# Unified Orbit Feedback at NSLS-II

NAPAC 2022

WEPA71

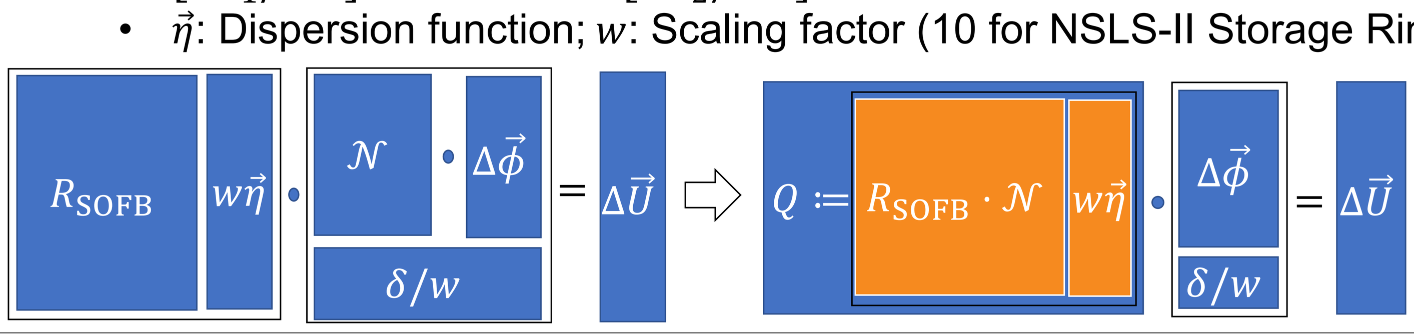
Y. Hidaka*, G. M. Wang, Y. Tian, R. Smith, Y. Li, X. Yang
Brookhaven National Laboratory, Upton NY 11973

## Abstract

We have developed an orbit correction / feedback program to unify the existing orbit-related feedback systems for stable beam operation at NSLS-II. Until recently only a handful of beamlines have been benefiting from long-term orbit stability provided by a local bump agent program. To expand this to all the beamlines as well as correct more frequently, a new slow orbit feedback program called unified orbit feedback (UOFB) was written from scratch that works with the fast orbit feedback transparently, while accumulated fast corrector strength is continuously shifted to the slow correctors and RF frequency is adjusted for circumference change. UOFB can lock 3 different types of local bumps to the target offsets/angles for days: those for insertion device (ID) sources with only ID RF beam position monitors (BPM) or mixtures of ID RF BPMs and X-ray BPMs, and those for bending magnet sources with arc BPMs between which orbit correctors, dipoles and quadrupoles exist. Furthermore, this feedback can accommodate beamline user requests to enable / disable the feedback loop for their beamline and to change bump target setpoints without turning off the loop.

