BNL-219886-2020-TECH

NSLSII-ASD-TN-338

Accelerator Physics at NSLS-II: Research Accomplishments in 2018

V. Smaluk

December 2018

National Synchrotron Light Source II

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC), Basic Energy Sciences (BES) (SC-22)

Notice: This technical note has been authored by employees of Brookhaven Science Associates, LLC under Contract No.DE-SC0012704 with the U.S. Department of Energy. The publisher by accepting the technical note for publication acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this technical note, or allow others to do so, for United States Government purposes.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party's use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

NSLS-II TECHNICAL NOTE
BROOKHAVEN NATIONAL LABORATORY

NUMBER
NSLSII-ASD-TN-338

Accelerator physics at NSLS-II: research accomplishments in 2018

V. Smaluk, G. Bassi, A. Blednykh, W. Guo, Y. Li,
B. Podobedov, X. Yang, L.H. Yu

Dec. 31, 2018

Abstract

Scientific support for user operations is the main mission of the NSLS-II Accelerator Physics group. At the same time, NSLS-II accelerator physicists were working in 2018 on the following research and development projects: development of HLA common tools for beam studies and operations; online optimization of Injector and Storage Ring (Facility Improvement Project); development of a new operation mode for time-resolved experiments; high-brightness upgrade options for NSLS-II; ultra-fast electron diffraction (LDRD); APS upgrade project and the electron-ion collider project at BNL (MOUs). A summary of the research accomplishments of the NSLS-II Accelerator Physics group is presented in this report.

1 Introduction

Scientific support for user operations is the main mission of the NSLS-II Accelerator Physics group. There are three key criteria of the machine performance the physicists are working to improve: reliability, stability, and intensity. In 2018, the NSLS-II reliability was 96-97%; the beam stability was maintained at the level of 1% of the beam size (horizontal) and less than 10% of the beam size (vertical). The machine was routinely operated with the beam current of 400 mA, and beam studies were done with the current of 450 mA. An operation mode with low vertical emittance has been tested and implemented into user operations.

In parallel to the support of operations, NSLS-II accelerator physicists were working on a number of research and development projects: development and testing of HLA common tools for beam studies and operations; online optimization of Injector and Storage Ring (Facility Improvement Project); development of a new operation mode with hybrid fill pattern for time-resolved experiments. Studies of high-brightness upgrade options of NSLS-II are in progress. The LDRD on ultra-fast electron diffraction has been completed with the results exceeding expectations. Within the framework of several MOUs, the Accelerator Physics group also contributed to the APS upgrade project and to the electron-ion collider

project at BNL. A summary of the most significant research accomplishments of the NSLS-II Accelerator Physics group is presented in the next sections of this report.

A list of major accomplishments is below:

- HLA common tools.
- Routine "transparent" lattice measurement.
- Beam stability.
- Online optimization of the Injector and Storage Ring.
- Single-klystron operation mode of the Injector.
- Feasibility analysis of a superconducting wiggler for HEX beamline.
- Beam deviation envelope for ray-tracing.
- Analysis of beam dynamics with a 3rd harmonic cavity.
- Split-bend lattice development for NSLS-II upgrade.
- Concept of Complex Bend magnet.
- Multi-Objective Genetic Algorithm with machine learning.
- Lattice correction based on betatron phase.
- New aspects of longitudinal beam instabilities.
- Comparison of impedance computations and beam-based measurements.
- Studies of beam-beam effects and impedances for eRHIC.
- Ultra-fast electron diffraction.

2 HLA common tools

During NSLS-II commissioning, accelerator physicists created a powerful suite of high-level applications (HLAs) with capabilities sufficient to successfully put the machine into operation. However, the tight commissioning schedule made it difficult to debug HLAs and convert them into a common format with a uniform interface. After the commissioning was complete, NSLS-II has entered user operations with machine ramping up the current regularly, and new IDs are installed almost every shutdown. To sustain our progress we need highly efficient machine studies, which, in turn, require reliable and efficient software tools having an interface to the EPICS process variables and to the virtual machine model. The HLA common tools program was initiated to develop a set of well-tested and documented software tools available for all Accelerator Division staff. After thorough testing and debugging of every application, it is uploaded to a GitLab-based library, which is the only source of the software used in the control room. Once a code is tested and released, all NSLS-II accelerator physicists are trained on how to use the software. As a result, every physicist is now prepared for independent control and tune-up of the machine.

