ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-THBPP04

HARD X-RAY PAIR DISTRIBUTION FUNCTION (PDF) BEAMLINE AND END-STATION CONTROL SYSTEM*

O. Ivashkevych†, M. Abeykoon, J. Adams, G. Bischof, E. Dooryhee, J. Li, R. Petkus, J. Trunk, Z. Yin, BNL, Upton, USA

Abstract

The Pair Distribution Function (PDF) beamline is the latest addition to the Diffraction and In Situ Scattering program at the National Synchrotron Light Source-II (NSLS-II) at Brookhaven national Laboratory. The DW100 damping wiggler on 28-ID is the source for two branch lines: X-ray Powder Diffraction beamline, XPD (28-ID-2) constructed in 2015 and Pair Distribution Function, PDF (28-ID-1) beamline constructed in 2018. The state-of-the-art gantry system (Bridge) of the PDF beamline end-station consists of two detector translation stages and one sample translation stage. The detectors and sample stage move at 300 mm/s using Linear Brushless DC motors that are controlled by a Geo Brick LV Delta Tau motor-controller. All three translation stages are equipped with absolute encoders and proximity sensors to avoid collisions. The control system slows down the stages when proximity switches are activated. A complex controls and safety systems with multiple custom features are required to provide the full functionality of the Bridge and to protect equipment and users. An optics conditioning module (OCM) located upstream of the Bridge contains clean-up slits, a fast shutter that is synchronized with detector frame rate, an alignment LASER, and an X-ray Energy Calibration System (ECS). The controls system of the OCM supports automatic operation of the ECS followed by unexpected beam dumps to recalibrate the X-ray wavelength.

INTRODUCTION

PDF is a powerful technique to study local structural fluctuations in complex materials, which are very often responsible for tuning their interesting properties. 28-ID-1 is the dedicated PDF beamline at the NSLS-II. The beamline is optimized for total scattering measurements over a large Q-range with very low background. Beamline end-station experimental setup is designed to provide complementary Wide angle X-ray Scattering (WAXS) and Small Angle X-ray scattering (SAXS) data along with PDF data to enable multi-modal approach. The beamline end-station Bridge provides fast exchangeability between PDF, SAXS and WAXS setups. A variety of sample environments including a (5-500) K liquid He cryostat coupled to a (0-5) T superconducting magnet, a (80-500) K liquid nitrogen cryostream, a hot air blower and a gas flow-cell heater are available on a large optical table located underneath the Bridge. Currently, the beamline can operate at two discrete energies, 75keV and 117 keV using 2 special cut monochromator crystals.

A schematic layout of the beamline optical configuration is shown in Figure 1. The first optical component of the PDF beamline, Side Bounce Monochromator (SBM) receives the part of white beam that is transmitted through the first crystal of the 28-ID-1 (XPD) beamline Double Laue monochromator. The SBM is used to select the X-ray photon energy of the PDF beamline and to focus the monochromatic X-ray beam in the horizontal plane. The second optical component of the PDF beamline, the Vertically Focusing Mirror (VFM) is used to focus the X-ray beam in the vertical plane. The Beam Diagnostic Module (BDM), located downstream of the VFM, contains beam-defining slits and a beam monitor. The PDF monochromatic beam travels between the First Optical Enclosure (FOE) and experimental hutch B inside a shielded beam transport.

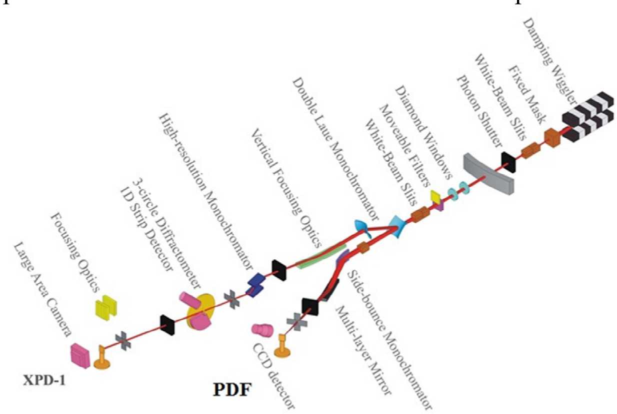

Figure 1: A schematic layout of the 28-ID optical configuration.