## UOFB Algorithm

- Goal: To unify slow orbit feedback (SOFB), fast orbit feedback (FOFB), and RF frequency feedback (RFFB) w/ ability to offload fast corrector strengths to slow correctors & flexibility to adjust all types of local bumps at any time.
- SOFB component of UOFB based on [1]: Change slow corrector currents by $\Delta\vec{I}_{\mathrm{SOFB}}$ while changing the FOFB reference orbit by $\Delta\vec{W}$, the expected orbit movement after applying $\Delta\vec{I}_{\mathrm{SOFB}} = \Delta\vec{I}_{1,\mathrm{SOFB}} + \Delta\vec{I}_{2,\mathrm{SOFB}}$.
    - $\Delta\vec{I}_{1,\mathrm{SOFB}} = R_{\mathrm{SOFB}}^{-1} \cdot \Delta\vec{U}$: Changes that would be applied to correct orbit error $\Delta\vec{U}$ when FOFB is not running
    - $\Delta\vec{I}_{2,\mathrm{SOFB}} = R_{\mathrm{SOFB}}^{-1} \cdot (R_{\mathrm{FOFB}} \cdot \Delta\vec{I}_{\mathrm{FOFB}})$: Changes that will shift the DC part of fast corrector currents $\Delta\vec{I}_{\mathrm{FOFB}}$ to slow corrector currents
    - $\Delta\vec{W} = R_{\mathrm{SOFB}} \cdot \Delta\vec{I}_{1,\mathrm{SOFB}}$
    - $R_{\mathrm{SOFB}}$ & $R_{\mathrm{FOFB}}$: Orbit response matrices (ORMs) for slow and fast correctors
- RFFB component of UOFB to compensate ring circumference change.
    - Constrain slow corrector changes to not alter beam energy in order to allow RF frequency adjustment to correct beam energy.
    - Utilize the null space $\mathcal{N}$ of the energy response matrix $D$ for $\Delta\vec{I}_{\mathrm{SOFB}}$ such that $D \cdot (\mathcal{N} \cdot \Delta\vec{\phi}) = 0$, i.e., preserving beam energy.
    - Use the following $\Delta\vec{I}_{1,\mathrm{SOFB}}$ & $\Delta\vec{I}_{2,\mathrm{SOFB}}$ and energy correction $\delta = \delta_1 + \delta_2$ instead:
        - $\Delta\vec{I}_{1,\mathrm{SOFB}} = \mathcal{N} \cdot \Delta\vec{\phi}_{1,\mathrm{SOFB}}$ & $\Delta\vec{I}_{2,\mathrm{SOFB}} = \mathcal{N} \cdot \Delta\vec{\phi}_{2,\mathrm{SOFB}}$
        - $\begin{bmatrix} \Delta\vec{\phi}_{1,\mathrm{SOFB}} \\ \delta_1/w \end{bmatrix} = Q^{-1} \cdot \Delta\vec{U}$ & $\begin{bmatrix} \Delta\vec{\phi}_{2,\mathrm{SOFB}} \\ \delta_2/w \end{bmatrix} = Q^{-1} \cdot (R_{\mathrm{FOFB}} \cdot \Delta\vec{I}_{\mathrm{FOFB}})$
        - $\vec{\eta}$: Dispersion function; $w$: Scaling factor (10 for NSLS-II Storage Ring)




## 3 Types of Local Bumps

- ID RF-BPM bumps: 13 beamlines (BLs)
    - Simplest (bump offsets & angles defined by 2 RF BPMs bounding an ID without any orbit corrector or multipole magnets in between).
- BM (Bending Magnet) bumps: 9 operational BLs (1 BL not archived)
    - Specially derived formula [2] needed to estimate bump offsets and angles due to the presence of orbit correctors & quadrupoles between the bounding BPM pair.
    - Not as reliable as ID RF bumps because these magnet properties are not exactly known (e.g., inaccurate calibration, hysteresis, quadrupole center deviation).
- ID bumps with X-ray BPMs: 3 BLs ("X beamlines": C03, C16, C17)
    - 1 ID RF BPM and 1 front-end X-BPM positions as the feedback target.
    - Provides the best orbit angle accuracy.
    - Can be switched to RF-BPM-only bump when ID gap is open.
    - Feedback auto-disabled when gap out of calibration range or move by >150 $\mu$m.
- 360x360 ORM for arc BPMs, computed by ELEGANT, as the base for $R_{\mathrm{SOFB}}$. Enabled bumps replace the corresponding rows. No singular value cut is necessary.
- All BL feedbacks always enabled except for "X beamlines," which can enable/disable their feedbacks on their own.
- Bump adjustments can be performed at any time by calling Control Room (C17 users are given special permission to adjust their bump without calling.)

