ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-THPRB104

IMPROVEMENTS IN LONG-TERM ORBIT STABILITY AT NSLS-II*

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Abstract

We report our latest efforts to further improve long-term orbit stability at NSLS-II, on top of what is already provided by fast orbit feedback (FOFB) system. A DC local bump generation program, only utilizing RF beam position monitors (BPM) and compatible with FOFB, was first implemented and deployed in operation successfully, allowing on-demand fine adjustments of beamline source positions and angles. Then we introduced a simple feedback version that performs these bump corrections automatically as needed to maintain the sources within in 1 um/urad for select beamlines. In addition, an RF frequency feedback was also implemented to improve stability for 3-pole wigglers and bending magnet users. As a parallel effort, X-ray BPMs were included in a local feedback system to stabilize photon beam motion for several ID beamlines. However, this feedback scheme is not transparent to FOFB, and suspected to be the source of occasional saturation of fast corrector strength. As an alternative solution, the local bump program and its feedback version has been recently upgraded to include bumps with X-ray BPMs and in operation since April 2019.

INTRODUCTION

The National Synchrotron Light Source II (NSLS-II) is the latest third-generation light source in the United States, located at Brookhaven National Laboratory [1]. Since the storage ring commissioning in 2014, the stored beam current for routine beamline operation was gradually raised to 400 mA, with top off injection. The number of beamlines has grown from 7 insertion devices (IDs) on 6 straight sections to 23 IDs on 16 straight sections as well as 5 three-pole wigglers (3PWs), one bending magnet (BM) source, and another BM as infrared radiation source. As the facility matures, and the number of users expands, we have been making continuous efforts to improve the stability of the machine for the beamline users. One area of focus has been the long-term orbit stability, as many users identified it as the most impactful if resolved. In this paper, we report our evolving solutions to further improve this stability on top of what was achieved due to the meticulous design of the building and various storage ring systems with stability in mind.

FAST ORBIT FEEDBACK

The fast orbit feedback system (FOFB) at NSLS-II [2] currently suppresses orbit noise up to 200 Hz. We define the short-term orbit stability to be the integrated power spectrum density (PSD) of the beam orbit from 0.1 Hz up to 500 Hz. These integrated PSDs for the horizontal and vertical plane are typically 0.8 and 0.6 um, respectively. Given the nominal 0.9 nm horizontal and 8 pm vertical emittance, and the rms energy spread of 9×10^{-4}, the current FOFB system meets the short-term orbit stability requirement of 10% of beam size in both planes (even reaching 1% horizontally).

As a practical metric for long-term orbit stability, we take the first uninterrupted (i.e., no beam dump with continuous topoff running) 24-hour period each week during beamline operation, sample the ID source angles and positions hourly within that period, and calculate the median of the peak-to-peak variations among all the ID beamlines [3]. The latest such statistical analysis shows the current long-term orbit stability to be 1.7/1.6 urad (H/V) for ID angles and 5.5/4.4 um (H/V) for ID positions [3].

FOFB-COMPATIBLE LOCAL BUMP

The most noticeable and persistent sources for degradation of long-term orbit stability were local orbit bump corrections for ID beamlines. Our original local bump program (called v2) was written without FOFB compatibility. As FOFB was fighting back the bump correction, the program was slow to converge and generated global orbit distortion. Initially we tried to alleviate the problem by "relaxing" the FOFB gain while creating a bump. Later, to completely resolve this issue, we adopted the bump feedforward method used at APS [4]. The new bump program (called v3) creates a local bump at an ID straight using slow ring orbit correctors, as v2 did. However, before applying the slow corrector setpoint changes, the program modifies the FOFB reference orbit to the orbit the change in the slow correctors will produce. This way FOFB does not try to fight back the change.

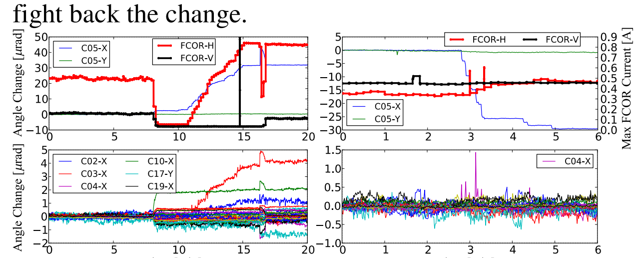

Figure 1: Comparison between (left) v2 bump with FOFB "relaxed" mode and (right) v3 bump with normal FOFB, showing horizontal 30-urad bump creation at C05 ID (top) and the impact on all the other ID sources (bottom).

As shown in Fig. 1, an attempt to create a 30-urad horizontal angle bump at C05 ID with the v2 program used to affect a neighboring ID as much as 4 urad, while pushing fast correctors near saturation. With v3, the residual equilibrium ID source angle change around the ring was

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suppressed well below 1 urad. The transient spikes both in orbit and fast corrector strength are due to the time lag between the FOFB reference orbit change and the time it takes the slow correctors to ramp up/down their currents.

During the upgrade to v3, not only adding the FOFB compatibility, the program was also completely re-written such that multiple local bumps can be simultaneously corrected. This allowed the Control Room operator to quickly set up the local bumps for all the ID beamline users at the beginning of a user operation period.

