

PRECISE BEAM ORBIT RESPONSE MEASUREMENT WITH AC EXCITATION*

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Abstract

Fast correctors at NSLS-II storage ring have broad frequency response (~1kHz bandwidth). Together with high accurate BPM 10kHz data, they makes the broadband fast orbit feedback realistic. Fast orbit feedback (FOFB) calculation is taking place in the cell controller where BPM 10kHz data is transferred from local BPMs in the cell and shared with other cells around the ring. With integrated numerical controlled oscillator (NCO) inside the cell controller FPGA, beam orbit response can be precisely measured while driving the electron beam with AC current. Compared to the normal DC orbit response measurement, this method eliminates the measurement errors due to orbit drift. Accurately measured orbit response matrix can be used to characterize the machine lattice. Fast corrector frequency responses have been measured using the same method, by scanning the excitation frequency. This information can be used to optimize the fast orbit feedback control loop.

INTRODUCTION

NSLS2 is an ultra-low emittance light source recently constructed and open for user operation. Fast orbit feedback system (FOFB) is critical to maintenance the beam orbit stability. NSLS2 FOFB system has two-tier structure for fast data communication and feedback calculation. Each cell there is a cell controller (CC) which collects the local BPMs 10kHz data within the cell. The CC also calculates the fast corrector set points and sends them to the power supplies in the cell. Each CC delivers the local BPM data to neighbor cells. This two-tier structure makes sure BPM 10kHz data is available for around the ring within 14us [1].

Typical FOFB signal processing is going through the U^T , W^{-1} , V matrix calculation loop. Q is the programmable controller for individual eigen modes. CC receives data from BPMs and set the fast corrector power supplies (PS) through serial device interface (SDI). BPMs 10kHz data, eigen-space data and fast corrector setting values can be saved to the on-board DDR memory. EPICS IOCs are available to acquire the on-demand data for BPM/PS as well. With this configuration, synchronized data can be compared at different locations in the FOFB loop to check the data transfer and signal processing latency.

Besides the FOFB processing loop, the CC includes a programmable numerical controlled oscillator (NCO) is available to drive the fast corrector with sine wave. NCO clock is 10 kHz to generate the signal up to 1 kHz. FOFB feedback loop can be opened while NCO signal is

injected. The signal can be injected at eigen mode controller Q or to the PS SDI link directly, see Fig. 1. Instead of NCO, arbitrary setting values can also be used to drive the PS with current range from +/-1.25A.

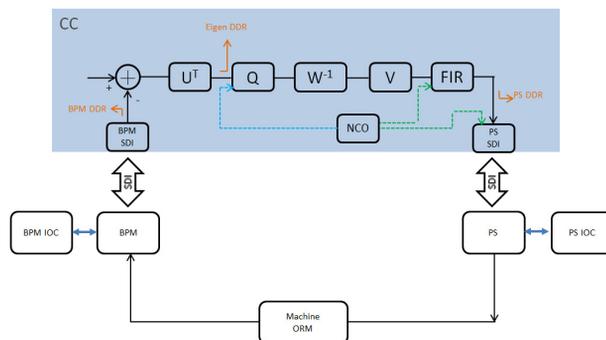


Figure 1: Schematic of NSLS-II BPM, CC and PS. FOFB signal processing is implemented in the CC where a NCO is available to drive the fast corrector. Similar NCO function can also be generated inside the BPM electronics.

Sine wave signals can also be generated inside the BPM electronics. Similar to the CC NCO excitation, SDI received BPM excitation signal can be injected to the Q controller and drive the fast corrector power supplies.

STEP RESPONSE

After the timing triggers are setup correctly, CC DDR memory data and IOC 10kHz data from BPM and PS can be synchronizely acquired on the same external trigger. Fig. 2 is an example when one of the fast corrector was switched to be driven with offset value from the CC. The offset was stepped up at sample #0 which creates a current change of 0.24A. As can be seen in the PS IOC waveform data, the power supply received the current setup change within 3 FA samples. The PS has current ramp rate of 4mA/100us step, that's the reason it takes ~60 FA samples to reach the 0.24A step. Later during the CW excitation test, the PS ramp rate was increased to 16mA/100us step so that sufficient excitation is possible at high frequency sine wave drive. The PS itself responds almost instantly with little latency observed between the received the setting values (DAC) and DCCT readback.

BPM 10kHz data at different locations of the ring has been saved. Bottom plot in the figure shows one of the BPM's reponse to the step current change of 0.24A. At this particular location, beam orbit changed by 5um and there is very small latency from the PS driving waveform to the beam position responding. Also the BPM IOC data and CC control received 10kHz data sit right on top of

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each other. This verifies the data transfer speed with the two-tier SDI link is well below one FA tick (100us).

During studies, the PS current ramp rate is able to set high so that FOFB open and close loop step responses can be measured. Compliment to the transfer function measurement describe in the following section, step response will be helpful to optimize FOFB controller parameters.