The Optics Conditioning Module (OCM) located upstream of the Bridge in hutch B consists of a fast photon shutter, a set of attenuators, clean-up slits, a beam alignment system using a LASER pointer, a telescopic beam guide, and a movable 2-circle Diffractometer for energy calibration. A 3-D CAD layout of the PDF end-station in shown in figure 2.

The two detector stages and the sample stage move independently from each other 3m along the path of the X-ray beam. Detector and sample stages are certified for carrying up to 200kg, and 100kg loads respectively. They are configured to move at 300 mm/s. The unique design of the bridge combines versatility of high speeds with experiment automation, and meets the NSLS-II Personal Protection System (PPS) and Equipment Protections System (EPS) requirements.

The NSLS-II uses Experiment Physics and Industrial Control Systems (EPICS) [1] as the controls framework.

* This research used resources of the National Synchrotron Light Source II, a U.S. Department of Energy (DOE) Office of Science User Facility operated for the DOE Office of Science by Brookhaven National Laboratory under Contract No. DE-SC0012704."
†oksana@bnl.gov

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-THBPP04

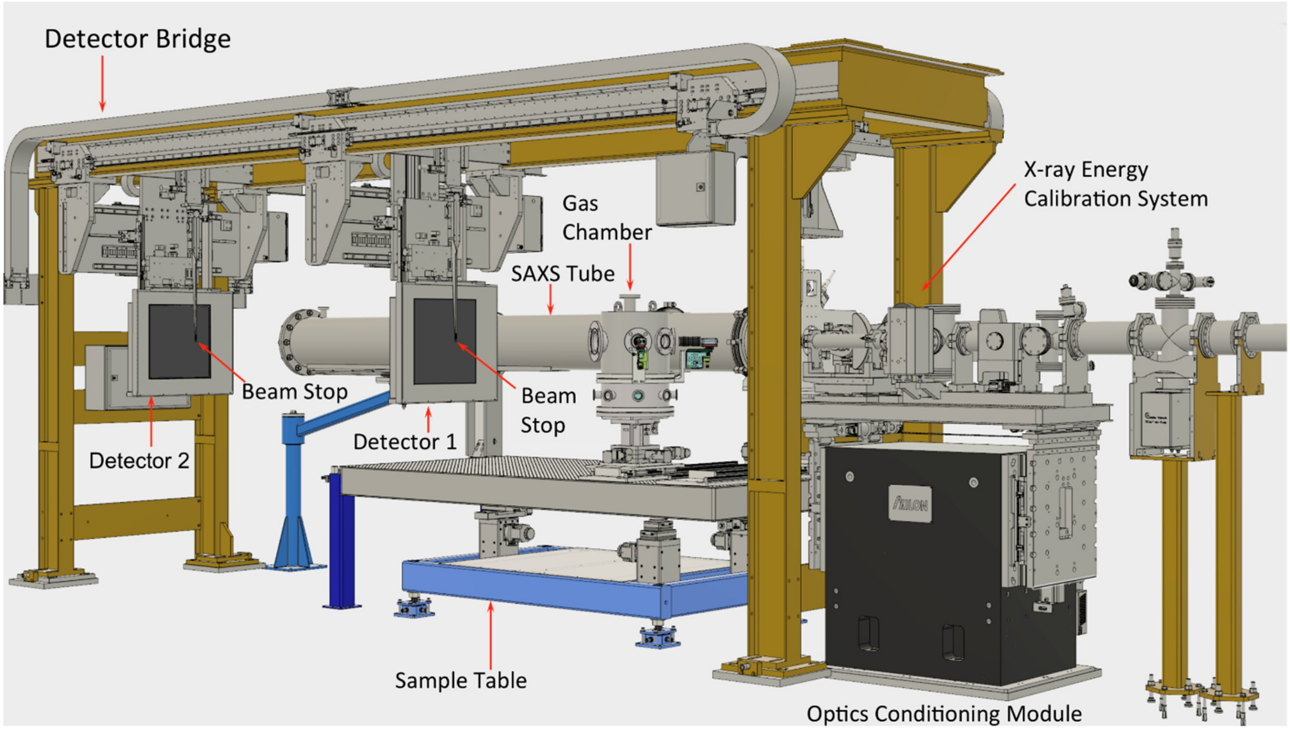

Figure 2: 3-D CAD layout of the OCM, Bridge, and the optics table.