In 2018, a set of basic HLA common tools for beam studies and operations has been developed and tested. The common tools listed below are ready to use:

- orbit correction;
- measurement and correction of linear optics (beta functions and dispersion);

- measurement and correction of linear coupling;
- correction of betatron tunes;
- measurement of chromaticity (up to 5th order);
- correction of linear chromaticity;
- measurement of beam-based alignment;
- orbit noise locator;
- injector energy knob;
- LTB energy measurement;
- LTB trajectory correction;
- measurement of dynamic aperture and betatron tune shift with amplitude;
- lattice characterization using gated BPM functionality.

Trainings of physicists working in the Accelerator Physics group and Accelerator Coordination groups are complete.

3 Routine "transparent" lattice measurement

A technique for characterizing a storage ring lattice transparently to routine operations has been developed [1, 2]. The technique is based on selective beam excitation and beam position data acquisition. The gated functionality has been implemented in the NSLS-II in-house developed beam position monitor (BPM) system [3]. This approach adopts a dedicated beam filling pattern with a short, separate diagnostic bunch train, which can be selectively excited by the bunch-by-bunch feedback system. To characterize the lattice, the gated BPMs measure turn-by-turn betatron oscillation of the diagnostic bunch train only. As the diagnostic train comprises only about one percent of the total beam, the effects of its excitation are negligible to the beamline users.

4 Beam stability

Beam stability task force (BSTF) continued throughout the year, two BSTF reports [4] were released and a summary talk was presented at the NSLS-II Beam Stability Review. The origin of the CHX (11-ID) high-frequency noise was found. The local-bump auto-correction was optimized. The Photon Local Feedback was implemented in the HXN (3-ID) beamline. Investigations of the CSX (23-ID) beamline stability resulted in several machine issues found. The reason for photon beam instabilities at the SST (7-ID) was found not related to the machine. The performance and sensitivity of the bending magnet beamlines (4-BM, 11-BM, 17-BM) were studied. Long-term drift of the storage ring girders in Cell 4 caused by the high air temperature in the steam tunnel has been investigated and fixed.

Besides the BSTF, real-time redistribution of the fast correctors' strengths to slow correctors [5, 6] has been implemented in routine operations to prevent saturation of the fast correctors. A set of tools to generate weekly beam stability reports was developed.

5 Online optimization of the Injector and Storage Ring

The Facility Improvement Project "Methods of online optimization of NSLS-II storage ring concurrent with user operations" is dedicated to developing a set of software tools for online optimization of linear optics and nonlinear beam dynamics, as well as for minimization of the injection transients. The final goal of the project is to improve the beam quality for the user experiments. The expected benefits for the NSLS-II user community are reduced top-off injection frequency, improved beam stability, and minimized orbit perturbation during the injection. The online optimization approach is based on model-independent methods using beam-based measurements and advanced algorithms designed to work reliably in noisy environments, such as the Robust Conjugate-Gradient Algorithm (RCDS). The first results summarized in a Technical Note [7] look encouraging: a 20% increase in the horizontal dynamic aperture and reduction of the beam oscillation after injection by a factor of 5, were achieved.

6 Single-klystron operation mode of the Injector

The 100 MeV Injector program is complete. The goal is to implement a single-klystron injection in the case of a long-term klystron failure. Top-off injection with a single klystron at 100 MeV was tested and optimized [8]. The optimization included the beam loading compensation for the minimum energy spread of the Linac beam, lattice matching of Linac-to-Booster transport line, optimization of Booster sextupoles, Booster orbit correction, and Linac-to-Booster trajectory steering. The overall 20% Injector efficiency in the 100 MeV mode has been achieved. The principal limit of the efficiency results from the transverse and longitudinal emittance of the Linac beam exceeding the Booster acceptance. The storage ring was filled up to 375 mA in 15 minutes. Top off ran for 2.5 hours with one issue fixed. The ring current variations stayed less than 0.5%, the bunch-to-bunch charge deviation was 12% with injections every 22 seconds [9]. Thus the emergency operation mode with a single klystron is ready.

