

EXPLOITING BLUESKY TO ENHANCE UNDULATOR CHARACTERISATION AND COMMISSIONING PROCESSES AT BESSY II

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Abstract

Undulators at BESSY II are routinely inspected for their impact on the machine tune and orbit, with the goal of ensuring tune and orbit feedforward tables remain fit for purpose. In particular this is necessary following modifications to the storage ring, as well as more obvious cases such as the installation of new devices and repositioning of existing devices. To that end a commissioning framework exploiting the Bluesky ecosystem has been established. Undulators and diagnostic hardware are represented through Ophyd device abstractions, and measurements are orchestrated as Bluesky plans with full metadata stored in a mongoDB database with databroker. This has enabled the creation of an ID scan dataset for real-time analysis during commissioning, rather than relying on post-hoc extraction of data from the Archiver for offline analysis. Consequently, this work has brought more consistency and better reproducibility of undulator scans, and provides the infrastructure required for more ambitious commissioning goals. It has also brought flexibility to commissioning scripts to take advantage of other innovations on the BESSY II machine and control environment. This paper outlines the application of this work to routine undulator commissioning and future goals to further simplify commissioning workflows.

INTRODUCTION

Distortions to the beam optics at BESSY II, caused by the motion of installed insertion devices, are corrected through feedback and feed-forward systems [1]. Correction coil feed-forward tables can suppress residual orbit distortion to below 1 μm RMS, and quadrupole trim tables hold tune drift to less than 1 kHz through the full range of undulator motion. These tables are routinely checked during machine commissioning weeks to account for long-term drifts and step changes in the BESSY II configuration.

For many years this was achieved with bespoke scripts written in Perl. These were effective at generating feed-forward corrections but recorded no contemporary dataset. Comparing table effectiveness over time required either screenshots or archiver archaeology. Meanwhile, accelerator control systems at HZB were broadly migrating to Python, leaving the Perl toolchain isolated in the wider control environment.

Migrating to Python has made it possible to leverage community packages — Ophyd, Bluesky [2], and databroker — to build a toolchain that continues to provide effective feed-forward tables, while also producing well-

formatted, contemporary datasets consistent with other experimental data collected at the facility. This enables systematic assessment of feed-forward table effectiveness over time, and positions undulator commissioning data for future use in machine learning and digital twin applications.

The conceptual structure of the work is described below, as well as a case study comparing the evolution of behaviour of an undulator over three years. This was enabled by collected datasets that allowed systematic assessment of feed-forward table effectiveness over that time.

IMPLEMENTATION

The BESSY II control system is EPICS, and this is connected to Python environments through PyEPICS.

The final design goal of the new toolchain was to record a contemporaneous dataset of machine orbit and tune parameters in a comprehensive, self-describing format consistent with other datasets and tools used at HZB. The Bluesky package was chosen for the orchestration layer, as it was beginning to be used across accelerator operations and was being rolled out across select beamlines at BESSY II. Bluesky already had a well-developed data export pipeline through databroker, and is designed to be a device- and detector-agnostic orchestration layer. Although designed with beamline experiments in mind, Bluesky is trivially portable to devices such as undulators and detectors, for instance BPMs in storage rings.

The most challenging aspect of the work was representing the various undulator styles installed at BESSY II as Ophyd components that Bluesky could consistently interact with. BESSY II is furnished with 13 undulators: 5 out-of-vacuum planar undulators, 7 APPLE II devices, and one CPMU. The first of these devices was installed in 1997, the most recent in 2025. Although all have been designed and built in-house, designs and control systems have developed over the last three decades. The Ophyd device classes therefore needed to be flexible enough to handle the variation across device generations, whilst retaining a consistent interface to the Bluesky orchestrator.

Although the creation of a unified Ophyd class sounds straightforward, several technical challenges presented themselves during implementation. The undulator IOC updates at 10 Hz, but small gap motions can complete within a single update cycle — meaning motion can occur without any change in the 'run' PV state. Wiring the completion callback to the gap PV readback proved inadequate: dead-band settings could exceed the requested step size, suppressing any PV change, while the controller's in-position window meant the readback never settled to the target with sufficient precision to trigger reliably. A run-count register

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(incremented by the controller on each motion event independently of position readback) provided a robust alternative. Separately, legacy staging and locking logic within the undulator control system required handling beyond the normal Ophyd stage/unstage cycle; in practice this extended to the use of stub plans to ensure devices are in the correct state prior to motion.