Control System Studio (CSS) [2] for the GUI and bluesky [3] framework for data collection and management [4].

NETWORK INFRASTRUCTURE

PDF network is designed to be an isolated entity from accelerator and other beamlines. See figure 3.

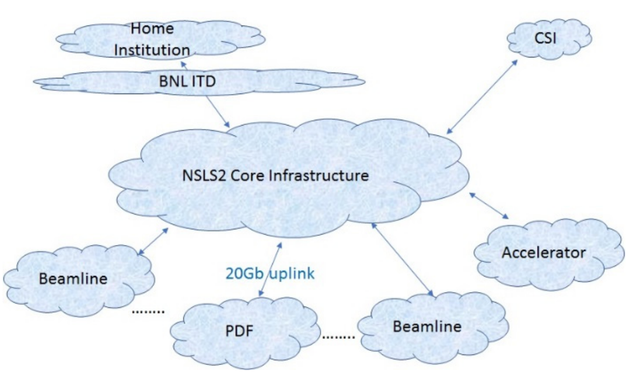

Figure 3: Top level network infrastructure.

Figure 4 shows a schematic representation of the PDF network infrastructure. Following NSLS-II standards, the PDF network is divided into three VLANs: controls, camera, and instrumentation. This architecture segregates network traffic and ensures resource priority for each subsystem. The controls VLAN is reserved for general services and Channel Access (CA) data, which encompasses EPICS Process Variables (PVs) from devices and formatted camera images. The camera VLAN is available for detectors and cameras, including raw detector data, diagnostic camera streams, and surveillance web cams for in-hutch visuals. Lastly, the instrumentation VLAN is predominantly populated with low bandwidth devices related to motion, vacuum, and diagnostics.

Beamlines can access accelerator PVs and other beamline PVs via gateway IOCs. An Access Configuration Control Gateway (ACG) configuration file determines which PVs have write or read access. If a PV is not defined in the ACG file, it cannot be accessed from the local network. This implementation ensures that only approved traffic can path through the gateway. 28ID has 3 gateway IOCs: XPD-Accelerator, PDF-Accelerator, and XPD-PDF.

LEVERAGING COST WITH XPD

PDF and XPD beamlines share common front-end equipment before beamlines split as discussed earlier. Also, PDF and XPD beamlines share other expensive equipment, such as, Allen Bradly PLC for the EPS systems, GPFS data storage infrastructure, and FMB C400 pulse counting detector controller. The C400 is residing in XPD controls equipment rack with the first 2 channels connected to XPD, and the last 2 channels connected to PDF via ACG configuration file described above. Both beamlines have read-only access to the PVs of all 4 channels of the C400 pulse counting detector controller and write access only to their own channels.

GPFS DATA STORAGE

The PDF and XPD beamlines share an IBM DCS3700 disk array, a high-density solution housing (60) 4 TB drives in a single (4) RU (Rack Unit). The disk drives are organized into resilient double-parity pools and mapped to (3)

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-THBPP04

data analysis servers via dual fibre-channel multipath connections.

The IBM Spectrum Scale (GPFS) provides an 80 TB high-performance clustered file system for exclusive use at PDF. The cluster is composed of network shared disks and (18) nodes: (3) servers and (15) clients. The Spectrum Scale architecture provides a global namespace and distributed metadata and file locking. The file system is organized into directories for software, user, and experimental data. (5) special file sets (directories) are created to provide redundancy. Data written into these file sets are asynchronously cloned to NSLS-II central storage for export and tape archival.

