NSLS-II FILLING PATTERN MEASUREMENT*

Yong Hu#, Leo Bob Dalesio, Kiman Ha, Igor Pinayev, BNL, NSLS-II, NY 11973, U.S.A.

Abstract

Multi-bunch injection will be deployed at NSLS-II. High bandwidth diagnostic beam monitors with high-speed digitizers are used to measure bunch-by-bunch charge variation. The requirements of filling pattern measurement and layout of beam monitors are described. The evaluation results of commercial fast digitizer Agilent Acqiris and high bandwidth detector Bergoz FCT are presented.

INTRODUCTION

NSLS-II is designed to deliver photons with average spectral brightness in the 2 keV to 10 keV energy range exceeding 10^{21} ph/mm^2/mrad^2/s/0.1%BW [1]. This cutting-edge performance requires the storage ring to support a very high-current electron beam (500 mA) with sub-nm-rad horizontal emittance (~0.5 nm-rad) and diffraction-limited vertical emittance at ~8 pm-rad. To achieve this high-current (high intensity) requirement, NSLS-II will utilize a full-energy Injector which consists of a 200 MeV Linac, Linac to booster transport line (LtB), 3 GeV booster (BSR), booster to storage ring transport line (BtS). The Injector will operate in top-off mode and must supply ~ 7.3nC of charge once per minute. For single-bunch injection mode and a moderate repetition rate of a few Hz, replenishing this amount of charge would take a few seconds, occupying a significant fraction of the overall beam time. Therefore, multi-bunch injection (80~150 bunches) has been adopted, leading to minimal disturbance for user experiments.

In order to minimize intensity-correlated orbit oscillations due to uneven bunch patterns [2], we need to measure the filling pattern (also named bunch pattern or bunch structure) and then find a way to minimize bunch-to-bunch variation of current (or charge) if the variation exceeds 20%.

NSLS-II FILLING PATTERN

NSLS-II storage ring contains 1,320 RF buckets at 500 MHz. To alleviate the problems of ion trapping in the stored electron beam, approximately one-fifth of the buckets must be left empty. NSLS-II Injector will support uniform filling pattern in the storage ring. Two basic patterns were considered (two upper plots in Figure 1): uniform fill with the ion-clearing gap of about 20%; multiple uniform bunch trains with mini-gaps between them.

In addition to the nominal uniform fill, consideration is being given to specialized and complex bunch patterns: a single high-current bunch (named "camshaft" bunch, two lower plots in Figure 1) located in the middle of the ion-clearing gap; multiple camshaft bunches whose repetition rate is matched to the pulse format of modern pump lasers.

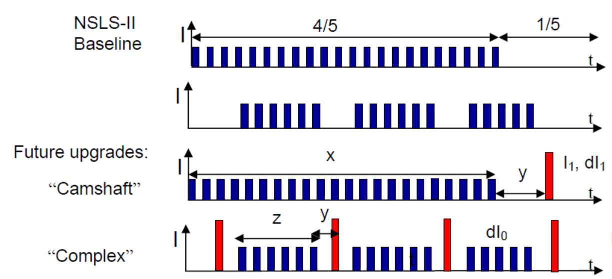

Figure 1: NSLS-II Filling Pattern [1]

One requirement [3] for NSLS-II filling pattern is that bunch-to-bunch charge variation should be less than 20%.

Filling pattern involves timing, diagnostics, injection / extraction, controls, etc. It will take efforts to implement arbitrary patterns for multi-bunch injection via filling pattern feedback. This paper focuses on filling pattern measurements: how to measure bunch structure and make this information available in EPICS [4]-based control system.

BEAM MONITORS

NSLS-II filling pattern measurement system provides relative bunch-to-bunch charge distribution along with the whole machine. This measurement requires combination of beam monitors (WCM, FCT, etc.), data acquisition (DAQ) and controls (fast digitizer, EPICS software, etc.) and Event Timing system [5]. Figure 2 shows the system architecture.