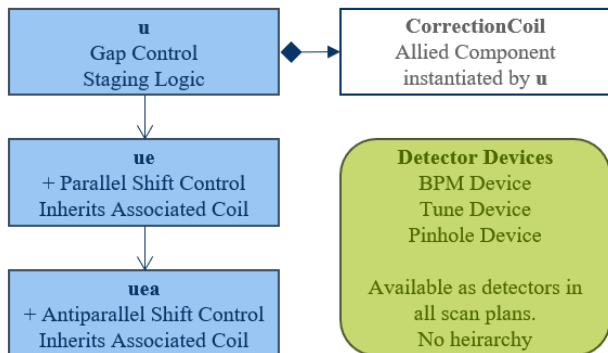


Figure 1: Inheritance and instantiation structure of the BESSY II Undulator Ophyd Device.

It was decided to initially disregard the shift motion of the elliptical devices, the one common feature of all BESSY II undulators being that they have a variable gap. Once the peculiarities of the BESSY II undulator gap had been captured by an Ophyd base class (known as `u`), an elliptical undulator child class was created (`ue`), which introduced parallel shift control, as all BESSY II APPLE devices are capable of parallel shift. The `ue` class was then subclassed to `uea`, capable of antiparallel shift motion. The allocation of each undulator is listed in Table 1. Although not intrinsically part of the undulator, the orbit correction coils were also created as an Ophyd component instantiated by the `u` class. In this way all devices associated with the undulator are accessible through a single Ophyd undulator object, as illustrated in Fig. 1. All functionality is exposed as a Python module importable within the HZB control system.

Table 1: Undulator Types at BESSY II

Class	Motion	Undulators
<code>u</code>	Gap	U17, U41, U49/1, U49/2, U125/2, U139
<code>ue</code>	+ Parallel Shift	UE56/1
<code>uea</code>	+ Anti-parallel Shift	UE46, UE48, UE49, UE51, UE52, UE112

In addition, detector components were created for the tune and pinhole devices, which can be dropped into Bluesky plans alongside the existing BPM device infrastructure. The value of this device-agnostic abstraction was demonstrated when BPM signal processing hardware was replaced across BESSY II: updating the orbit readback required modification of a single PV pattern within the Ophyd component, with no changes to plan logic.

Commissioning Workflow

A series of Jupyter notebooks were developed to exploit the undulator Ophyd class and ensure consistent application of diagnostic undulator scans. To avoid hard-coding, drift, and poor traceability, four canonical notebooks are curated under HZB's GitLab instance (for orbit and tune, covering both scanning and correction).

The scan notebooks contain comprehensive instructions for running the scan and correction experiments, as well as Bluesky plan blueprints for each undulator type, covering staging, gap sweep, parallel and antiparallel shift sweep, and unstaging in sequence. On completion, databroker stores the measured data as a run identified by a unique UID. These UIDs are manually entered into analysis cells further down the notebook template, producing a measurement summary of orbit and tune disturbance across the scanned parameter space. The complete workflow, and wider process stack, is shown in Fig. 2.

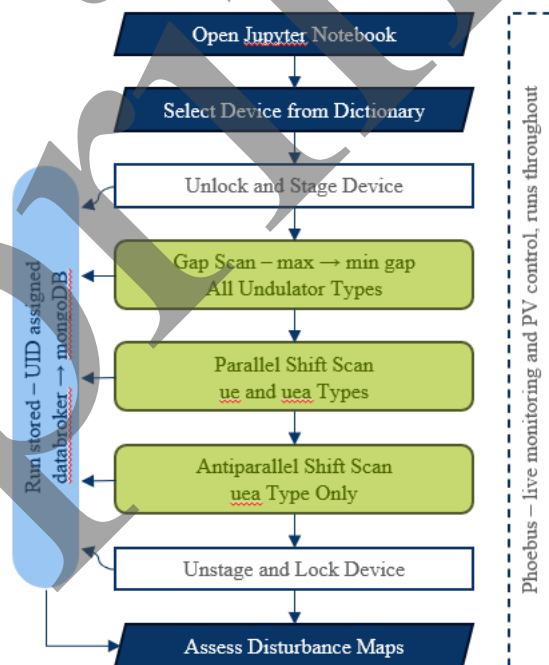


Figure 2: Commissioning process flowchart using new Ophyd Structure

The contemporaneous nature of this dataset allows robust, repeatable analysis — a significant improvement over the previous method of eyeballing residuals from archived data.

Scans are repeated across all installed devices, and the worst offenders are progressed to the orbit or tune correction workflows. The correction workflows do not currently record their progress through Bluesky (the process being a correction rather than a measurement) but all Ophyd development required for the scan functions is directly applied. Following correction, the diagnostic scan can be repeated and the improvement assessed directly across gap (and shift) spaces, an example of which can be seen in Fig. 3.

