# USING BIG DATA IN NSLS-II STORAGE RING COMMISSIONING*

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*Abstract*

Big data from both beam position monitor turn-by-turn readings and the designed model are intensively used in the NSLS-II storage ring commissioning. From beam-based data, various beam parameters, including Twiss parameters, tune, dispersion, chromaticity, linear coupling, are characterized and compared against the design model. Then, iterative optimizations yield very promising results, such as, nearly 100% injection efficiency, small Beta-phase beat, a diffraction limit vertical beam size, etc. within a short period of time. Various lattice configurations of w/o damping wigglers, high linear chromaticity have been optimized and commissioned successfully also.

## NSLS-II STORAGE RING

The NSLS-II storage ring is a 30-cell (15-superperiod) double-bend achromat structure (with 30 dispersive straights): 15 low-βx (short) straights of length 6.6m and 15 high-βx (long) straights of length 9.3 m. The designed linear optics for one cell is illustrated in Fig. 1. One long straight is used for injection and two are used for RF cavities. Three long straights are used for damping wigglers (1.8T peak field, 2×3.4 m length each), which lower the horizontal emittance down from 2 to 1 nm rad. In-vacuum undulators with full-gaps as small as 5 mm can provide very high brightness x-ray sources. Elliptically polarized undulators will also provide important sources for user research.

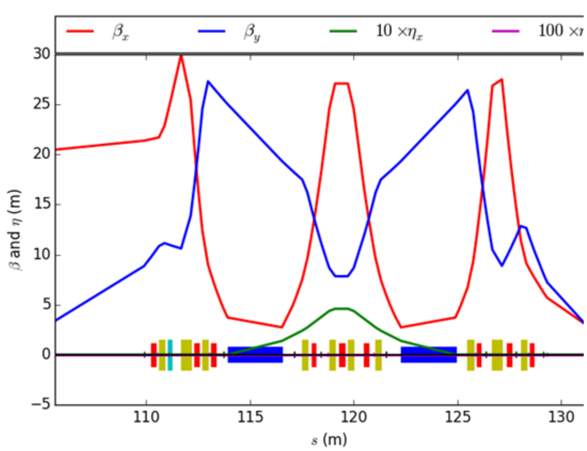


Figure 1: NSLS-II storage ring linear optics for one cell.

The storage ring commissioning began since March 2014. After several months of commissioning, a promising agreement between measured linear optics parameters and the designed model was achieved. The injection efficiency was verified to be above 95%. Three pairs of damping wigglers, four in-vacuum undulators and two elliptically polarized undulators have been successfully incorporated into the ring lattice. Electron beam with an emittance as low as 1 nm rad was seen on a pinhole x-ray camera in December 2014.

## COMMISSIONG TOOLS

### *Development Tools and Libraries*

Python was chosen as the main developing tool, which is a powerful programming language with huge community support [1, 2]. Many well-developed tool-boxes provide powerful and convenient numeric and interface capabilities during the commission process, such as scipy and numpy [3] used for scientific application, matplotlib to produce publication quality figures in a variety of hardcopy formats and interactive environments across platforms, ipython-notebook [4] used as an interactive computational environment, in which user can combine code execution, rich text, mathematics, plots and rich media. A typical ipython notebook interface to obtain tune from turn-by-turn data is shown in Fig. 2.

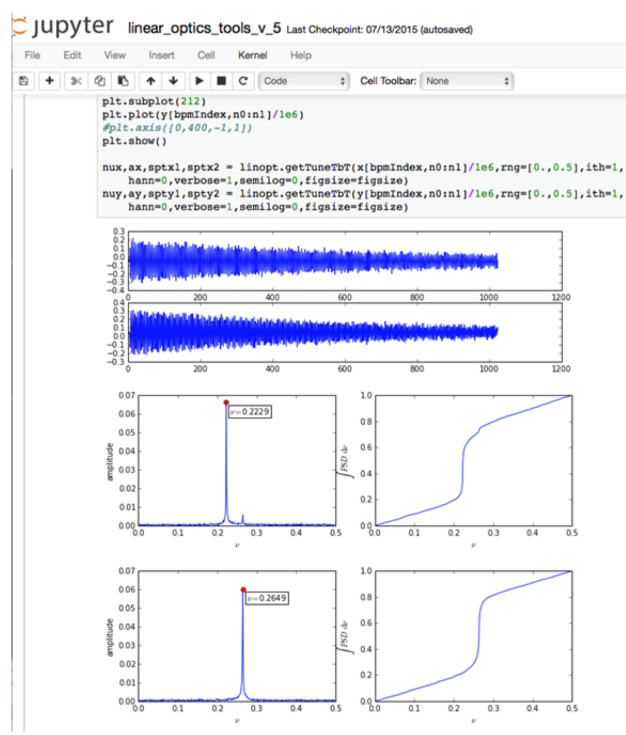


Figure 2: IPython notebook interface for TbT data analysis.