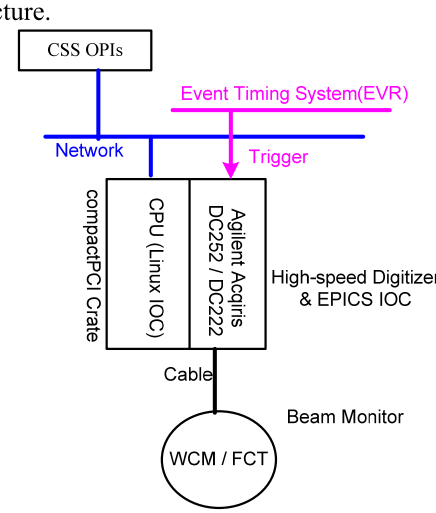

Figure 2: Overview of Filling Pattern Measurement

Since NSLS-II RF (Radio Frequency) is ~500 MHz, the bandwidth of beam monitors should be at least 500 MHz in order to distinguish individual bunch from the bunch-train (multi-bunch, 80~150 bunches). There will be 3 types of beam monitors distributed around the machine and all of them have very high bandwidth (>1 GHz): 5

* Work performed under auspices of the U.S. Department of Energy
#yhu@bnl.gov

wall current monitors (WCM) in Linac, 2 Bergoz FCTs (fast current transformer) in LtB, 1 FCT in BSR, 2 FCTs in BtS and 1 BPM (beam position monitor) button in Storage Ring.

Wall Current Monitor

The Linac diagnostics consist of five resistive WCMs to observe the longitudinal profile/bunch shape of the electron bunches after the gun, pre-buncher, and buncher. The WCM is formed by equally spaced broadband ceramic resistors mounted on a flexible circuit board, wrapped around a short ceramic break. The WCM has very high analog bandwidth at ~3GHz.

Fast Current Transformer

Commercial off-the-shelf Bergoz FCT, usually directly mounted on the beam chamber with a ceramic break and RF shielding, will provide electrical signal proportional to the charge of individual bunches. Its specification claims 1.75 GHz bandwidth with a 200 ps rise time. But our real measurements show only ~1 GHz BW which is still sufficient to get 500 MHz bunch-to-bunch information.

Beam Position Monitor

All BPMs in NSLS-II will utilize high precision 4-button pickup electrodes that are diagonally incorporated into the aluminium extrusion vacuum chamber. The diameter of BPM in the storage ring is only 7mm so that this kind of BPM has wide analog bandwidth (~ 2GHz) while minimum impact on the Ring impedance. The circulating current of 500 mA in the storage ring is expected to produce -1.1dBm signal into 50 Ω load at 500 MHz on BPM button. This signal is strong enough for filling pattern measurement.

CONTROLS

High-bandwidth filling pattern monitor requires high-speed digitizer to sample its analog output signal. According to the Nyquist sampling theorem, the minimum sampling rate of the digitizer required to discriminate 500 MHz bunch-to-bunch information is 1GS/s.

Hardware

Agilent U1065A Acqiris high-speed compactPCI digitizers (DC252 and DC222, 10-bit resolution, 2 GHz bandwidth, DC252 is 2-channel, 4 GS/s per channel, DC222 is 1-ch with 8GS/s) are selected for NSLS-II filling pattern measurement. Beam monitors associated with controls hardware in each sub-accelerator are listed in Table 1.

The cable length from the beam monitors to the digitizers is more than 100 feet. To reduce signal loss and attenuation, low loss RF cable LMR900 will be used. Although NSLS-II bunch length itself is very short at ~ 15 ps (RMS), the actual output signal from filling pattern monitor is Gaussian-shape pulse with ~ 1 ns width. In this case, 4 GS/s digitizer DC252 will provide at least 4 samples per bunch which should be sufficient to calculate individual bunch charge with appropriate algorithms such as Gaussian data-fitting and integrating samples' voltages.

