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Vertical Emittance Control Application for NSLS-II Operation

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Introduction:

Vertical emittance of the NSLS-II storage ring can be reduced to ~8 pm by correcting linear coupling and vertical dispersion with the high-level accelerator physics applications developed at NSLS-II [1,2]. However, there has been no strong demand from beamline scientists to operate at such a low vertical emittance during normal user operation so far. Therefore, we typically set the emittance to ~30 pm during normal user operation by adjusting skew quadrupole strengths in order to increase the beam lifetime (~10 hr at 400 mA total beam current with 1200 bunches). When a lead operator adjusts the emittance, there was initially no protocol to follow other than randomly selecting a skew quadrupole and modify the power supply current until the emittance reaches ~30 pm. This occasionally led to a situation where emittance control became irreversible, as it was hard to figure out who used which skew quadrupoles and how much the currents were changed. The emittance can be restored to a low value if we run the aforementioned tools, but they involve invasive measurements and are normally used at low beam current, i.e., not suitable during user operation. Therefore, to avoid this situation, simple scripts were written to unify the operator control of vertical emittance during user operation.

Before you use this unified vertical emittance control program, the linear coupling and the vertical dispersion of the storage ring should be minimized first using the correction tools mentioned above. This control program is meant to only increase the vertical emittance from this minimum emittance state.

This control program provides 2 ways to increase the vertical emittance: coupling and vertical dispersion.

Main Repository, Dependencies & IOC:

The main repository of this application is hosted at https://gitlab.nsls2.bnl.gov/hlatools/vEmitControl.

Requirements of this program are the following:
- A Python 2 or 3 environment with the packages `cothread` [3], NumPy, and h5py.
- EPICS libraries for `cothread` to work.

A dedicated IOC has been set up and is running on “hlaioc01” within NSLS-II Control Network as of this publication. The IOC files can be found at /epics/iocs/vEmitControl.

Vertical Emittance Control by Linear Coupling:

The first way to increase vertical emittance from the minimum or to decrease it from a blown-up state is to add or reduce a linear coupling wave. One such wave can be added by applying the following power supply current change for the 15 SQH skew quadrupoles in the non-dispersive sections of NSLS-II:

$$\Delta I \cdot \cos\left(\overline{\phi_x}_i - \overline{\phi_y}_i\right),$$

where ΔI in the unit of Amperes is specified by the PV `SR:VertEmitCtrl{CouplingWave}Amplitude-SP`. The approximate averages of the horizontal and vertical phase advances at the *i*-th SQH skew quadrupole, $\overline{\phi_x}_i$ and $\overline{\phi_y}_i$ are defined as:

$$\overline{\phi_{x,y}}_i = \frac{\phi_{x,y}(s_{i,b}) + \phi_{x,y}(s_{i,e})}{2},$$

where $s_{i,b}$ and $s_{i,e}$ are the beginning and ending of the *i*-th SQH quadrupole, respectively, and $\phi_{x,y}$ are the horizontal and vertical phase advance values obtained from a lattice code such as Tracy [4] and ELEGANT [5].

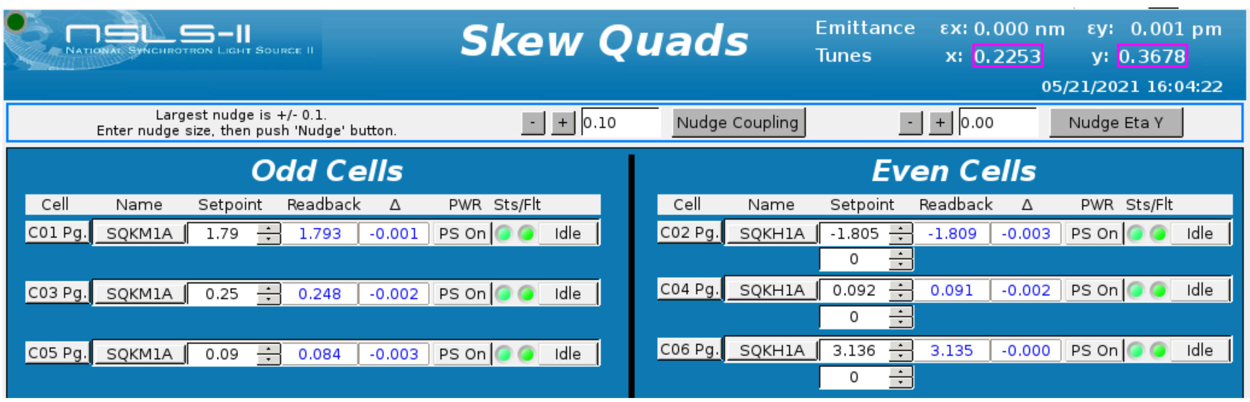


Figure 1: CSS panel for vertical emittance control (bottom part is clipped).