7 Feasibility analysis of a superconducting wiggler for HEX beamline

A 1.2 m long superconducting wiggler (SCW) is planned to be installed in NSLS-II Cell 27 for the HEX beamline. In the original design, the superconducting wiggler was proposed to be placed at the center of the straight section but the downstream vacuum chamber is exposed to the intensive radiation. To mitigate this issue, a shift of the device downstream by 1.0 m or 1.8 m was considered so the fan would pass through the straight vacuum chamber. As it was found, the SCW has minor effects on the horizontal optics but it affects the optics in the vertical plane significantly (tune shift of 0.042 and maximum beta-beat of 8 m). For correction of the lattice perturbations caused by the SCW, two schemes were considered: a global one (all quadrupoles) and a local one (6 quadrupoles near the SCW) [10]. Using both the global and the local scheme, the linear optics can be well restored but the

dynamic aperture and energy acceptance become smaller, the amplitude-dependent tune shifts also changed significantly, and some betatron resonances become stronger as well. So the optimization of sextupoles is essential. Interaction of the electron beam with the resistive-wall impedance of the low-gap SCW liner and with the geometric impedance of the transition sections was studied analytically and numerically to estimate heat load in the cold volume [11]. The total beam-induced power in the HEX SCW is expected to be about 10 W with a strong dependence on the bunch length.

8 Beam deviation envelope for ray-tracing

At NSLS-II, the unused radiation from the dipole magnets is intercepted by the water-cooled photon absorbers installed inside the vacuum chamber to keep the temperature within the safe limits. However, if the beam orbit is severely perturbed, the radiation fan can bypass the absorbers and heat the vacuum chamber components. A series of simulation studies were carried out with the goal to find the maximum beam deviation and to re-examine ray-tracing under the operational constraints. The beam could be lost in any unpredictable direction if a magnet malfunctions. Reasonable constraints were made to determine the beam deviation envelope: 1) damage can only be caused by stored beam, therefore closed orbit must exist in simulations; 2) the error sources are the orbit correctors and the RF frequency variation; 3) beam is limited by the physical aperture of the vacuum chamber and the photon absorbers; 4) beam is confined by the active interlock at the centers of straights. Based on these assumptions, the correctors' strengths and the RF frequency were scanned to explore the maximum beam deviation. The results are summarized in a Technical Note [12]. While the root causes of beam deviations are reasonable and conservative, they do not cover all possible failure modes, so the recommended beam deviation envelopes should be used only for the equipment protection system (EPS). For personal protection system (PPS) a more stringent approach should be taken to include all possible failures.

9 Analysis of beam dynamics with a 3rd harmonic cavity

A 3rd-harmonic RF cavity is included in the NSLS-II original design to mitigate the beam-induced heating of the vacuum chamber at the design beam current of 500 mA, as well as to improve beam lifetime. The primary beneficial effect provided by a high-harmonic RF cavity is the bunch lengthening without energy spread increase. For a few modes of operation, a number of numerical simulations and analytic calculations were done to understand the beam dynamics with a 3rd harmonic cavity. Self-consistent simulations were done using SPACE, a novel parallel code for the simultaneous simulation of single- and multi-bunch collective effects. These calculations agree qualitatively with the effects observed on other machines equipped with harmonic cavities. For the non-uniform fill pattern with an ion-cleaning gap of 10-20%, severe phase transients were found, which strongly limit the bunch lengthening provided by the harmonic cavity. For the case with a superconducting passive 3rd-harmonic cavity and two superconducting fundamental RF systems, the achievable bunch lengthening

of a stable beam is around 2 out of 3.5 due to the non-uniform bunch filling. The results of the 3rd-harmonic RF cavity studies were discussed at the NSLS-II Beam Intensity Review [13], published in a Technical Note [14], and presented at the 13th International Computational Accelerator Physics Conference [15].