Table 1: Filling Pattern Monitors & DAQ Hardware

Sub-accelerator	Beam Monitor	Digitizer
Linac	6 WCMs	3 DC252
LtB	2 FCTs	1 DC252
Booster	1 FCTs	1 DC222
BtS	2 FCTs	1 DC252
Ring	1 BPM	1 DC222

Software

NSLS-II beam diagnostics control system [6] will be completely based on EPICS. For OPI (operator interface) GUIs, CSS (Control System Studio) is our preference. The preferred operating systems are RTEMS (Real-Time Executive for Multiprocessor Systems) and Linux/Debian. For cPCI-based controls, the CPU board will be standardized as GE CT11 and diskless PXE booting Linux & EPICS driver is done by Debirf (DEBian on Initial Ram Filesystem [7]).

The EPICS driver for Acqiris digitizer is originally developed at SLAC. Several improvements are made at NSLS-II, including a few bug fixes and filling pattern related data processing.

Here's the basic implementation of our filling pattern measurement: the filling pattern EPICS IOCs will provide the following data: number of bunches (max. 150), normalized filling pattern (array data like filling[150]: 0.85, 1.00, 0.96, …), maximum bunch-to-bunch variation (i.e. $\Delta Q = 5\%$), individual bunch charge calibrated against ICT or DCCT or computed from integral voltage signal. If measured $\Delta Q < 20\%$, our job is done; If $\Delta Q >= 20\%$, we need to find out what's the cause and find a way to minimize ΔQ.

Here's our procedure to compute normalized filling pattern inside EPICS IOC software:

1) Search for positive (or negative)pulse peaks with peak threshold;
2) Gaussian-fitting on 5 samples (2 samples before the peak, 2 after the peak) and then integrate(sum) them;
3) Find the max. integrating value;
4) Normalize all integrating values against the max.

BENCH TESTS

We have performed bench tests on Bergoz FCT and Acqiris digitizer.

Bench Tests on FCT

We have purchased 5 Bergoz FCTs and performed acceptance tests. We have measured FCT bandwidth using network analyzer. Figure 3 shows that one of the FCTs has ~ 1GHz BW (-3dB).

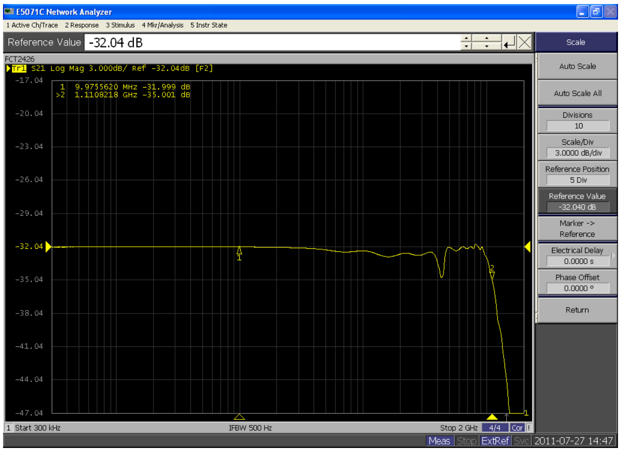

Figure 3: FCT Bandwidth Measurement

Bench Tests on Acqiris

We have completed performance evaluation on the ultra fast digitizer Acqiris DC252, including max. sampling rate at 8 GS/s by combining 2 channels to 1 channel (interleaving), effective number of bit (ENOB), etc. The input test signal is 500MHz sine wave, 0.9Vpp.

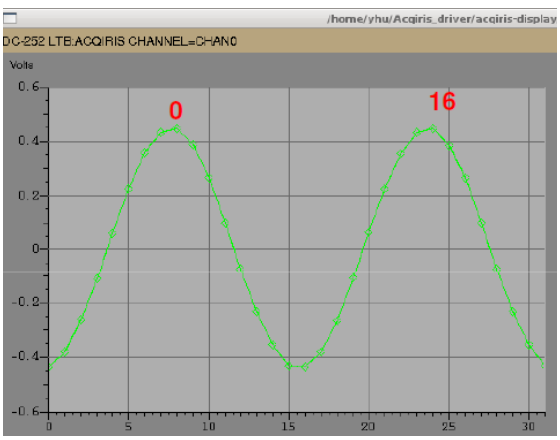

Figure 4: 8GS/s acqiris Digitizer.