MAINTENANCE AND STANDARDS

The PDF control system is designed with "maintenance free" vision, automated recovery from failures, equipment protection from unintended actions from users and for a positive User Experience. The PDF control system equipment selection followed NSLS-II standards, which were adopted at the beginning of NSLS-II project. For motion control, we use Delta Tau GeoBrick LV NSLS-II controller, SmarAct MCS for piezo assemblies, Allen Bradley PLC solution for Equipment Protection Systems (EPS), Prosilica cameras for diagnostic, and Axis webcams for in-hutch visuals.

The bend and twist motions of SBM are built with low current (125 mA) Faulhaber motors. These motors are not controlled by a special low current motor-controller, but by a standard 5 A Delta Tau unit [5,6] and protected from current spikes by a fuse box [6]. Using standard motor controller for nonstandard motors helps keeping low cost small equipment diversity by efficiently using all available channels. Delta Tau configuration files are version controlled together with EPICS soft Input Output Controller (soft IOC) deployment. In case of a hardware failure, motor controller will be swapped, and the versioned configuration file will be downloaded.

The PDF Control System is built using EPICS [1] framework. EPICS community offers a very good coverage of device drivers support, areaDetector package [7] with rich features for data conditioning, processing, and saving in variety of data formats. Process Variables (PVs), an EPICS unit of data are archived in Archiver Appliance [8]. Control System Studio (CSS) [2] is used as a front-end GUI and operation environment. CSS's rich features include integrated Logbook, Best Ever Alarm System Toolkit (BEAST), Data Browser, and others. Data Browser is integrated with Archiver Appliance and can plot data from live or archived PVs. equipment protection

The Equipment Protection System (EPS) is responsible for protecting various components from damage. This includes isolation of vacuum sections with poor vacuum to prevent contamination of adjacent sections, overheating protection, collision prevention, control of filters to prevent damage to detectors. The EPS system has interlocks for each shutter on the beamline. This means that a set of conditions needs to be met to enable its operation. If any of these conditions are not met, the shutter will be closed. The EPS is implemented with an Allen Bradley PLC and Point I/O.

All gate valves that can be exposed to white beam are part of a "beam dump" circuit, which will cause the beam in the storage ring to be dumped if the valve closes before it's upstream shutter. This prevents the beam from damaging the gate valves [9].

All motions are equipped with limit switches, which provide signals to Delta Tau motor controller to stop. In addition to limit switches, overtravel switches are installed on axis where limit switch failure can cause equipment damage [9].

The white beam slits installed upstream of SBM, have a collision switch, which is wired in series with positive and negative limits so that activating the collision switch will stop the motion just if the regular switch is activated. The collision switch signal is also part of the EPS system.

OCM table has the tilt switch, which is wired and activated the same way as the collision switch described earlier.

As it was noted earlier, PDF and XPD beamlines share Compact Logic 5000 Allen Bradley PLC for their respective EPS systems. A 1768-L43 was selected because it supports having two isolated network adapters. One network is used for communication to the remote Point I/O, and the other is used for connection to the beamline controls network. This unit has 2MB of memory, 600kB are used for both PDF and XPD. The average cycle time is 7ms. This unit reliably serves both beamlines needs. PDF and XPD each run a separate EPICS IOC within their own subnets and connect to the Allen Bradley PLC beamline port. Hardware serves both beamlines, PDF and XPD without them being aware of it on the user end. Each beamline can read and write only to their own set of PVs.

BRIDGE

The Bridge is the jewel of PDF beamline end-station. It has two detector carrier stages and a stage for sample environments. All three stages can move independently along 3m travel. See figure 5 and the 3D schematic layout in figure 2.

Each stage is driven by two linear servo motors in a gantry configuration. Magnetic rails are mounted on both sides of the bridge for commutation of the motors. A 3 m absolute RESOLUTE Renishaw encoder with 50 nm resolution is installed on one side of the bridge. The absolute encoder and magnetic rails provide feedback and commutation signals to all 3 motions. Both motors in a gantry pair are wired in parallel so that a single Delta Tau channel drives both motors in a gantry stage motion.