10 Split-bend lattice development for NSLS-II upgrade

An option of NSLS-II low-emittance upgrade with a splitting dipole scheme is being studied [16]. All 30 2.6m-long dipoles of the NSLS-II storage ring are proposed to be replaced by two short combined-function dipoles with an extra quadrupole between them to reduce the horizontal beta-function and dispersion inside the dipoles. This will allow us to achieve the beam emittance of 300 pm·rad, which can be further reduced by the use of the existing damping wigglers. The upgrade must satisfy the following constraints: 1) the same layout of insertion devices; 2) keeping existing magnet supporting girders; 3) maximum possible re-use of the magnets and their power suppliers; 4) keeping the beta-functions in the straight sections close to the present values; 5) the dynamic aperture and energy acceptance sufficient for the off-axis top-off injection and decent beam lifetime. A linear optics with the horizontal emittance of 333 pm·rad has been developed; use of the currently installed damping wigglers results in further emittance decrease down to 200 pm·rad. For this lattice, stronger quadrupoles are required to match the linear optics and much stronger sextupoles are required to correct the linear chromaticity. The major issue is the lattice is highly nonlinear, both the dynamic aperture and energy acceptance are not sufficient. Optimization of sextupoles is now the first priority but no solution has been found yet. We plan to apply various optimization techniques: Multi-Objective Genetic Algorithm with Machine Learning; off-momentum beta correction; square matrix method combined with Robust Conjugate Direction Search. An alternative lattice layout with modification of the section between the dipoles is also being studied.

11 Concept of Complex Bend magnet

Multi-Bend Achromat (MBA) is now a standard approach to achieve low emittance in storage rings, all modern projects of low-emittance synchrotrons are based on MBA lattices. We propose an alternative way to reach low emittance by replacing regular dipole magnets with a novel lattice element that we call "Complex Bend" [17, 18]. The Complex Bend is a new concept of bending magnet consisting of a number of dipole poles interleaved with strong alternate focusing so as to maintain the beta-function and dispersion oscillating at very low values and therefore to reduce the emittance while localizing bending to a small fraction of the storage ring circumference. The details of Complex Bend, considerations regarding the choice of optimal parameters, thoughts for its practical realization and implementation in low-emittance lattices, are published in [19].

12 Multi-Objective Genetic Algorithm with machine learning

The multi-objective genetic algorithm (MOGA) has been enhanced by including machine learning techniques and applied to the optimization of the NSLS-II dynamic aperture [20, 21]. During the evolution process employed by the genetic algorithm, the population is classified into different clusters in the search space and the clusters with top average fitness are given "elite" status. Intervention via machine learning speeds up the evolution process and increases the number of elite candidates in the data pool. The average fitness of the population is therefore improved while diversity is not lost ensuring the optimization is global rather than local. The quality of the population increases and produces more competitive descendants accelerating the evolution process significantly. The quality of some optimal candidates obtained with this technique have been confirmed at NSLS-II experimentally and by simulation. This technique can be applied to other population-based optimization problems such as particle swarm algorithms.

13 Lattice correction based on betatron phase

Correction of beta functions and nonlinear lattice using the betatron phase measured from excited beam oscillation was studied [22]. Numerical simulations show the equivalence between the phase correction and the beta beat correction. At NSLS-II, the phase measurement accuracy was shown to be 1 mrad r.m.s., which corresponds to about 0.3 % of the beta beat. The beta beat was corrected to approximately 1 % in both planes and the results were confirmed by the LOCO measurement. Since the betatron phase probed by an off-axis beam provides information on the sextupole strength, this technique can be applied to the nonlinear lattice correction as well.

14 New aspects of longitudinal beam instabilities

Comprehensive studies of novel features of the single-bunch longitudinal instability in a low-emittance electron storage ring are complete at NSLS-II. Beam-based measurements and numerical simulations show a non-monotonic increase of the beam energy spread as a function of bunch current. Several local minima and maxima were observed in the intensity-dependent energy spread, and each local minimum is interpreted as a higher-order microwave instability threshold. It was also found the thresholds related to the same zero-intensity bunch length depend linearly on the accelerating RF voltage. These intensity-dependent features of the energy spread were measured using two independent diagnostics methods: 1) transverse beam profile measurement by a synchrotron light monitor and 2) measurement of the energy spectrum of undulator radiation. A theoretical interpretation was developed by applying a novel eigenvalue analysis based on the linearized Vlasov equation. The results of microwave instability studies are published in Scientific Reports [23]. This article was selected for a DOE Science Highlight in 2018.

