as used by FOFB, and HFC_{mean} and VFC_{mean} are the horizontal and vertical fast correction running averages.

ISSUES

There are a number of issues with the current system.

The first relates to the FPGA: the technology is at end of life, and more significantly the fabric is essentially full; we have very little spare capacity for any improvements and/or enhancements.

The second relates to the Orbit Feedback program. It does not operate in a perfect world; sometimes correctors and/or beam position monitors go offline, or report invalid data. Striking the balance between continued operation verses halting the system is an on-going challenge.

ENHANCED ORBIT DIAGNOSTICS

The next major planned improvement to orbit feedback at the Australian Synchrotron is the introduction of Enhanced Orbit feedback.

This will re-implement the FOFB firmware on new hardware platform, namely a Zynq chip hosted on a Trenz module. This will greatly increase the available of fabric and allow the introduction of new functionality. This includes the injection of random and/or sinusoidal noise, together with the making the applied corrections applied to the fast correctors available at 10 kHz for real time analysis.

REFERENCES

[1] http://www.earlevel.com/main/2013/10/13/bi-quad-calculator-v2/

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[3] http://math.stackexchange.com/questions/1084677/tikhonov-regularization-vs-truncated-svd