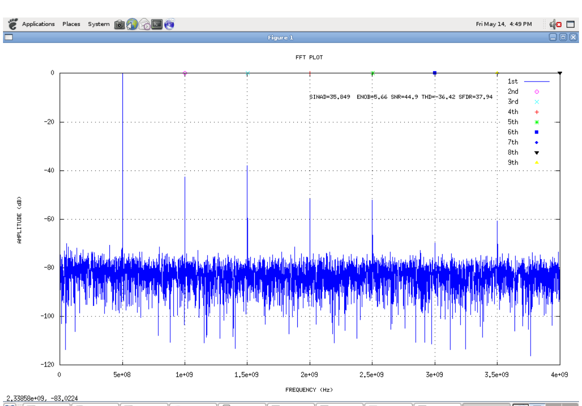

Figure 5: 7-bit ENOB after Sine-wave Data-fitting.

FILLING PATTERN SIMULATION

In order to test our algorithm software for filling pattern measurement as well as interface to Event timing system, we have setup a test stand to simulate filling pattern as shown in Figure 5.

- Timing EVG/EVR: provides 2 triggers, one is for triggering digitizer, the other for triggering pulse generator;
- pulse generator DG645: receive external trigger from EVR and then use burst mode to generate multiple pulses with 2ns width and 10MHz rate;
- FCT: input signal from DG645 and output to digitizer;
- Acqiris digitizer: triggered by EVR and acquire FCT signal;

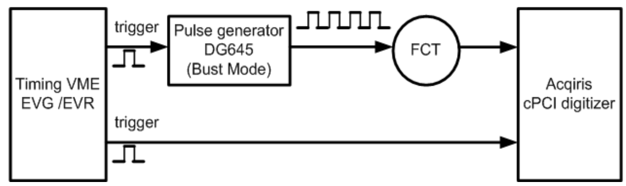

Figure 6: Filling Pattern Simulation.

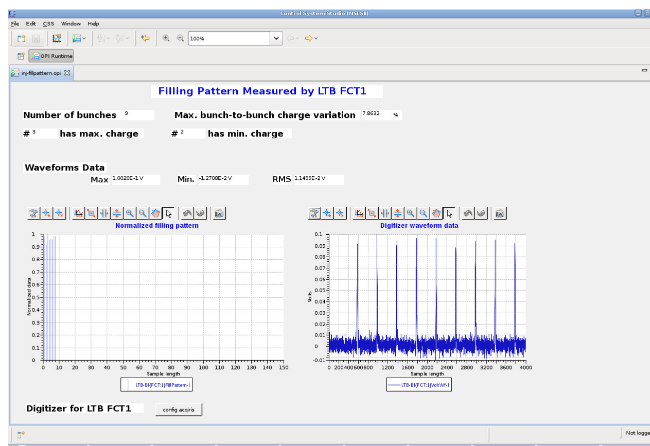

Figure 7: Filling Pattern Simulation Result.

CONCLUSIONS

Filling pattern measurement system is well understood and the controls hardware & software are well tested. We're ready for NSLS-II Injector installation and commissioning.

REFERENCES

[1] NSLS-II Preliminary Design Report", http://www.bnl.gov/nsls2/project/PDR.
[2] [sls2] http://slsbd.psi.ch/pub/slsnotes/sls1697.
[3] Yong Hu, et al., "Diagnostics Control Requirements and applications at NSLS-II", Proceedings of ICALEPCS 2011, Grenoble, France.
[4] http://www.aps.anl.gov/epics/.
[5] http://www.mrf.fi/.
[6] Yong Hu, et al., "NSLS-II Beam Diagnostics Control System", Proceedings of ICALEPCS 2011, Grenoble, France.
[7] http://cmrg.fifthhorseman.net/wiki/debirf.