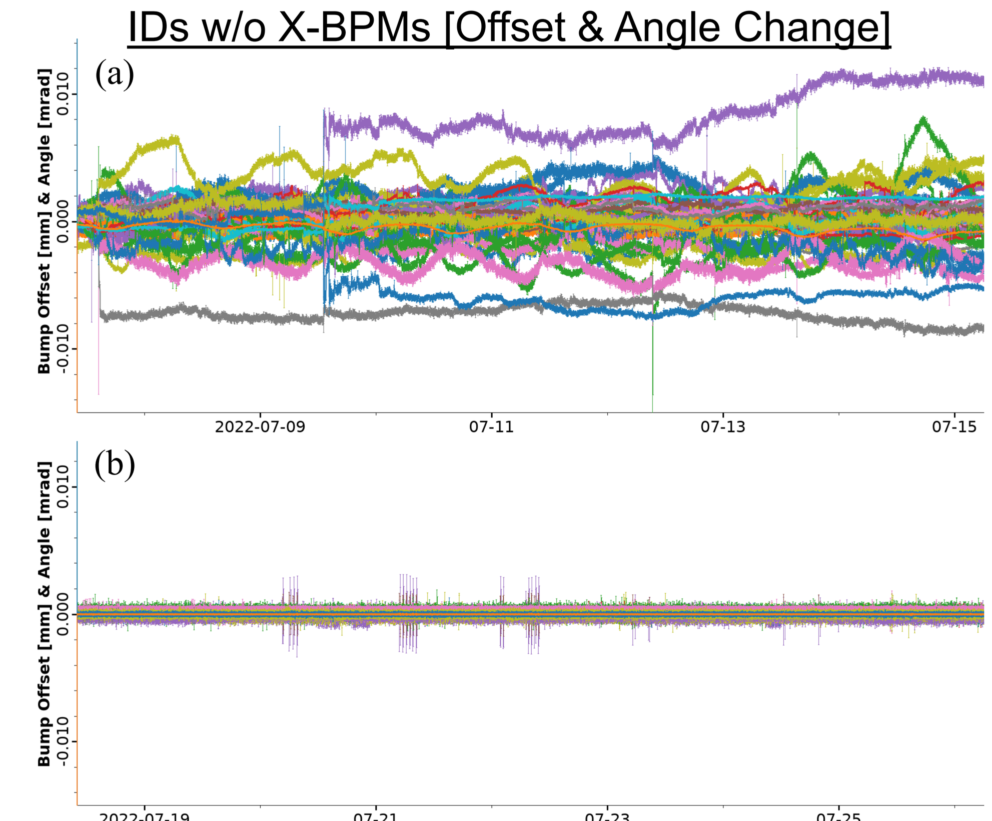
## References

[1] N. Hubert, L. Cassinari, J. Denard, A. Nadji, and L. S. Nadolski, “Global Fast Orbit Feedback System Down to DC using Fast and Slow Correctors”, in Proc. DIPAC'09, Basel, Switzerland, May 2009, paper MOOC01, pp. 27-31.
[2] Y. Hidaka, Y. Hu, B. Podobedov, R. Smith, Y. Tian, G. Wang, “Fast-Orbit-Feedback-Compatible ID Local Bumps with RF and X-ray BPMs at NSLS-II”, BNL Technical Note, NSLSII-ASD-TN-353 (2021).