Later, the v3 program was further enhanced to control local bumps for BM and 3PW users as well. As a separate effort, an RF frequency feedback was also implemented and deployed into operation to mainly improve the long-term orbit stability for these photon users affected by the ring circumference changes via dispersion [5].

LOCAL BUMP AGENT (FEEDBACK)

After disturbances from local bump corrections have been practically resolved by the new bump code, the next request from beamline scientists was to have an automated system that corrects their bumps once they drift out of a pre-defined target window. Hence, a new program called ID Local Bump Agent (also known as ID Bump Feedback), was created.

Once this system is activated, a Python script (agent) runs in an infinite loop, periodically (every 60 seconds) checking whether the source offsets and angles at selected IDs are within the specified windows. If an ID source is found to be outside of its window (typically +/-1 um and +/-1 urad), this agent initiates an ID local bump correction automatically, provided that the following conditions are satisfied to prevent any automated action from taking place in an abnormal machine condition: 1) There is enough beam current in the ring. 2) The required bump correction is less than 10 um in offset and 10 urad in angle. In addition, the last agent-initiated bump correction did not occur within the last 10 minutes to avoid too frequent corrections. The values of these conditions can be customized for individual beamlines. Each beamline is given a control to turn on or off their agent whenever they need. We also retain a master switch to globally disable all the beamline agents in case we need to stop all bump corrections for troubleshooting or any other purpose.

This system was first implemented in June 2018 and tested only with C11 ID. Initially the users were planning to turn on the agent before the start of their experiment to ensure the acceptable beam angle/offset, and then turn off the agent during their experiment as they were afraid that residual beam motion during automated bump correction can contaminate their data. However, given their tight tolerance, each bump correction was small enough that they could not distinguish when a bump correction is happening. Therefore, they have been keeping the agent always turned on since the sensitivity test. This beamline was particularly pleased with this system during the C04 orbit drift incident in Aug.-Sept. 2018 [6]. As shown in Fig. 2, the C04 ID source offset was moving significantly in both planes due to the orbit kicks caused by the floor motion in the vicinity. Since the C11 ID agent was on during this period, it was frequently performing bump corrections (indicated by the green bars at the bottom of the figure) in order to maintain its target bump offset and angle. Some of the other beamlines were not as shielded from the impact of this global event as C11 beamline.

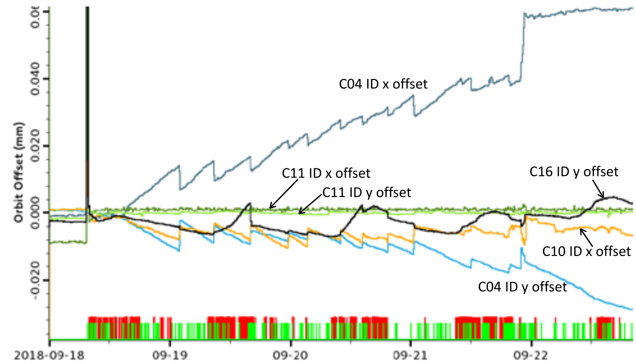

Figure 2: Local Bump Agent working hard to maintain C11 ID bump offset during the C04 orbit drift event. The red bars at the bottom indicate when any of the ID gaps was moving, while the green bars show when any local bump correction was happening.

Table 1: Long-Term Stability with Local Bump Agents

	Wk-1 p2p	Wk-1 rms	Wk-2 p2p	Wk-2 rms
C11 *x*' [urad]	1.6	0.3	1.9	0.3
C11 *y*' [urad]	2.0	0.3	4.8	0.5
C11 *x* [um]	3.2	0.6	11.8	1.1
C11 *y* [um]	4.2	0.5	2.7	0.5
C23-2 *x*' [urad]	10.3	2.9	7.0	0.7
C23-2 *y*' [urad]	3.7	0.9	11.7	1.1
C23-2 *x* [um]	9.6	2.1	3.7	0.7
C23-2 *y* [um]	6.2	1.4	10.5	1.0

Given this success, we added another beamline C23-2 ID to the list of agent-controlled bumps in Oct. 2018. The impact of the bump agents is shown in Table 1. On Week 1 (10/8-10/15/2018), only C11 agent was on, while on Week 2 (10/15-10/22/2018) both C11 and C23-2 agents were on. The rms orbit stability clearly improved for C23-2 with the agent, and stayed within the specified tolerance of 1 um/urad. On the other hand, the peak-to-peak values did not get better. This is due to the limitation of the system response, which is on the order of minutes, i.e., 60-second evaluation interval as well as 10-min cooldown limit. If any ID source jump occurs, correction will have to wait for the agent's next opportunity, during which the jump is captured by the archiver and hence included in the statistics.