15 Comparison of impedance computations and beam-based measurements

The beam intensity in modern electron-positron storage rings is limited by the interaction of the beam with self-induced electromagnetic fields (wakefields) characterized by the vacuum chamber impedance. For 15 electron-positron storage rings, a comparative analysis of impedance computations and beam-based measurements was done; the results are published in Nucl. Instrum. Meth. A [24]. Both computation and measurement results were taken from published materials for the analysis. The total broadband impedances were computed during the machine design by element-wise wakefield simulations using computer codes. After the machines have been commissioned, the impedances were measured experimentally using beam-based techniques. The measured data and the predictions based on the computed impedance budgets show a significant discrepancy. Three possible reasons for the discrepancy are studied using numerical simulations: interference of the wakefields excited by a beam in adjacent components of the vacuum chamber, the effect of computation mesh size, and the effect of insufficient bandwidth of the computed impedance.

16 Studies of beam-beam effects and impedances for eRHIC

In 2018, NSLS-II accelerator physicists made significant contributions to the design of eRHIC, a future electron-ion collider at BNL [25]. For the ring-ring option, coherent and incoherent beam-beam effects were studied using weak-strong and strong-strong simulations in order to determine the damping decrement required to reach the design beam-beam parameter in the electron storage ring. For the linac-ring option, strong-strong simulations of the beam-beam effects have been carried out to study the effects of electron beam fluctuations (intensity, emittance, etc) on the proton beam emittance. The results of these studies are summarized in Chapter 4.4 "Beam-Beam Effects" of the eRHIC Pre-Conceptual Design Report and presented at IPAC-2018 [26]. Work on the eRHIC impedance budget is in progress [27]. As a first step, geometric impedances computed for the vacuum chamber components of the NSLS-II storage ring were used together with the eRHIC lattice and beam parameters for preliminary estimates of beam instability thresholds.

17 Ultra-fast electron diffraction facility

NSLS-II accelerator physicists and engineers together with colleagues from CAD completed the LDRD project 16-010 with the results exceeding expectations. A high-charge high-brightness low-energy electron source for ultrafast electron diffraction (UED) experiments was demonstrated. A new transverse focusing system based on electromagnetic quadrupole lenses was designed, installed, and commissioned. The UED facility is capable to generate 3.3 MeV electron bunches with up to 13 pC charge, 75 μm focused transverse beam size, and 1 ps bunch length. The charge density of the electron beam is about two orders of magnitude higher than achieved previously using solenoid focusing only. As it was shown, the

intensity-dependent beam size growth caused by space charge can be largely compensated by the optimization of the quadrupoles in the beam charge range from 1 pC to 13 pC. Implementation of the new quadrupole focusing system resulted in significant improvement of the diffraction image with 3 times brighter and 2 times sharper peaks. Besides, the beam divergence was measured first time by analysis of the diffraction images. The possibility of real-time measuring the beam emittance was preliminarily tested, the result agrees well with simulations and with the traditional quadrupole scan. The bunch length of the 3 MeV beam was also measured using the interferometric technique.

18 Summary

In 2018, the Accelerator Physics group was working on a number of research projects and activities in parallel with the scientific support of NSLS-II operations and developments. The major accomplishments are summarized in this report: HLA common tools program; advanced techniques for lattice measurement, correction, and optimization; beam stability improvement; a single-klystron Injector mode to improve the machine reliability; feasibility analysis of a superconducting wiggler; lattice options for NSLS-II low-emittance upgrade; collective effects and beam instabilities; studies of beam-beam effects and impedances for eRHIC (MOUs with CAD); development and commissioning of the UED facility (LDRD).

The results of these studies are published in peer-reviewed journals [1, 3, 5, 19, 20, 22, 23, 24] and were presented at international conferences [2, 6, 8, 9, 15, 21, 25, 26, 27]. Figure 1 shows the statistics of journal articles and conference reports published by NSLS-II accelerator physicists in the past 5 years.