## Orbit Stability Comparison: LBA vs. UOFB

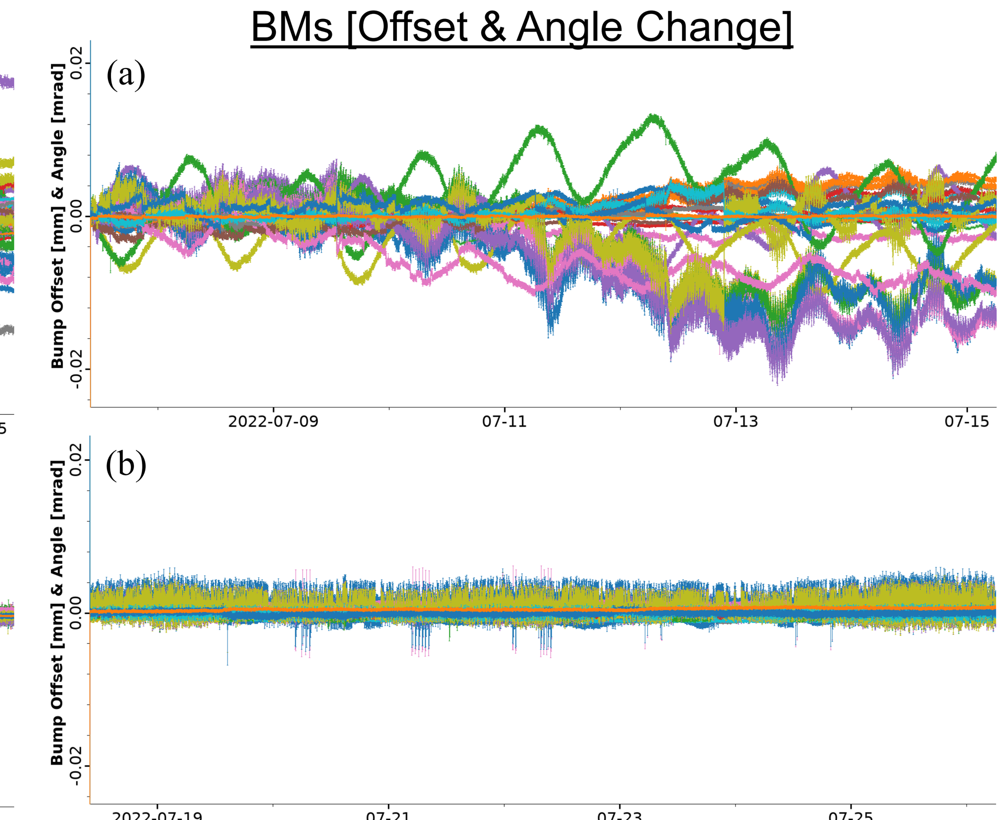
- UOFB officially deployed for beamline operation on 7/18/2022 at NSLS-II.
- (a) LBA Week (FOFB + Local Bump Agent) from 7/7 10 am to 7/15/2022 6 am (188 hrs)
- (b) UOFB Week (FOFB + UOFB) from 7/18 10 am to 7/26/2022 6 am (188 hrs)

IDs w/o X-BPMs [Offset & Angle Change]



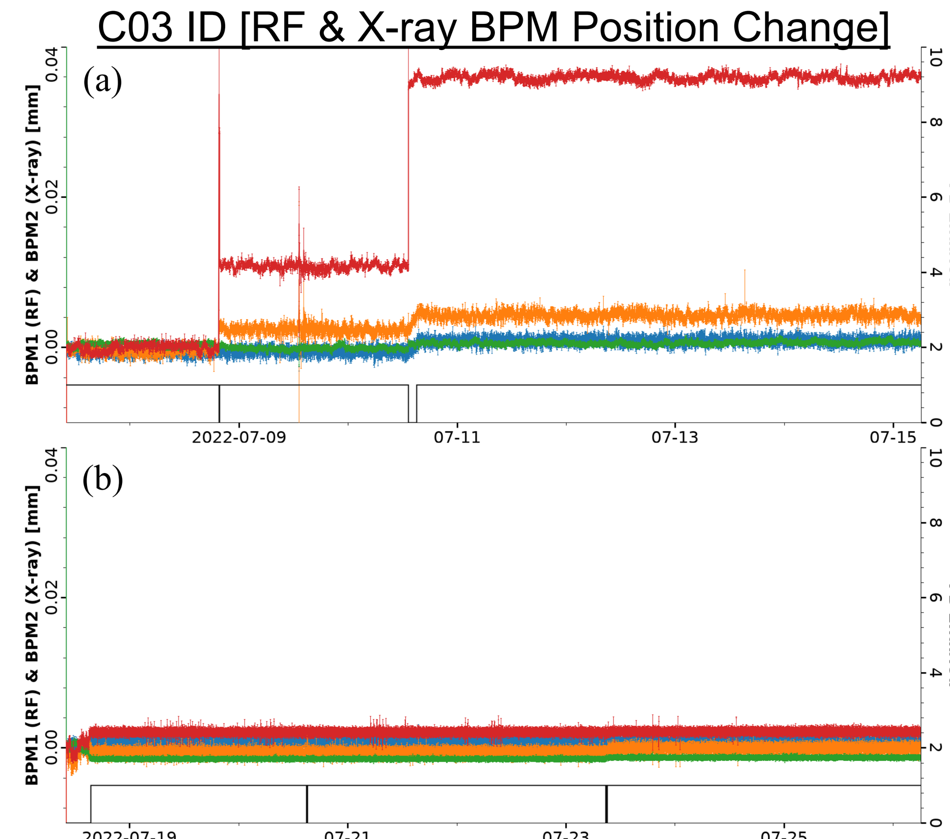

(a) 2 vs. (b) 13 feedbacked beamlines

BMs [Offset & Angle Change]

