Transparent Lattice Characterization with Gated Turn-by-Turn Data of Diagnostic Bunch-Train

Yongjun Li

Brookhaven National Laboratory, NSLS-II

yli@bnl.gov, mpyliyj@gmail.com

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Outline

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   - Main parameters
   - Linear optics and magnets

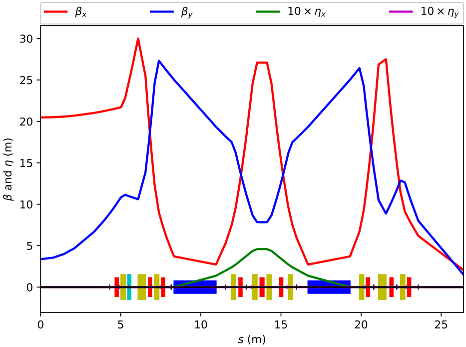
2. Transparent lattice characterization
   - Motivation: why develop this technique?
   - Selective excitation and gated TbT data acquisition
   - Significance: Transparency to operation
   - Summary of transparent lattice characterization

Main parameters

Main parameters of the NSLS-II ring

Parameters	**Values**
Energy	3.0 GeV
Circumference	792 m
Lattice type	DBA
Periodicity	15 mirror symmetry super-cell
Horizontal emittance	2.1/1.0 nm with damping wigglers
Chromaticity	-101/-40 (natural), +2/+2 (corrected)
Tune	33.22/16.26
Harmonic number	1320

Linear optics and magnets

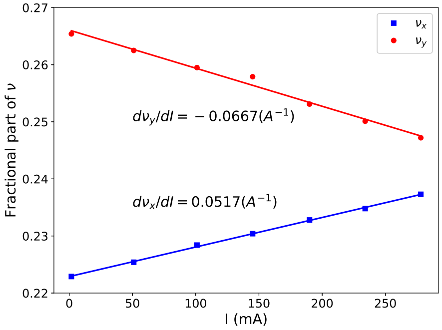


- # of quadrupoles: 300 powered independently
- # of sextupoles: 270 powered by 54 PS
- # of skews: 15/15 dispersive/non-dispersive
- # of slow/fast correctors: 180/90
- # of BPMs: 180 + user BPMs

Motivation of transparent lattice characterization

- Lattice drifting during accumulation
  - Tune moving $\rightarrow$ β-beat increasing
  - Injection efficiency drops
- Current methods are intrusive to operation, and time-consuming
  - LOCO
  - Turn-by-turn data with continuous and small excitation (Diamond)
- Limitation of the NSLS-II's diagnostics
  - Long pulse of pinger, no flat top
  - No bunch-by-bunch capability
- Localization of impedance

Optics drifting with beam current



Tunes vs. beam current

- Tune correction is easy, but β-beat and phase-beat not
- Blind tune correction $\rightarrow$ large β-beat $\rightarrow$ reduce brightness, dynamic aperture and energy acceptance
- where is the impedance?

NSLS-II Beam diagnostics tools

BPM functionalities

- Slow acquisition (SA) 10Hz - orbit monitoring & correction
- Fast acquisition (FA) 10kHz - fast orbit feedback
- Turn-by-turn mode (TbT) of a short bunch train - optics study
- Gated TbT for selected bunch-train

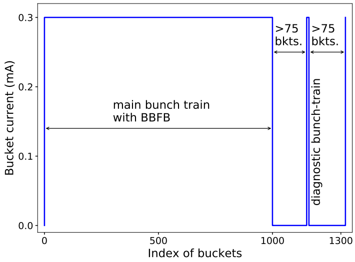
Pulsed excitation

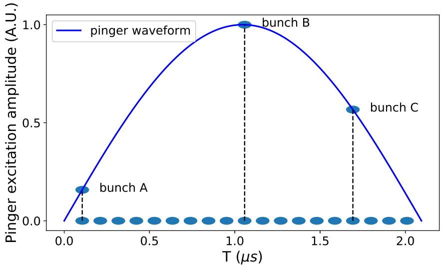
- Pinger (both H and V)
- Bunch-by-bunch feedback (selective bunch)

Cameras

- X-ray pin-holes
- Visible SR

Filling pattern and pinger pulse waveform





Filling pattern: main bunch train (MBT) + diagnostic bunch train (DBT)

Pinger's pulse too long to excite a long bunch train coherently

Transparent for operation: two channels

Two separated Channels without interference in-between

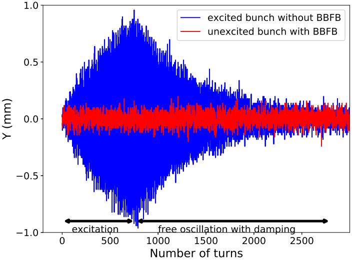
Channel 1: operation

- BPMs' signals provide SA and FA orbit data for MBT only
- BBFB is functional in suppressing coupled bunch instabilities