Accelerator Physics High Level Application (APHLA) is a python library developed for accelerator commissioning and beam study. It takes advantages of NSLS-II service oriented architecture, e.g. channel finder service, model service and unit conversion service, to become a

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package more than equipment control. It can be imported as a standard python library,

```
  >>> import aphla as ap
  >>> ap.machines.load("nsls2","SR")
>>> ap.getOrbit(spos=True)
```

### *Data Storage and Access*

Before and during commission, big data are created from either the design model or beam-based measurement. Some of them need to be accessed for optimization, or stored and archived for off-line analysis. Hierarchical Data Format (HDF) is adopted for this purpose, which provides a data model, library, and file format for storing and managing data. It supports an unlimited variety of datatypes, and is designed for flexible and efficient I/O and for high volume and complex data. A python library - h5py, can support python to communicate with HDF5 files flexibly. HDF5 files can be transferred and viewed among different operation platforms. A typical HDF5 file including NSLS-II storage ring lattice parameters and various response matrices is shown in Fig. 3.

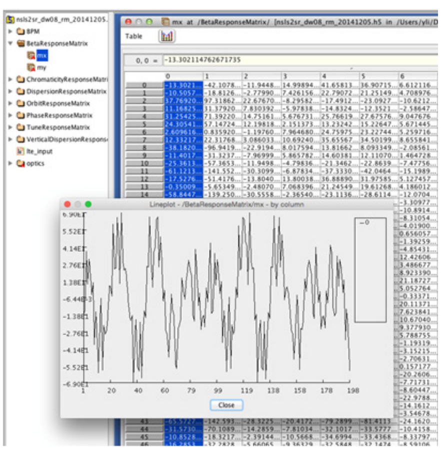

Figure 3: View of a HDF5 files including NSLS-II storage ring lattice and various response matrices.

## BIG COMMISSIONING DATA

There are two sources of commissioning data. First data source is the design model. The linear optics model, including, beta-function, phase, dispersion, etc., at each observation point was pre-calculated, which are used as the optimization goals. All measurable parameters dependency on controllable variables (basically, the magnets power suppliers DC currents, or AC voltage settings), are also pre-calculated and saved as various response matrices for computing correction strength. Second data source is real-time beam-based measurement, basically BPM turn-by-turn data. With some algorithms, the actual real-time beam parameters are extracted from these data, and compared against the design model, a suitable corrections are calculated by inversing the corresponding response matrices, then implementing through APHLA, which is integrated with all necessary unit conversions.

Since there are numerous BPMs, beam diagnostics outputs, and controllable parameters, real-time beam information is usually redundant. Therefore, in most case, we can identify some errors or exceptions due to hardware malfunctions, like bad BPMs, etc. A big data allows us to characterize beam parameters, and then to implement optimization more precisely.

## COMMISSIONING ACHIEVEMENTS

### *Hardware Failure Identification*

When stored beam was first established, it must follow an ugly closed orbit. Any attempts of improving the orbit leaded to beam dump. Thus, we suspected that some physical obstacles inside vacuum chamber actually block beam trajectory. A moving orbit bump was created with the pre-calculated design orbit response matrix to localize these obstacles. This application helped us to localize two hanging RF springs as illustrated in Fig. 4. In the meantime, BPM sum signal provides similar beam loss information to indicate the location of hanging RF spring at cell 10.

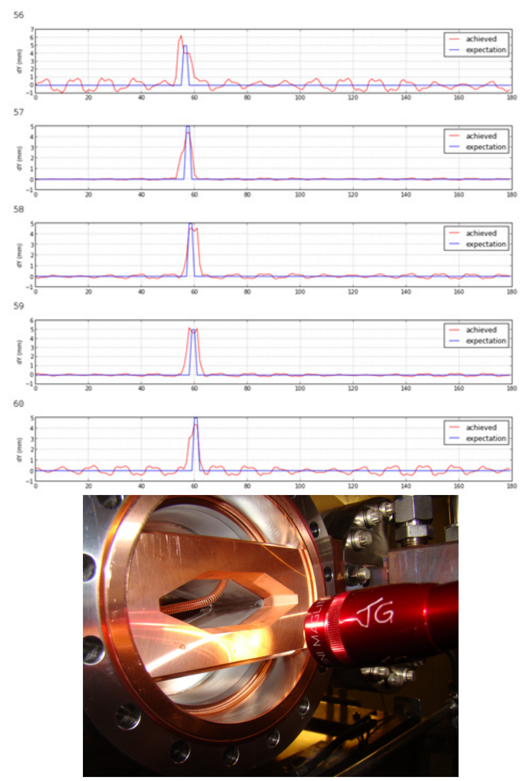


Figure 4: Moving bump to localize the physical obstacle in vacuum chamber.