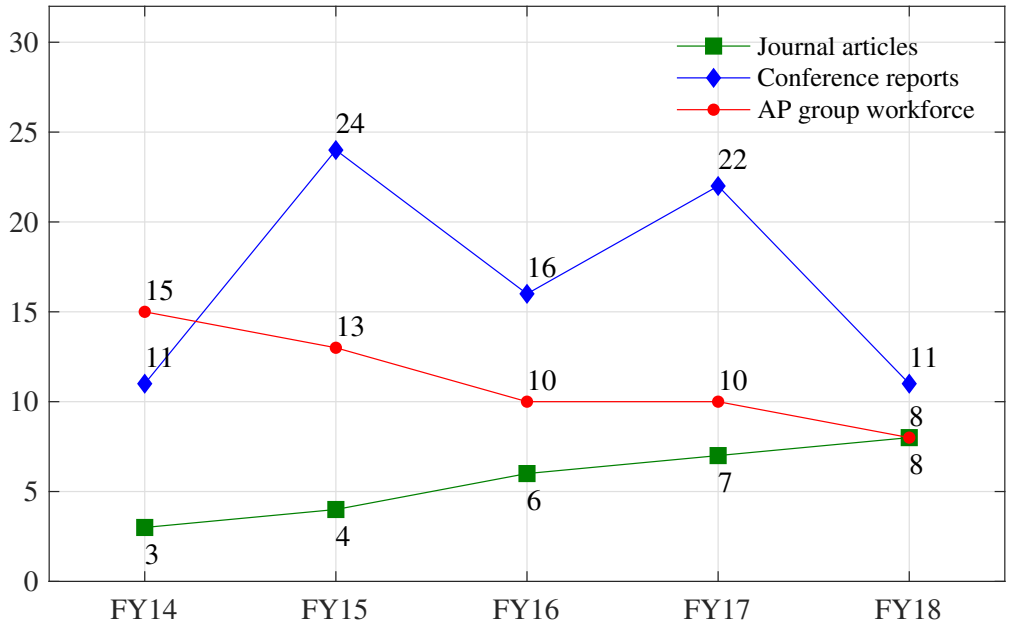


Figure 1: Number of journal articles and conference reports published by the NSLS-II Accelerator Physics group in FY14-FY18.

References

[1] Y. Li, W. Cheng, K. Ha, R. Rainer, *Transparent lattice characterization with gated turn-by-turn data of diagnostic bunch train*, Phys. Rev. Acc. Beams 20, 112802 (2017).

[2] Y. Li, W. Cheng, K. Ha, R. Rainer, *Transparent lattice characterization with gated BPM signal*, in Proceedings of 60th ICFA Advanced Beam Dynamics Workshop on Future Light Sources, Shanghai (2018), THP2WB03.

[3] W. Cheng, K. Ha, Y. Li, B. Podobedov, *Beam position monitor gate functionality implementation and applications*, MethodsX 5 (2018) 626-634.

[4] NSLS-II Beam Stability Task Force.

[5] X. Yang, Y. Tian, L. Yu, V. Smaluk, *First demonstration of the fast-to-slow corrector current shift in the NSLS-II storage ring*, Nucl. Instrum. Meth. A 886, 140-144 (2018).

[6] X. Yang, Y. Tian, L.H. Yu, V. Smaluk, *First Demonstration of the Transparent Fast-to-slow Corrector Current Shift in the NSLS-II Storage Ring*, in Proceedings of IPAC-18, Vancouver (2018), TUPMF035.

[7] X. Yang, G. Wang, V. Smaluk, L. Yu, T. Shaftan, P. Zuhoski, Y. Hidaka, *RCDS online optimization the NSLS-II dynamic aperture and injection transient*, BNL-211216-2019-TECH (NSLSII-ASD-TN-284), 2018.

[8] X. Yang, R. Fliller, V. Smaluk, A. Derbenev, T. Shaftan, *Development of New Operational Mode for NSLS-II Injector: Low-energy 100 MeV Linac-to-Booster Injection*, in Proceedings of IPAC-18, Vancouver (2018), TUPMF037.

[9] R. Fliller, A. Derbenev, V. Smaluk, X. Yang, *Top Off of NSLS-II with Inefficient Injector*, in Proceedings of IPAC-18, Vancouver (2018), TUPMF036.

[10] W. Guo, Y. Li, *Lattice Schemes for the HEX Beamline at Cell 27*, BNL-211221-2019-TECH (NSLSII-ASD-TN-289), 2018.

[11] V. Smaluk, A. Blednykh, B. Podobedov, T. Tanabe, C. Hetzel, *Beam-induced power in HEX SCW*, BNL-211214-2019-TECH (NSLSII-ASD-TN-282), 2018.

[12] W. Guo, *Reasonable Beam Deviation Envelope For Ray-tracing*, BNL-211206-2019-TECH (NSLSII-ASD-TN-269), 2018.

[13] G. Bassi, *Beam Dynamics with a 3rd Harmonic Cavity*, NSLS-II Beam Intensity Review, 2018.