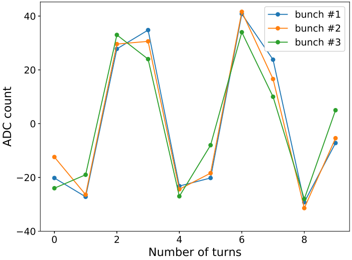
Channel 2: diagnostics

- Gated BPM TbT signals is available for DBT on-demand
- BBFB can excite DBT and be switched-off on-demand
- Excitation and data acquisition is synchronized for 180 BPMs

Selective excitation on diagnostic bunch-train

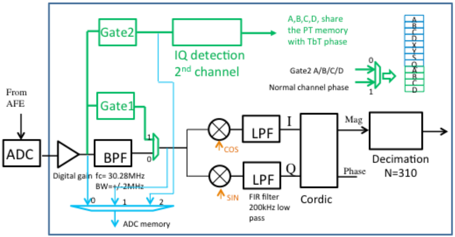


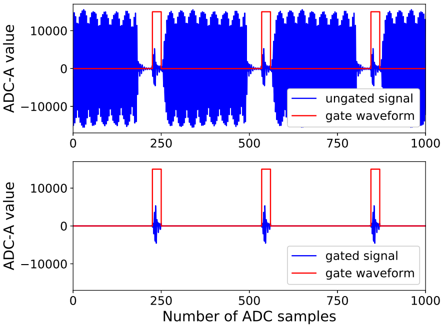
Excited DBT vs. suppressed MBT



Coherent excitation of DBT bunches

Gated TbT data acquisition





FPGA to implement the gated functionality (W. Cheng and K. Ha)

Gate waveform to filter the DBT signal. There is a trade-off between accuracy and transparency.

Orthogonal decomposition of TbT data

Betatron

$$x_i = A\sqrt{\beta_x(s)}\cos[2\pi\nu_x \cdot i + \psi_x(s)]$$

Decomposition

$$C = \sum_{i=0}^{N-1} x_i \cos(2\pi\nu_x \cdot i), \quad S = \sum_{i=0}^{N-1} x_i \sin(2\pi\nu_x \cdot i)$$

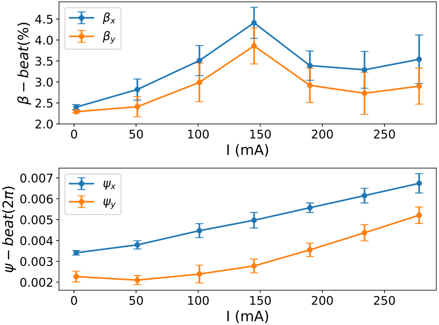
Amplitude and phase

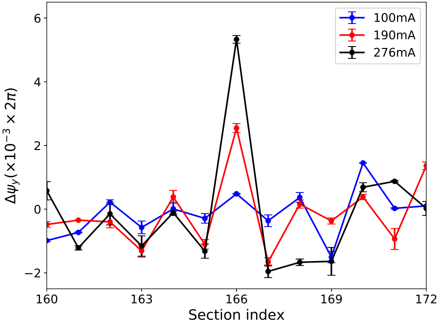
$$A\sqrt{\beta_x} = \frac{2\sqrt{C^2+S^2}}{N}, \; \psi_x = -\tan^{-1}\left(\frac{S}{C}\right)$$

Errors

$$\sigma_{A\sqrt{\beta_x}} = \sqrt{\frac{2}{N}}\sigma, \; \sigma_{\psi_x} = \frac{1}{A\sqrt{\beta_x}}\sqrt{\frac{2}{N}}\sigma.$$