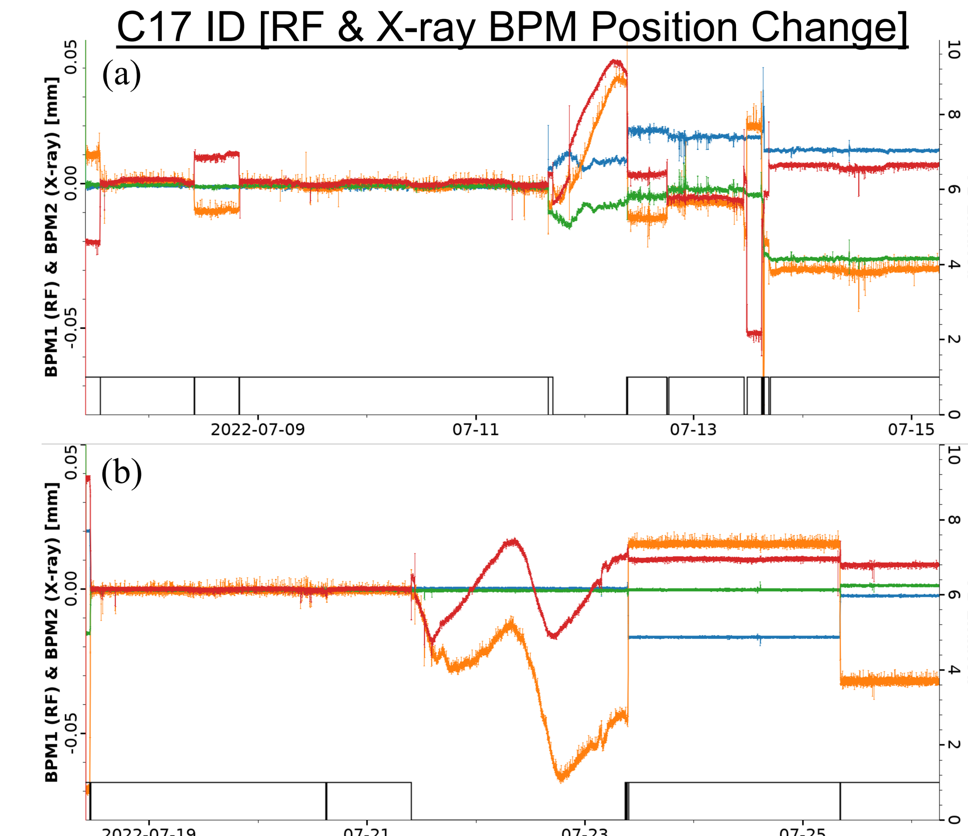



(a) 0 vs. (b) 8 feedbacked beamlines

C03 ID [RF & X-ray BPM Position Change]