PHOTON LOCAL FEEDBACK

As a parallel effort, an entirely different feedback system called photon local feedback (PLFB) was also implemented [2]. This system employed an X-ray BPM (X-BPM) located at the front-end or further downstream on

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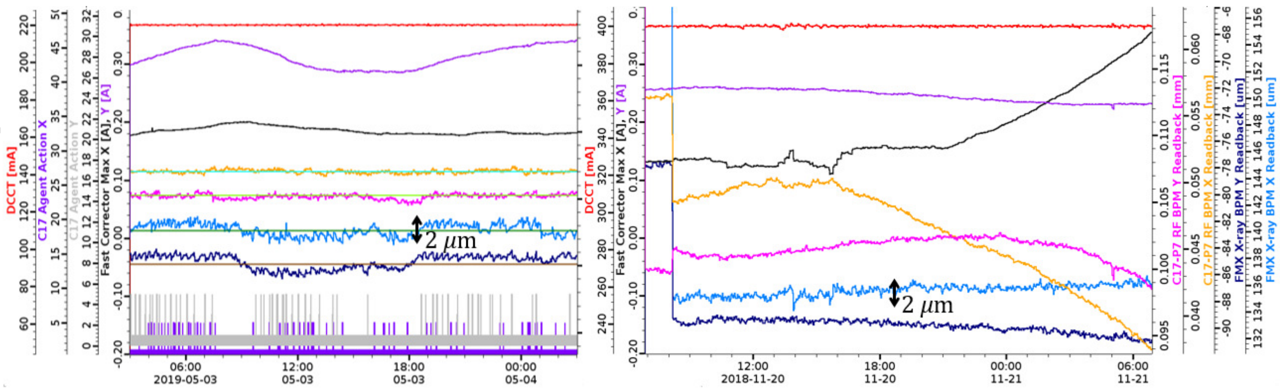

Figure 3: Performance of v4 local bump agent (feedback) (left) and PLFB (right).

the beamline to provide better long-term stability locally for a beamline equipped with X-BPMs.

We decided to use the ID orbit correctors, which are located right next to the ID and dedicated for correction of its residual field integrals, as the actuators for this local feedback. This system was deployed for the four beamlines that have front-end X-BPMs. The beamline X-BPMs were not used for this feedback, as their readings depend on many beamline settings and are deemed not reliable enough to be included in a feedback loop that can directly affect the ring e-beam orbit. As an alternative configuration, in addition to an X-BPM, some PLFB utilizes an ID RF BPM as its sensor to stabilize both the angle and offset.

PLFB has been particularly crucial for the beamline operation at two of the beamlines C17-1 and C17-2 IDs. These IDs are located very close to and their beamline components go over an outdoor vehicle tunnel, susceptible to daily outdoor temperature swings. This effect is easily visible on the e-beam orbit as FOFB tends to significantly vary the corrections strengths of the fast correctors in that region. Combined with the system's inherent lack of transparency against FOFB, the C17 PLFB system has occasionally driven the nearby fast correctors to saturation, forcing us to run a fast-to-slow-corrector shifting program, which is not a fully transparent process to the other beamlines. This has recently led to a suspension of PLFB use for C17 IDs.

V4 LOCAL BUMP

As an alternative solution to satisfy the C17 beamline scientists and avoid operational difficulty, we have decided to upgrade the existing v3 local bump program to be able to generate bumps that include X-BPMs. This so-called v4 bump program has been verified to work very recently for both a bump that includes only one X-BPM and another bump that consists of an upstream ID RF BPM and one X-BPM for C17. Subsequently, the feedback version (i.e., bump agent) of this mixed-type C17 bump passed a long-term test without any adverse effect on the global e-beam orbit. The new C17 agent was officially deployed into user operation on 04/22/2019, and has been running reliably ever since.

The performance of the v4 bump agent for C17 is shown in Fig. 3, along with the performance of C17 PLFB. The specified tolerance of +/-1 um for both the RF BPM and X-BPM is being satisfied for v4. The purple (H) and gray (V) bars at the bottom of the left plot indicates when bump corrections were performed. The PLFB plot shows the runaway situation of the fast correctors (black curve), while the v4 plot shows a flat (black) and oscillatory (pink) fast corrector trend.

CONCLUSION AND OUTLOOK

In this paper we described the history of our solutions to improve long-term orbit stability at NSLS-II. Starting from the already good orbit stability provided by FOFB, we have been gradually resolving the issues preventing us from achieving better long-term orbit stability. By listening to the requests from the beamline scientists, and focusing to come up with solutions that meet those demands, we are now able to deliver stability the absolute majority of our users are quite satisfied.

Is it important to emphasize that at many beamlines, long-term drifts of the photon beam mainly occur due to sources unrelated to electron beam orbit (e.g., varying heat load on optics, thermally-induced motions of beamline components), which should be addressed by beamline-specific solutions. However, identifying and separating these drift sources from orbit motion is often not trivial, and requires a continued dialog and occasional joint machine studies with beamline scientists.

A work is in progress to further evolve the v4 local bump and its feedback into a unified orbit feedback system by frequently performing simultaneous multiple bump corrections and shifting DC currents of fast correctors to those of slow correctors to reduce long-term drifts at all active beamlines with minimal DC currents accumulated by fast correctors. Finally, as we envision achieving sub-micron and sub-microradian long-term stability at the majority of NSLS-II ID beamlines in the future, further improvements in long-term RF and X-BPM stability would be of great benefit.

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