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-THBPP04

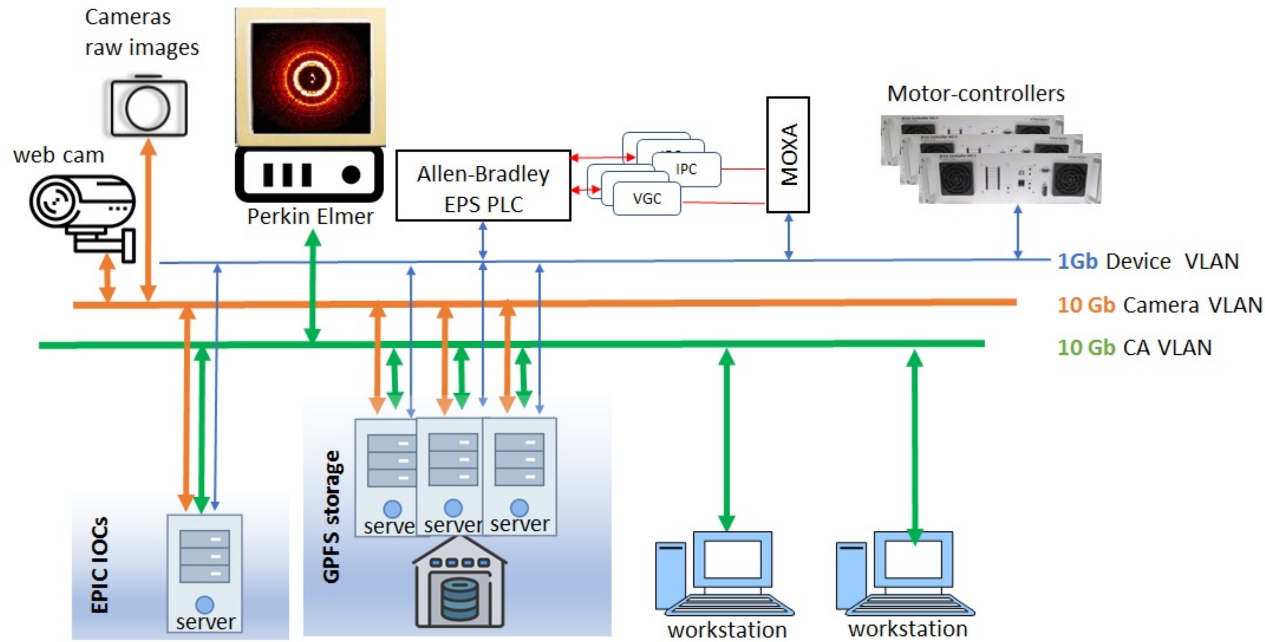

Figure 4: Beamline network has three dedicated Virtual LAN: low bandwidth device, raw camera data, and Channel Access (CA) client services.

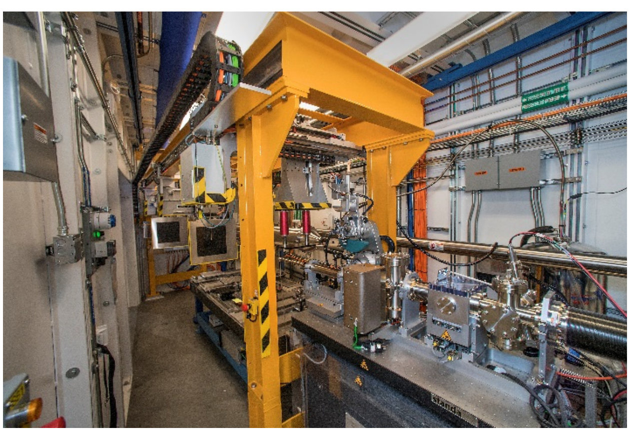

Figure 5: Picture of the Bridge showing two detector stages and the sample grid.