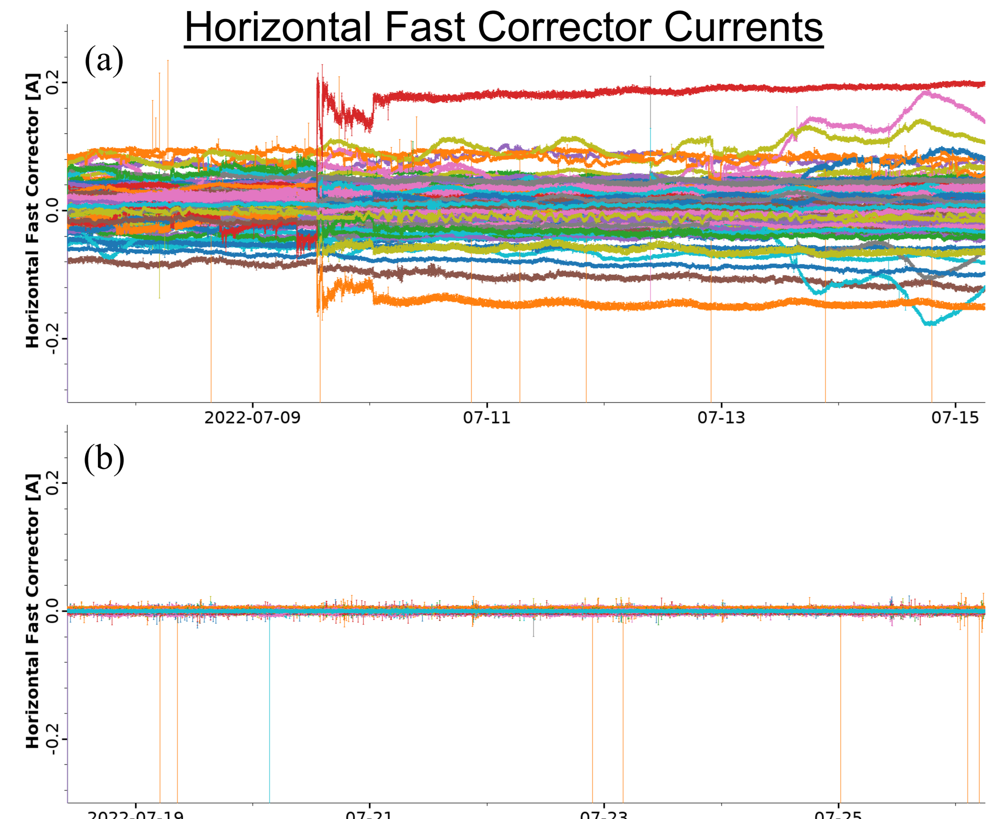



C17 ID [RF & X-ray BPM Position Change]