When the button labeled "Nudge Coupling" on the CSS panel shown in Fig. 1 is pressed, the current value of the wave amplitude PV mentioned above is first substituted into ΔI. Then using the pre-computed values for $\overline{\phi_x}_i$ and $\overline{\phi_y}_i$ for the ideal NSLS-II lattice with 3 damping wigglers closed, the new power supply current value $I_{\mathrm{new},i}$ for each SQH skew quadrupole is computed and applied as follows:

$$I_{\mathrm{new},i} = I_{\mathrm{cur},i} + \Delta I \cdot \cos\left(\overline{\phi_x}_i - \overline{\phi_y}_i\right),$$

where $I_{\mathrm{cur},i}$ is the present value of the power supply current in Amperes.

This functionality is also accessible via the following terminal command in the repository folder:

```
$ python adj_epsy_via_lin_coup.py
```

In fact, clicking on the "nudge" CSS button is setting the PV `SR:VertEmitCtrl{CouplingWave}Adjust-Cmd` to 1, which simply executes this command.

As the coupling is added, the beam images at the pin-hole cameras at C22 (both BM-A and 3-pole wiggler) should start to rotate from the initially flat images, as shown in Fig. 2.

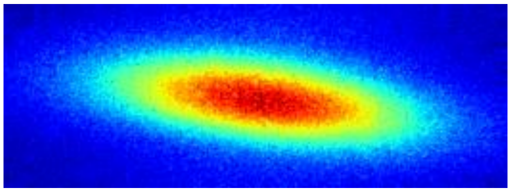


Figure 2: C22 BM-A pin-hole camera image with some coupling $\epsilon_y = 11.6$ pm

If any one of $I_{\mathrm{new},i}$ exceeds the maximum limit of ±17.5 A, the computed change will not be applied to the machine. The range of ΔI is limited to ±0.1 A at the PV level. If you press the "+" and "-" buttons on the left of the "Nudge Coupling" button on the CSS panel, the wave amplitude PV will be set to +0.1 and -0.1 A, respectively.

When you click the nudge button *n* times, you can restore the original coupling state by simply changing the sign of ΔI and clicking the button *n* times, since the skew quadrupoles have negligible hysteresis.

Vertical Emittance Control by Vertical Dispersion Wave:

The second way to increase vertical emittance from the minimum or to decrease it from a blown-up state is to add or reduce a vertical dispersion (η_y) wave. One such wave can be added by simply adding or subtracting the same amount of power supply current for the 15 SQM skew quadrupoles in the dispersive sections of NSLS-II:

$$I_{\mathrm{new},i} = I_{\mathrm{cur},i} + \Delta I,$$

where ΔI in the unit of Amperes is specified by the PV `SR:VertEmitCtrl{EtaYWave}Amplitude-SP`, and $I_{\mathrm{cur},i}$ is the present value of the power supply current in Amperes. Figure 3 shows an example of measured vertical dispersion wave.