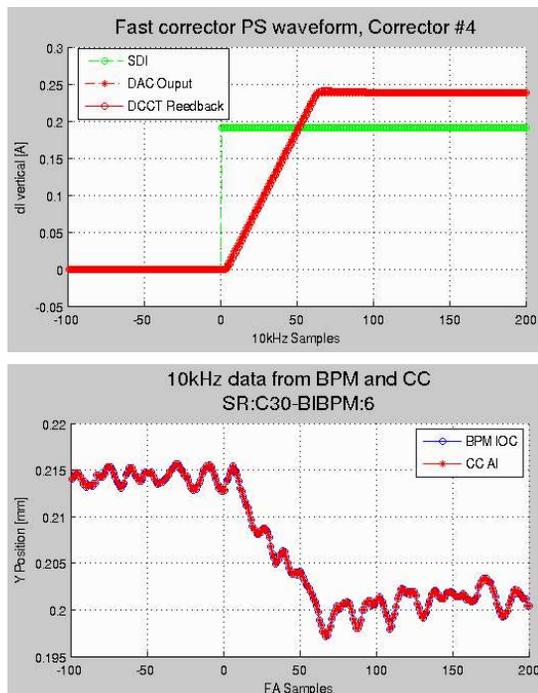


Figure 2: Fast corrector to BPM setup response. (Upper) green - Fast corrector setting value from CC NCO; red – power supply received data and readback current. (Lower) BPM 10kHz data from IOC and CC.

CW EXCITATION RESPONSE

Fast corrector to BPM orbit response was measured with sinewave excitation at different frequency. Synchronized waveform data of PS and BPM 10kHz was acquired. Figure 3 shows the C30 6 BPMs response while one of the fast corrector (C30 fast corrector #1) was driving the beam at 20Hz. Depending on the phase advances from corrector to BPM and beta-function, the BPM orbit oscillates either in-phase or out-phase with the driving current waveform. Precise beam orbit response was calculated from the frequency domain power spectrum density (PSD). FFT phase at the excitation frequency was used to get the AC orbit response around the ring, similar to the method described in [2]. Shown in the Fig. 4 is the BPM PSD spectrum calculated from the 10-seconds of 10kHz data while beam was excited with the corrector. RMS motion due to excitation was calculated from the integrated PSD spectrum around the driving frequency. With 180 BPMs around the ring, AC orbit response can be measured. The corrector was driven in both X/Y planes.

To check the resolution of the orbit response measured with AC excitation, multiple data sets were captured with same fast corrector driving. Xrms motion was measured to be $38.68\mu\text{m} \pm 0.013\mu\text{m}$ and Yrms motion was $37.95\mu\text{m} \pm 0.008\mu\text{m}$. This gives signal noise ratio $\sim 2e-4$. Compared to the typical DC orbit response measurement method, there is about 10-100 times improvement. Increasing the drive current and improving the signal processing may further improve the measurement accuracy. By driving the beam from each individual corrector, precise AC orbit response matrix can be measured which can be used for lattice characterization/correction. This is an ongoing work and future progress will be presented.

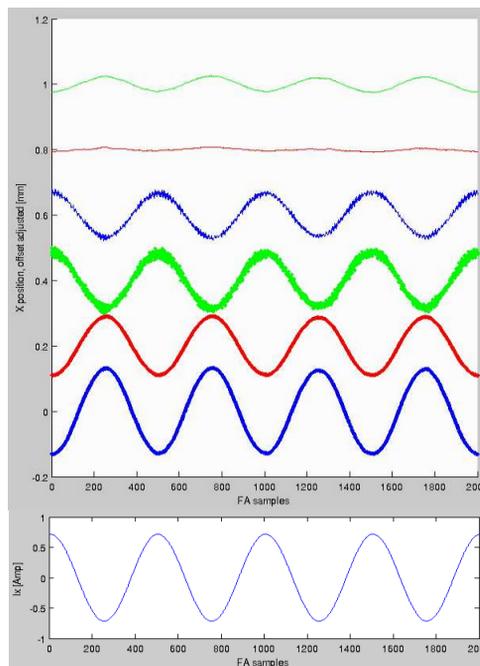


Figure 3: Time domain beam orbit response when one corrector was exciting the beam at 20Hz. C30 six BPMs X position FA data is plotted together with the fast corrector current waveform in the bottom.

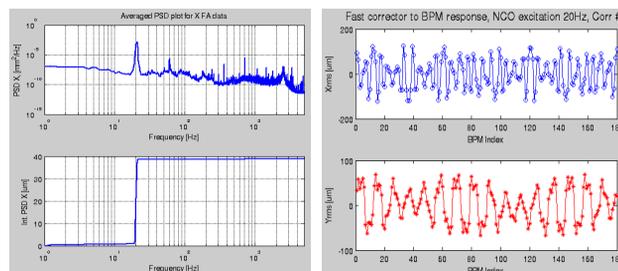


Figure 4: (Left) PSD spectrum while beam was excited by one fast corrector with driving frequency of 20Hz. (Right) RMS motion around the excitation frequency was calculated from the PSD spectrum at BPMs around the ring.