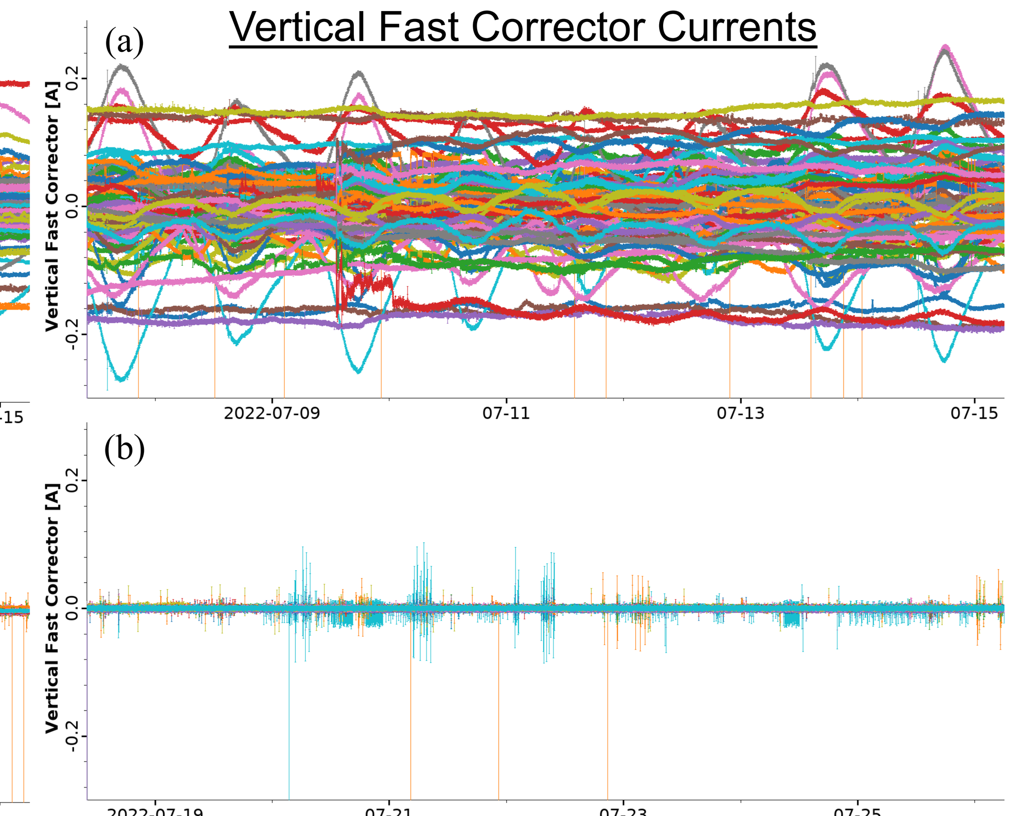



## Continuous Shifting from Fast to Slow Correctors with UOFB

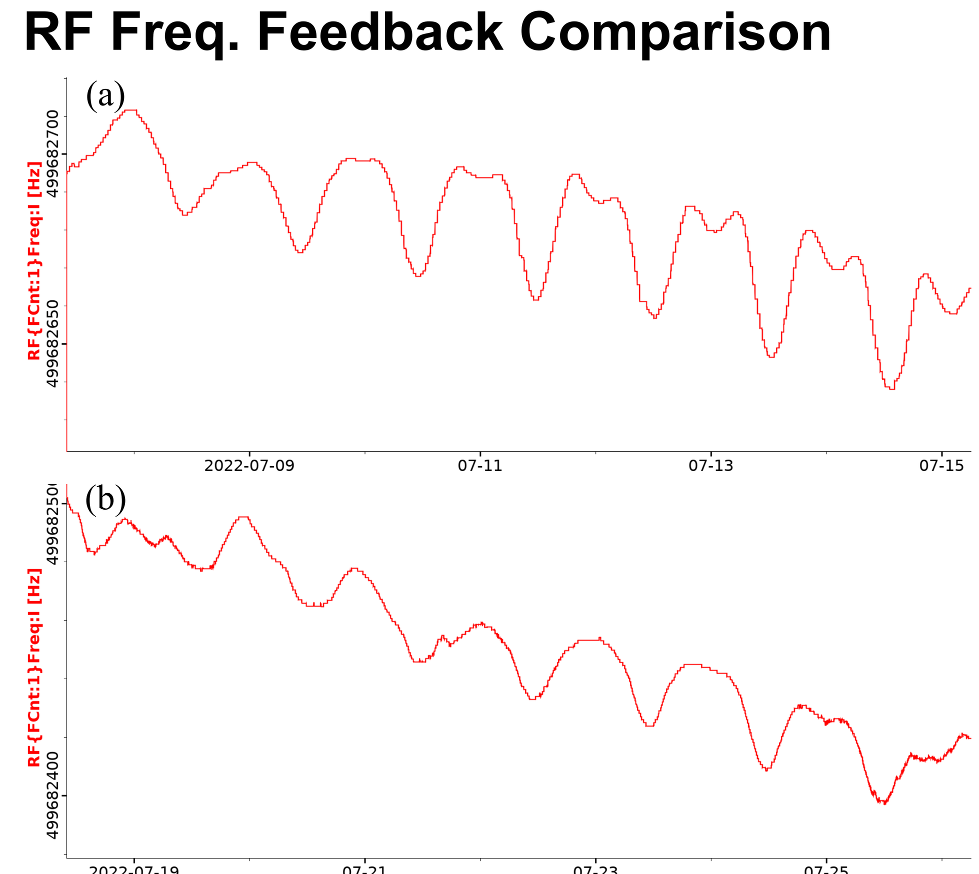
Horizontal Fast Corrector Currents




Vertical Fast Corrector Currents




## RF Freq. Feedback Comparison




## Conclusion

A new orbit feedback called UOFB was implemented to provide excellent long-term orbit stability for all the existing beamlines at NSLS-II. The new system has been successfully tested and officially deployed into beamline operation recently. In addition to the source stability, UOFB compensates circumference change by adjusting the ring RF frequency as well as continuously distributes accumulated fast corrector kicks into slow correctors. This program can also accommodate 3 different types of local bumps and perform flexible adjustments whenever on-demand requests from beamline users are received.

Acknowledgments:
This work was supported by U.S. DOE under Contract No. DE-SC0012704.

National Synchrotron Light Source II

* yhidaka@bnl.gov

U.S. DEPARTMENT OF ENERGY

Brookhaven National Laboratory