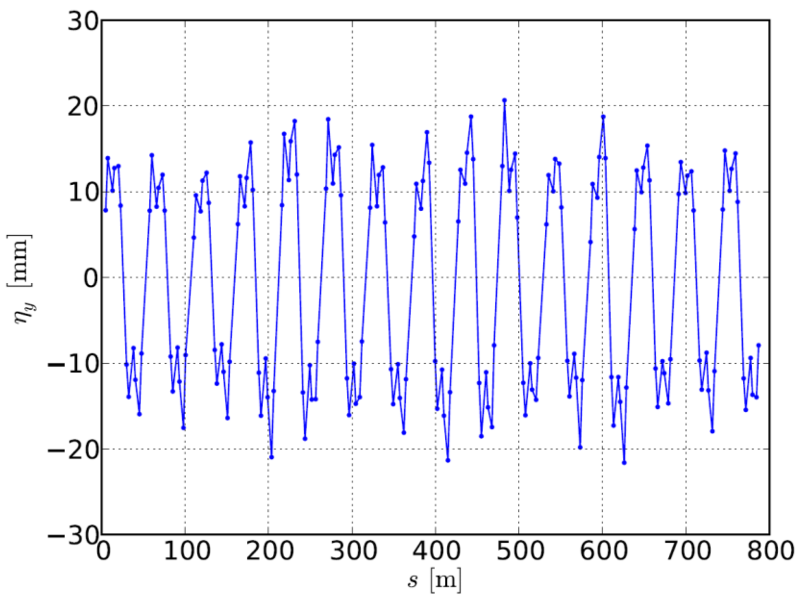


Figure 3: A measurement of vertical dispersion wave with ΔI~5 A.

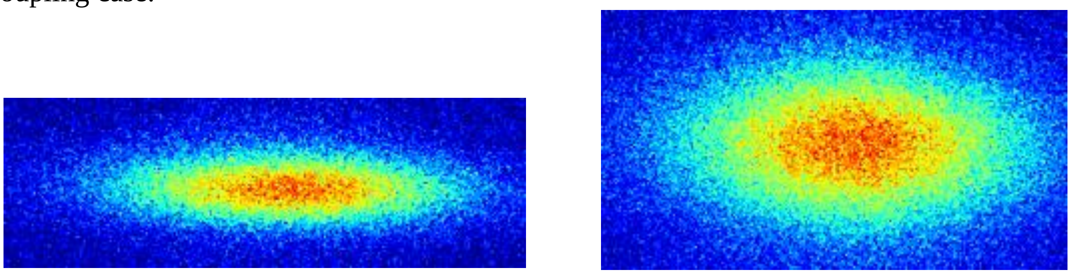
When the button labeled “Nudge Eta Y” on the CSS panel shown in Fig. 1 is pressed, the current value of the wave amplitude PV mentioned above is substituted into ΔI, and the new power supply current value $I_{\text{new},i}$ for each SQM skew quadrupole is computed and applied to the machine.

This functionality is also accessible via the following terminal command in the repository folder:

```
$ python adj_epsy_via_etay.py
```

In fact, clicking on the “nudge” CSS button is setting the PV `SR:VertEmitCtrl{EtaYWave}Adjust-Cmd` to 1, which simply executes this command.

As the vertical dispersion wave is added, the beam images at the pin-hole cameras at C22 (both BM-A and 3-pole wiggler) should stay flat, but they start to vertically blow up as shown in Fig. 4, unlike the linear coupling case.



(a) (b)

Figure 4: C22 BM-A pin-hole camera images (a) minimum $\epsilon_y = 5.8$ pm and (b) $\epsilon_y = 27.8$ pm with η_y wave shown in Fig. 3.

If any one of $I_{\text{new},i}$ exceeds the maximum limit of ±17.5 A, the computed change will not be applied to the machine. The range of ΔI is limited to ±0.1 A at the PV level. If you press the “+” and “-“ buttons on the left of the “Nudge Eta Y” button on the CSS panel, the wave amplitude PV will be set to +0.1 and -0.1 A, respectively.

When you click the nudge button *n* times, you can restore the original vertical dispersion wave state by simply changing the sign of ΔI and clicking the button *n* times, since the skew quadrupoles have negligible hysteresis.

References:

[1] Y. Hidaka, B. Podobedov, and J. Bengtsson, “Linear Optics Characterization and Correction Method using Turn-by-Turn BPM Data Based on Resonance Driving Terms with Simultaneous BPM Calibration Capability,” Proc. NAPAC2016, Chicago, IL, USA (2016).

[2] Y. Li, “NSLS-II APHLA Linear Coupling Correction Tools,” BNL Technical Note, NSLSII-ASD-TN-351 (2021).

[3] http://controls.diamond.ac.uk/downloads/python/cothread/; https://github.com/dls-controls/cothread

[4] J. Bengtsson, E. Forest, and H. Nishimura, “Tracy User Manual,” Internal SLS document, PSI, Villigen (1997).

[5] M. Borland, "elegant: A Flexible SDDS-Compliant Code for Accelerator Simulation," Advanced Photon Source LS-287, September 2000.