All three stages can also move vertically (Y) and horizontally (X). Two of these motions use linear servo motors and the other four use Brushless DC (BLDC) servo motors. Each stage has a motorized beam stop. The upstream detector stage can be fully retracted from the X-ray beam path by pneumatic actuator to allow the use of downstream detector.

Since the two detector stages are certified for carrying up to 200kg, and the sample stage is certified for carrying up to 100 kg, all three vertical (Y) motions have brake support installed to prevent the stages from sliding down. The brake is disengaged if the amplifier is enabled and engaged otherwise. The holding current provided by 5 A Delta Tau channel is enough to keep 200kg phased stage in place.

Each carrier assembly is equipped with optical proximity switches on both ends (see Figure 6). Those switches get activated and remain activated when the stages get as close as 30 – 40 cm to their end of travel or close to another stage, respectively. In response to this signal, the moving stage(s) slow down to 30mm/sec, and always move with the reduced speed if the proximity signal is activated. If the motion command started in the fast region and ended in the slow one, the stage will travel 300 mm/s in the first, and 30mm/sec in the second region respectively and stop at the requested position. This has been implemented using motion program and slew rate features of the Delta Tau motor controller.

Figure 6: Proximity sensors, hard stop, and the soft dumper.

Bridge Personnel Protection

The Personal Protection System (PPS) for the bridge was implemented with an Allen Bradley CR30 programmable safety relay (see Figure 7). The PPS system is an independent system that ensures that the grid and detector carriers cannot be moved while the hutch is open. The CR30 monitors the position of the hutch doors, e-stops, over-travel switches and engages the safety brakes for all motions if an input is not satisfied. A reset button is mounted outside of the hutch to rearm the system.

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-THBPP04

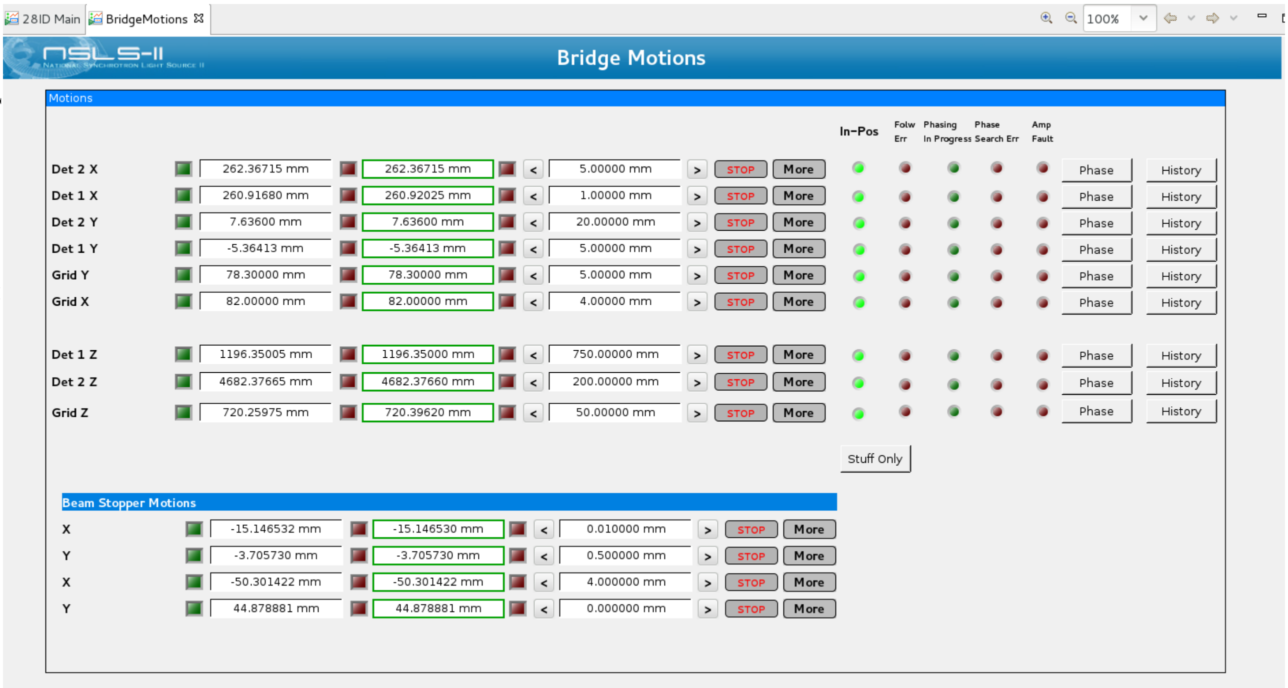

Figure 7: Bridge Control System Studio GUI.