### *Linear Optics Optimization*

Beam position monitor's turn-by-turn capability synchronized with injection kickers or pingers provides sufficient information to characterize the linear lattice [5]. The uncorrected beta-beat was 20-30%. After implementing beam-based alignment [6] as shown in Fig. 5, the linear optics was optimized to 1-2% (see Fig. 6), and injection efficiency was achieved close to 100%.

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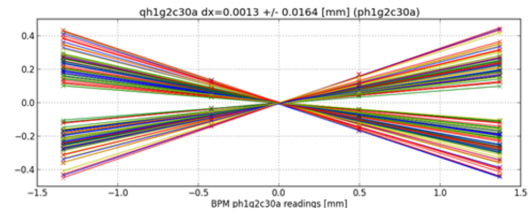


Figure 5: Beam-based alignment for one of quadrupoles.

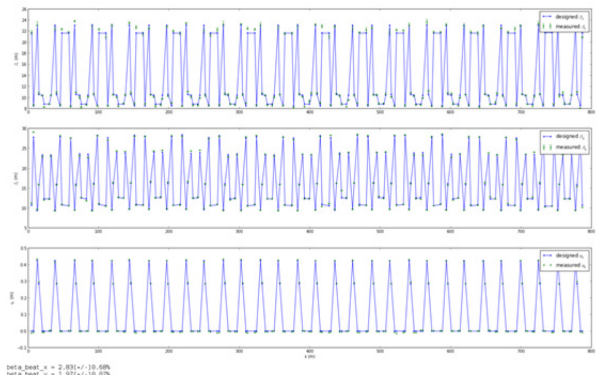

Figure 6: Corrected linear optics (horizontal, vertical beta-functions, and horizontal dispersion).

### *Diffraction-Limit Vertical Beam Size*

A new application of measuring symplectic generators to characterize and control the linear betatron coupling was used to achieve diffraction-limit beam size in the vertical plane. Figure 7 illustrates the transverse x-ray beam profiles as seen by a pinhole camera before and after coupling correction. From synchronized and consecutive TbT readings, symplectic and coupled Lie generators describing the coupled linear dynamics are extracted. Four plane-crossing terms in the generators directly characterize the coupling between the horizontal and the vertical planes. Coupling control can be accomplished by utilizing the dependency of these plane-crossing terms on skew quadrupoles. This method can be automatized to realize linear coupling feedback control with negligible disturbance on machine operation.

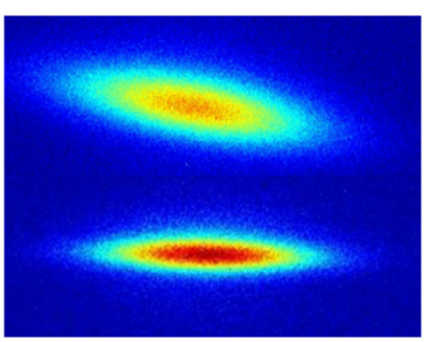

Figure 7: X-ray beam profiles seen by a pinhole camera before/after coupling correction.

In the meantime, the coupled beta-function was extracted by fitted one-turn map. It can be found the two coupling modes were effectively suppressed around the whole ring after correction, as illustrated in Fig. 8.

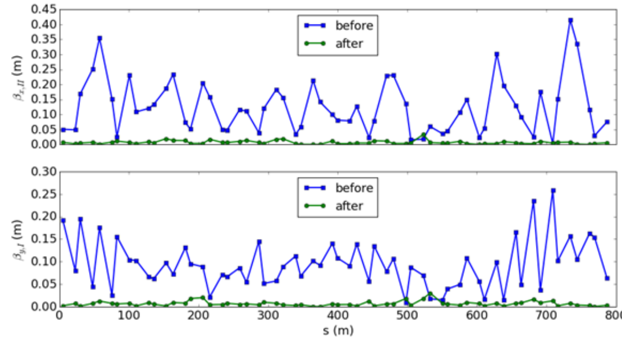


Figure 8: Comparison of the coupled beta-function before and after correction.

## SUMMARY

The big data pool holding both the design model and real-time measurement is helpful in the commissioning the newly built NSLS-II ring. With the powerful python scripts and libraries, we achieved many promising results within the project time budget

## ACKNOWLEDGMENT

We would like to thank NSLS-II colleagues for many helpful and stimulating discussions, and continuous support from operation group.

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