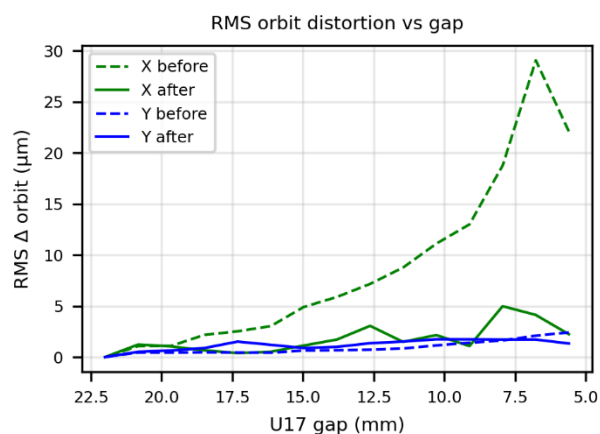


Figure 3: Rapid analysis of before and after responses of the CPMU17 [3] feed forward tables.

Case Study: Long-term Monitoring of UE48

In February 2020, a water leak at BESSY II resulted in the magnets of the UE48 [4] device being irrigated for an extended period of time.

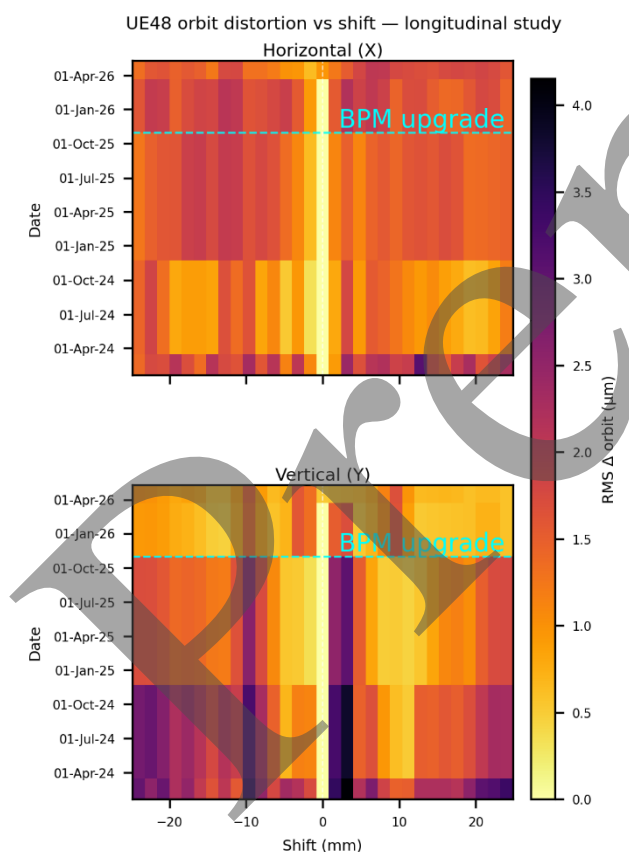


Figure 4: Time series plot of UE48 parallel shift scan at 16 mm minimum gap. The cyan line represents the upgrade to new BPM electronics [5].

The magnets of UE48 are uncoated, and such extensive exposure to water entails the risk of highly accelerated oxidation at the magnet surfaces. The proximity of the magnets to the electron beam, due to the 16 mm minimum gap

of the device, means that any change in the magnetisation characteristics of the device will manifest first as orbit and tune disturbances.

The standardisation of the measurement plans allows for exactly the kind of longitudinal study required to monitor the long-term effects on UE48. Fig. 4 shows RMS orbit distortion due to UE48 at minimum gap, as a function of shift and date. Although the behaviour of UE48 across the time period does not remain exactly the same, the plots do show us that deviations of the RMS orbit are in the order of 1 micron over the last three years. Continuing corrosion of the device would have presented a much stronger signal over that time, and so using the newly accessible datasets, we are able to confidently assert that there is no measurable detriment to the performance of UE48 in the years following its unintended baptism.

FUTURE WORK AND CONCLUSION

Future Work

The development of commissioning tools is a never-ending task, but the specific roadmap for this work has several concrete plans outlined. The notebooks will be published into the BESSY II eLog, providing a robust record of work and results in the institution's log. The measurement datasets generated by this toolchain are well-positioned for use as inputs to digital twin or machine learning applications to improve the generation of feed-forward tables at BESSY II. Finally, migration from databroker to Tiled (the data access layer now recommended by the Bluesky project) is planned in line with upstream development.

This work is designed to sit naturally within the wider community trend to move accelerator toolchains to Python and Bluesky implementations, such as pyAML [6].

Conclusion

Since 2023 there has been an ongoing effort to migrate undulator commissioning tools to a Python environment, and to exploit Bluesky as a framework for seamlessly collecting contemporaneous results from insertion device scans. The Ophyd undulator components are flexible enough to cope with continually evolving hardware, whilst maintaining a coherent and consistent interface to allow Bluesky plans to be executed device-agnostically. The work has proved itself robust to hardware changes and has demonstrated its worth through the validation of undulator performance at BESSY II over a long timeframe.

The structured notebook approach to commissioning is still being established, but represents a substantive move away from previous ad-hoc scripting practices; providing a repeatable and traceable commissioning framework for the facility.

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