From the AC orbit response near some particular frequency, localized noise source can be located by inverse matrix calculation. This kind of tool is useful to

identify a bad power supply or other localized noise sources.

Fast corrector transfer function can be measured by changing the driving frequency. Fig. 5 is the amplitude and phase response for one corrector with driving frequency up to 1kHz. Amplitude response can be precisely determined using the PSD spectrum. Phase response however is not easy to be precisely measured. Sine fitting or I-Q detection methods have been tried to measure the phase advance from corrector to BPM. It has been noticed that the phase response is noise especially for high frequency driving ($>300\text{Hz}$). This may be due to the NCO clock is 10kHz and the generated sine signal may see the phase jitter.

Measured amplitude response shows that the fast corrector has more than 800Hz bandwidth (-3dB). This includes the power supplies, fast corrector magnet, vacuum chamber, BPM electronics and SDI data communication to the CC. The method can be applied to measure the amplitude response for each individual corrector.

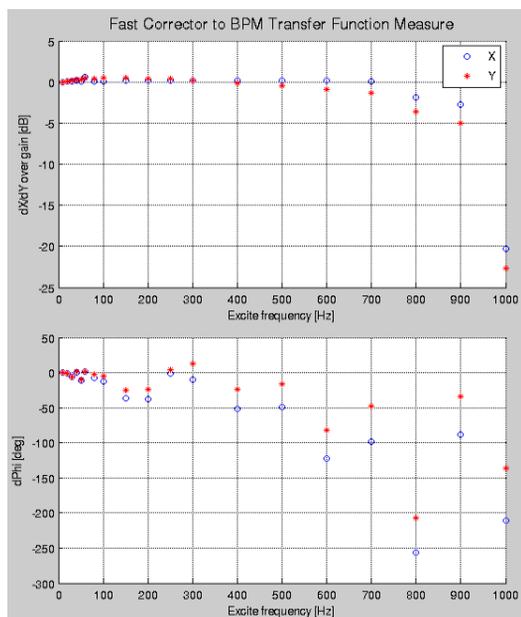


Figure 5: Amplitude and phase response for C01 fast corrector #1. Amplitude response was calculated from PSD spectrum and phase response from I-Q detection method.

NETWORK ANALYZER TRANSFER FUNCTION MEASUREMENT

As can be seen earlier, phase response for the fast corrector is not easy to be precisely measured in digital way. NSLS-II sweeping tune measurement system [3] has a broadband electronics to detect the beam motions from 10Hz to more than 10MHz . The tune measurement network analyzer was configured to measure the fast corrector transfer function near the area. Compared to the digital method which measures the fast corrector to digital BPM response, the tune system position response may be faster due the broadband analog processing. Considering the beta-function and phase advance to the tune system

BPM, several nearby fast correctors were measured. Fig. 6 is the results from C16 fast corrector #1. Due to larger beta-function in horizontal plane, the amplitude/phase response is smoother. Bandwidth of the fast corrector was measured to be around $2\text{kHz}/800\text{Hz}$ for horizontal/vertical plane. There was $\sim 12\text{dB}$ difference in the amplitude response which agrees with the model. Measured phase response curves are more reliable than the CC NCO excitation method.

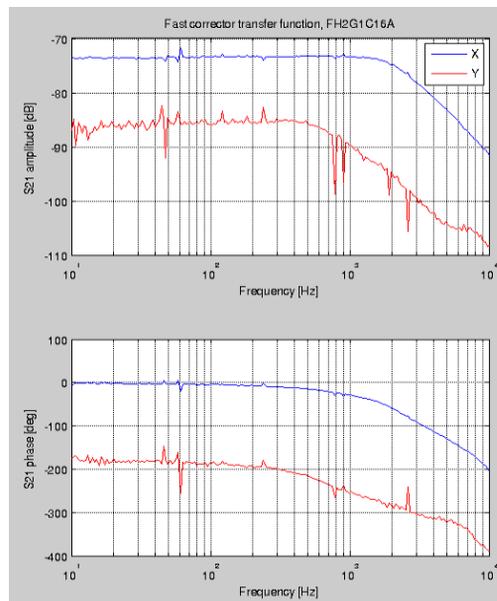


Figure 6: Amplitude and phase transfer function measured with tune system network analyzer.

SUMMARY

NSLS-II fast corrector response has been measured with integrated NCO in CC (or BPM) FPGA. Current step change was applied from CC to check the response from fast corrector to BPM. Sine wave excitation at $\sim 20\text{Hz}$ can precisely measure the AC orbit response. Frequency response of fast correctors can be measured with excitation frequency sweep up to 1kHz . Fast corrector bandwidth has been measured to be $\sim 1\text{kHz}/800\text{Hz}$ for X/Y plane. Similar measurement using network analyzer confirms the broadband response of NSLS-II fast correctors. Phase response was able to be measured with the network analyzer.

REFERENCES

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