[14] G. Bassi, J. Tagger, *Longitudinal Beam Dynamics with a Higher-Harmonic Cavity for Bunch Lengthening*, BNL-211218-2019-TECH (NSLSII-ASD-TN-286), 2018.

[15] G. Bassi, J. Tagger, *Longitudinal Beam Dynamics with a Higher-Harmonic Cavity for Bunch Lengthening*, in Proceedings of 13th Int. Computational Accelerator Physics Conf., Key West (2018), TUPAF12.

[16] Y. Li, *NSLS-II upgrade proposal with splitting dipole scheme*, BNL-211225-2019-TECH (NSLSII-ASD-TN-293), 2018.

[17] T. Shaftan, V. Smaluk, G. Wang, *A Concept of the Complex Bend*, BNL-211211-2019-TECH (NSLSII-ASD-TN-276), 2018.

[18] T. Shaftan, G. Wang, V. Smaluk, Y. Hidaka, O. Chubar, T. Tanabe, J. Choi, *Complex Bend II*, BNL-211223-2019-TECH (NSLSII-ASD-TN-291), 2018.

[19] G. Wang, T. Shaftan, V. Smaluk, N. A. Mezentsev, S. Sharma, O. Chubar, Y. Hidaka, C. Spataro, *Complex bend: Strong-focusing magnet for low-emittance synchrotrons*, Phys. Rev. Acc. Beams 21, 100703 (2018).

[20] Y. Li, W. Cheng, L. Yu, R. Rainer, *Genetic algorithm enhanced by machine learning in dynamic aperture optimization*, Phys. Rev. Acc. Beams 21, 054601 (2018).

[21] Y. Li, W. Cheng, L.-H. Yu, R. Rainer, *Genetic algorithm enhanced by machine learning for dynamic aperture optimization*, in Proceedings of 13th Int. Computational Accelerator Physics Conf., Key West (2018), SAPAF01.

[22] W. Guo, Y. Hidaka, F. Willeke, X. Yang, *Betatron phase and nonlinear lattice correction*, Phys. Rev. Acc. Beams 21 081001 (2018).

[23] A. Blednykh, B. Bacha, G. Bassi, W. Cheng, O. Chubar, A. Derbenev, R. Lindberg, M. Rakitin, V. Smaluk, M. Zhernenkov, K. Chen-Wiegart, L. Wiegart, *New aspects of longitudinal instabilities in electron storage rings*, Scientific Reports 8, 11918 (2018).

[24] V. Smaluk, *Impedance computations and beam-based measurements: a problem of discrepancy*, Nucl. Instrum. Meth. A 888, 22-30 (2018).

[25] V. Ptitsyn, G. Bassi, J. Beebe-Wang, J.S. Berg, M. Blaskiewicz, A. Blednykh, J.M. Brennan, S.J. Brooks, K.A. Brown, K.A. Drees, A.V. Fedotov, W. Fischer, D.M. Gassner, W. Guo, Y. Hao, A. Hershcovitch, H. Huang, W.A. Jackson, J. Kewisch, C. Liu, H. Lovelace III, Y. Luo, F. Meot, M.G. Minty, C. Montag, R.B. Palmer, B. Parker, S. Peggs, V.H. Ranjbar, G. Robert-Demolaize, S. Seletskiy, V.V. Smaluk, K.S. Smith, S. Tepikian, P. Thieberger, D. Trbojevic, N. Tsoupas, W.-T. Weng, F.J. Willeke, H. Witte, Q. Wu, W. Xu, A. Zaltsman, W. Zhang, E. Gianfelice-Wendt, *eRHIC Design Status*, in Proceedings of IPAC-18, Vancouver (2018), TUYGBD3.

[26] Y. Luo, G. Bassi, M. Blaskiewicz, W. Fischer, Y. Hao, C. Montag, V. Ptitsyn, V. Smaluk, F.J. Willeke, *Study of Crabbed Collision in eRHIC With a Combination of Strong-Strong and Weak-Strong Simulations*, in Proceedings of IPAC-18, Vancouver (2018), MOPMF012.

[27] A. Blednykh, G. Bassi, M. Blaskiewicz, C. Hetzel, V. Ptitsyn, V. Smaluk, F.J. Willeke, *Impedance Modeling for eRHIC*, in Proceedings of IPAC-18, Vancouver (2018), TUPMF027.