The stages with Brushless DC motors are equipped with a motor brake to ensure self-locking when no motor current is applied and / or the power is lost. The stages with linear servo motors including the fast-moving ones have safety breaks installed. All breaks are activated, when hutch is unsecured. All brakes are normally engaged so if the PPS system loses power, the system will be in a safe state.

The PPS system has an override capability, in the form of an override key. When the key is used, the detector carriers and bridge can be moved with the hutch door open. The other interlocks are still in place. The beamline staff keeps the key in a secure location. When the key is engaged an administrative procedure is followed to ensure there are no people in the path of the detectors. This enables the beamline staff to do setup, calibration, and custom operations.

FIRST USER EXPERIENCE

Complexity of servo motors with the need to phase has been hidden from the users. Motors are phased just once after motor controller power up. User can monitor the status of the phasing via LEDs on OPI screen as well as errors if they occur.

Only if the stage is manually moved by a qualified beamline stuf from the magnet locked position with the use of safety bypass key, it would need to be phased again. Phasing of the motors can be done from CSS GUI.

Technical commissioning demonstrated that experiments can safely and reliably run overnight from the bluesky [3] interface.

CONCLUSION

The new Pair Distribution Function (PDF) beamline of the NSLS-II is now available for general user operations. The unique design of the beamline end-station Bridge combines versatility of high speeds with experiment automation and meets all the NSLS-II EPS PPS requirements.

Design and construction of the PDF beamline controls system were completed following the NSLS-II standards, which greatly simplifies maintenance by limiting diversity of the equipment and solutions.

The network follows a clean distribution-edge architecture with ample 10 G port capacity for future growth. The Spectrum Scale filesystem allows shared file access without resorting to a slow, monolithic NFS solution. This architecture will enable the integration of new capacity and technology with minimal efforts.

Early user feedback during technical commissioning led to a higher degree of automation, and rich experimental features offered from the early days of operation.

REFERENCES

[1] EPICS, https://epics.anl.gov, https://epics-controls.org

[2] CSS, http://controlsystemstudio.org

[3] Bluesky, https://blueskyproject.io

[4] Danial Allen, Thomas Caswell, Stuart Campbell & Maksim Ratkin (2019) Bluesky's Ahead: A Multi-Facility Collaboration for an a la Carte Software Project for Data Acquisition and Management, Synchrotron Radiation News, 32:3, 19-22, doi:10.1080/08940886.2019.1608121

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-THBPP04

[5] Geo Brick Manual,
http://www.deltatau.com/manuals/pdfs/GEO%20BRICK%20LV.pdf

[6] O. Ivashkevych, A. Munoz, and D. Poshka, "Do You Really Need a Low Current Amplifier to Drive a Low Current Motor?", in *Proc. 16th Int. Conf. on Accelerator and Large Experimental Control Systems (ICALEPCS'17)*, Barcelona, Spain, Oct. 2017, pp. 730-733. doi:10.18429/JACoW-ICALEPCS2017-TUPHA134

[7] areaDetector, https://areadetector.github.io

[8] Archiver Appliance,
https://slacmshankar.github.io/epicsarchiver_docs/index.html

[9] H. Xu, H. Bassan, G. Bischof, B. T. Clay, and R. A. Kadyrov, "NSLS-II Beamline Equipment Protection System", in *Proc. 16th Int. Conf. on Accelerator and Large Experimental Control Systems (ICALEPCS'17)*, Barcelona, Spain, Oct. 2017, pp. 638-640.
doi:10.18429/JACoW-ICALEPCS2017-TUPHA095