Fluctuations in Undulator Radiation (FUR): Proposal for IOTA Run 2

PERSONNEL

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PURPOSE AND METHODS

This experiment will be a continuation of the Run-1 study described in detail in Ref. [1]. The significant improvements in beam characterization and beam stability in IOTA in Run 2 will allow us to collect higher quality data and to make theoretical predictions with smaller uncertainties. We plan to include these improvements in Ref. [1] and re-submit the article to Phys. Rev. Accel. Beams.

In particular, the improvements with respect to Run 1 include:

- Better undulator positioning and faster procedures for placing it in the ring.
- Better beam lifetime. We will be able to collect more data per injection.
- Synchrotron-light cameras are better calibrated. Measured transverse bunch sizes are continuously saved in the data logger. Saturation is avoided by closing the irises in the periscopes.
- The longitudinal picomotor on the detector stage was replaced with a faster stepper motor. This configuration proved very effective in finding the optimal position for the URSSE experiment, where the area of the detector was even smaller (0.18 mm diameter vs. 1 mm diameter).
- Longitudinal bunch lengths are now continuously measured by a bunch-profile monitor [2] and the measurements are saved in the data logger.
- We will save oscilloscope waveforms in binary format, reducing the collection time of each waveform from 1 minute to 5 seconds.
- A filter wheel with 8 positions was installed, replacing the 4-position slider that we had during Run 1.
- The collected data can now be analyzed on the UChicago computing cluster [3].

Unlike in Run 1, all the parameters required to make theoretical predictions for the magnitude of fluctuations in undulator radiation (beam current, transverse bunch sizes, and longitudinal bunch length) are now in ACNET and will be available for all data sets.

BEAM CONDITIONS

- Injections of up to 4 mA in IOTA.
- Beam in the main RF bucket and negligible charge ($< 1\%$) in the other 3 buckets.
- Two lattices: (1) Flat beams, uncoupled tunes, with transverse beam sizes at the undulator of the order of 1.0 mm $\times$ 0.1 mm (FUR_FLAT lattice file); (2) Round beams, on coupling resonance (FUR_ROUND lattice).
- Variable RF voltage to change bunch length in the range 25–50 cm.
- Beam lifetime longer than 10 minutes.

APPARATUS

The apparatus is described in detail in Ref. [1]. It is installed at the M4R synchrotron-light station in IOTA.

We will use a PIN InGaAs photodiode with peak quantum efficiency of about 80% at wavelengths around 1 μm. The fundamental wavelength of undulator radiation is at 1077 nm. The undulator radiation will be focused on the sensitive area of the detector (1 mm diameter) by one lens with a 15-cm focal length. The detector will be on a 3D movable stage for optimal positioning.

The photodiode will be on a board with a simple op-amp-based RC integrator, so that the amplitude of the resulting signal will be proportional to the number of generated photoelectrons.

The output of the integrator will then go to a comb filter with exactly one IOTA revolution delay. A hybrid component will be used to obtain sum and difference of the initial and delayed signals. It will help us remove the baseline and look directly at the fluctuations of the amplitude in the difference output of the comb filter. All 8 bits of our oscilloscope will be used effectively in this way.

We will collect 1.6-ms-long waveforms on the oscilloscope for both sum and difference channels at 20 GSa/s. The waveforms will be analyzed offline to determine the variance of the amplitude turn-by-turn.

RUN PLAN

We request two 8-hour shifts. Some of the proposed work has already been started or accomplished during the commissioning shifts. The status of each item is indicated below.

Shift 1

- Replace the SPAD with the InGaAs photodiode at M4R. (Accomplished.)
- Align the detector with the incoming undulator radiation. (Accomplished.)
- Record transverse and longitudinal scans by slowly moving picomotors and stepper motor to clearly see the shape of the light spot (resulting from the convolution of the light intensity with the detector size).

- Collect waveforms at different values of the beam current without ND filters and without the comb filter for the FUR_FLAT lattice. (Started.)

Shift 2

- Collect waveforms at fixed current (about 3.0 mA) with different neutral density filters with FUR_FLAT lattice and with the comb filter. (Started.)
- Collect waveforms at different values of the beam current without any filters with both FUR_FLAT and FUR_ROUND lattices and with the comb filter. (FUR_FLAT was started during commissioning. FUR_ROUND was not.)
- Collect waveforms at different values of the beam current without any filters with FUR_ROUND lattice and with the comb filter with lower RF voltage to increase the longitudinal beam size.

FUNDING

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[1] I. Lobach, V. Lebedev, S. Nagaitsev, A. Romanov, G. Stancari, A. Valishev, A. Halavanau, Z. Huang, and K.-J. Kim, *Statistical Properties of Undulator Radiation in the IOTA storage ring*, Tech. Rep. FERMILAB-PUB-19-616-AD-DI (Fermilab, 2019) arXiv:1912.06737 [physics.acc-ph].
[2] "Bunch profile monitor for IBS study," `https://cdcvs.fnal.gov/redmine/projects/ibs-study/wiki` [Online; accessed 17-Mar-2020].
[3] "University of Chicago Research Computing Center," `https://rcc.uchicago.edu` [Online; accessed 17-Mar-2020].
[4] "Quantum effects in undulator radiation," Fermilab LDRD Proposal L2019.025, June 2019 – September 2021, PI: Sergei Nagaitsev; Co-PIs: Ihar Lobach, Aleksandr Romanov, and Giulio Stancari.