β-beat and ψ-beat with beam current

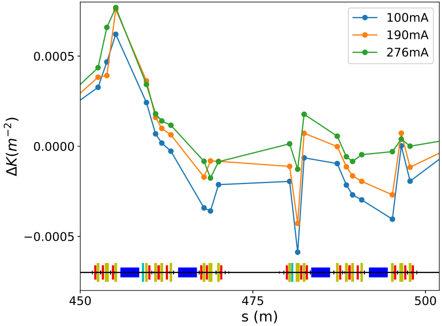


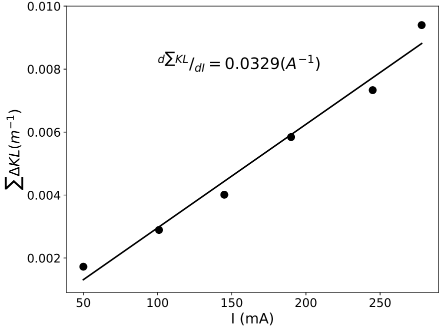


β, ψ-beat variation with beam current

Gradually increased local vertical phase advance at cell28's damping wiggler

β-beat and ψ-beat with beam current



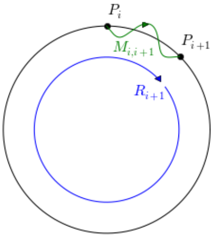


Distrubted quadrupole corrections

Integrated quadrupole corrections

$$\begin{pmatrix} w_\beta \Delta\beta \\ w_\psi \Delta\psi \end{pmatrix} = \begin{pmatrix} w_\beta \mathbf{M}_\beta \\ w_\psi \mathbf{M}_\psi \end{pmatrix} \begin{pmatrix} \Delta K_1 \\ \Delta K_2 \\ \vdots \\ \Delta K_q \end{pmatrix}.$$

Linear coupling via TbT data



One-turn-map

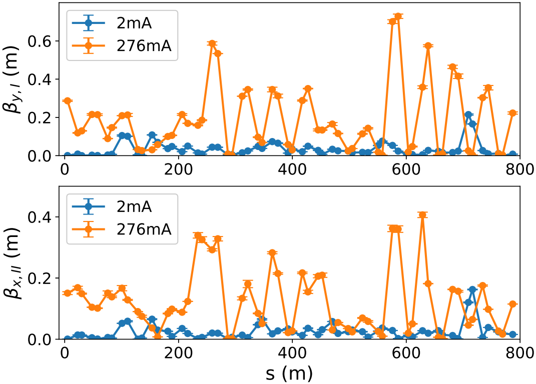
$$e^{\mathbf{SF}} = \mathbf{R}$$

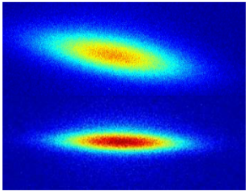
Linear Lie generator

$$\begin{aligned} f_2 &= -\frac{1}{2}\vec{v}^T\mathbf{F}\vec{v} \\ &= f_2^{(0)} + f_2^{(c)} \\ &= C_{2000}x^2 + C_{1100}xp_x + C_{0200}p_x^2 + \\ &\quad C_{0020}y^2 + C_{0011}yp_y + C_{0002}p_y^2 + \\ &\quad C_{1010}xy + C_{1001}xp_y + C_{0110}p_xy + C_{0101}p_xp_y \end{aligned}$$

C_{klmn} is not coupling driving terms (CDT). After using resonance basis to substitute x, p_x, y, p_y, we can obtain CDTs h_{klmn}.

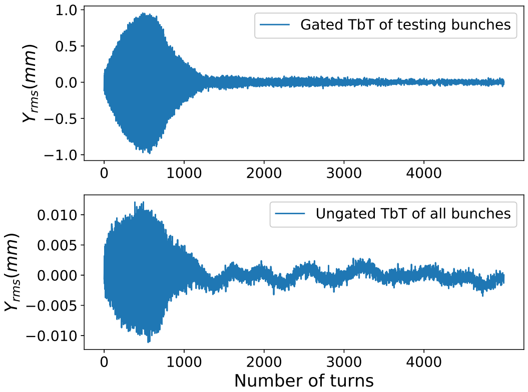
Coupling β-functions (Ripken-Maise parameterization)





It is possible to create some “coupling bump” to tradeoff between beam lifetime and brightness.

Transparency



- Max. DBT amplitude less than 1 mm, last for a few ms
- On-demand mode
- Data processing/correction can be done within 1-2 minutes
- MBT slow/fast orbit acquisition, and BBFB not affected,

Summary of transparent lattice characterization

- Real-time optics measurement and correction during operation
- Impedance localization (dipole and quadrupole mode)
- Alternative: continuous excitation to overcome decoherence and radiation damping
- TbT data can be processed with other techniques (MIA, ICA etc.)
- BPM's bunch-by-bunch resolution is desirable

Reference papers

Yongjun Li, Weixing Cheng, Kiman Ha, and Robert Rainer (2017)
Transparent lattice characterization with gated turn-by-turn data of diagnostic bunch train
Phys. Rev. Accel. Beams 20, 112802 (2017).

Weixing Cheng, Yongjun Li and Kiman Ha (2017)
Techniques for transparent lattice measurement and correction
Journal of Physics: Conference Series 874 – 1

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Thank You!