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SAMPLE AND DETECTOR POSITIONING INSTRUMENTS FOR THE WIDE ANGLE XPCS END STATION AT 8-ID-E, A FEATURE BEAMLINE FOR THE APS UPGRADE*

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Abstract

The X-ray Photon Correlation Spectroscopy (XPCS) beamline at the Advanced Photon Source (APS) has been selected as one of the nine feature beamlines being designed to take advantage of the increase in coherent flux provided by the APS Upgrade. The 8-ID-E enclosure at the beamline will have a dedicated instrument for performing Wide Angle XPCS (WA-XPCS) measurements across a range of length and time scales. The instrument will feature a high-stability 6-circle diffractometer, a moveable Long Distance Detector Positioner (LDDP) for positioning a large pixel array detector, and a removable flight path assembly. For intermediate sample to detector distances of 1.5 to 2 meters, a large pixel array detector will be positioned on the diffractometer detector arm. For longer sample to detector distances up to 4 meters, an horizontal scattering geometry will be utilized based on the LDDP to position a second large pixel array detector. The LDDP will consist of a large granite base on which sits a combination of motorized stages. The base will sit on air casters that allow the LDDP to be coarsely positioned manually within the enclosure. Final positioning of the detector will be achieved with the mounted stages. The spatial relationship between the sample and the free moving LDDP will be monitored using a laser tracking system. A moveable flight path will be supported by the diffractometer arm and a mobile floor support to minimize air scattering while using the LDDP. The WA-XPCS instrument has been designed with users and beamline staff in mind and will allow them to efficiently utilize the highly enhanced coherent beam provided by the APS Upgrade.

INTRODUCTION

The Advanced Photon Source Upgrade Project (APS-U) is planning a storage-ring upgrade that will reduce the electron-beam emittance by a factor of ~75. This ultra-low emittance is achieved by replacing the present storage ring lattice with a multi-bend achromat (MBA) lattice. The MBA lattice will increase the x-ray coherent fraction by two orders of magnitude and decrease the horizontal source size by a factor of ~20. In addition, the APS-U is planning to build nine new featured beamlines and make optics upgrades to many others.

One of the feature beamlines built as part of the APS-U will be dedicated to X-ray Photon Correlation Spectroscopy (XPCS) studies at sector 8ID of the APS. The 8-ID-E enclosure of the XPCS beamline will primarily perform Wide Angle XPCS (WA-XPCS) measurements and occasionally be used for positioning samples during Ultra-Small Angle XPCS measurements. Two key elements to the instrumentation required to perform these measurements are a large 6-circle diffractometer for precise positioning of samples in 3 spatial and 3 angular co-ordinates, detectors, and a Long Distance Detector Positioner (LDDP) that will allow x-ray detectors to be positioned up to 4 m away from the sample location and will span an angular range of 3-55 degrees. These instruments are shown in Fig. 1 below.

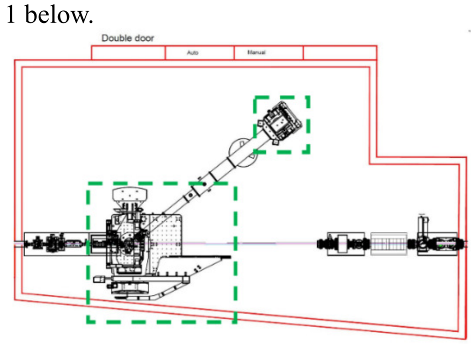

Figure 1: 8-ID-E enclosure layout with WA-XPCS instruments, diffractometer and LDDP outlined in green.

SCIENCE DRIVER

Photon correlation spectroscopy (PCS) provides information about dynamic heterogeneity in complex systems by characterizing fluctuations in condensed matter across a broad range of length and time scales while x-ray scattering provides sensitivity to order and motion at scales spanning the mesoscale to the atomic scale. A general subset of the areas of scientific investigation that will be pursued at the beamline include the role of fluctuations and dynamic heterogeneity in the properties of phase-change materials, understanding structural relaxations in supercooled liquids and their connection to glass formation, the effect of interfaces and confinement on nanoparticle dynamics, and the connection between dynamics and relaxation of shearthinned and shear thickened states. To perform successful WA-XPCS measurements requires, the formation of a small coherent x-ray spot, accurate and stable positioning of a sample, and the ability to resolve coherent x-ray speckles with an area detector. These requirements have driven the overall design of the WA-XPCS instrument.

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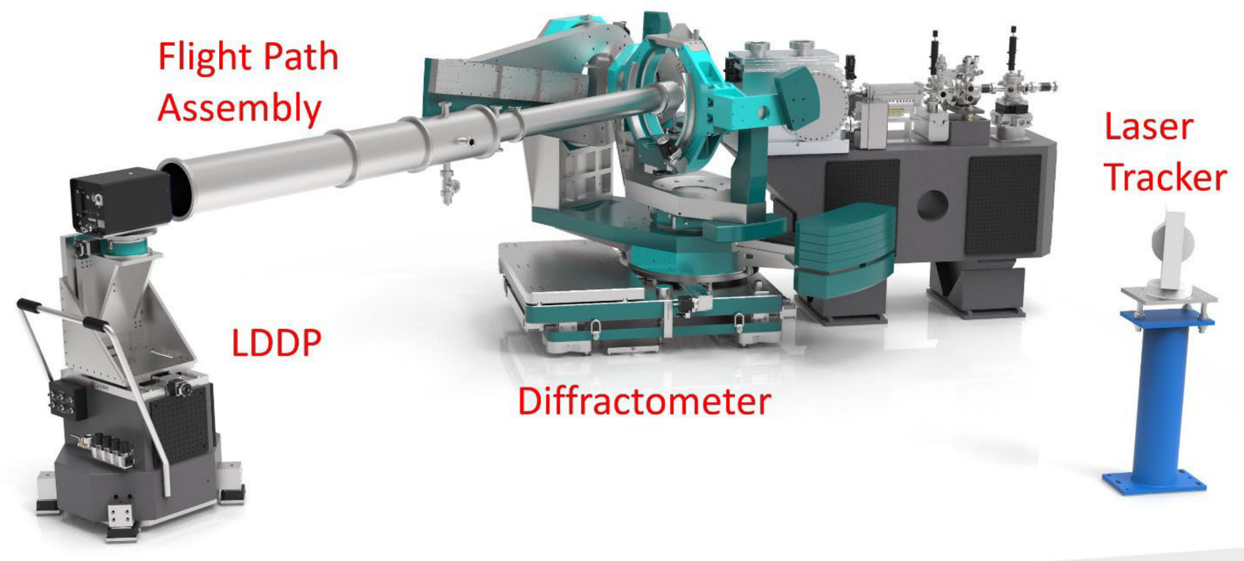

Figure 2: 8-ID-E instrument with the detector located 4 m from the sample on the LDDP. A laser tracking system positioned on a pedestal is also shown. Flight path support and window are not shown.

WIDE ANGLE INSTRUMENT OVERVIEW

The WA-XPCS instrument at 8-ID-E facilitates a variety of operating modes and experimental methods. The combination of the 6-circle diffractometer and the mobile LDDP creates a highly versatile instrument capable of positioning state-of-the-art pixel array detectors at a variety of locations throughout the enclosure. The 3 primary configurations of the instrument will be the following:

1. **Short sample-to-detector WA-XPCS (vertical scattering geometry):** In this configuration, a pixel array detector will be positioned on the diffractometer detector arm at a sample-to-detector distance of 1.5-2 m.
2. **Long sample to detector WA-XPCS (horizontal scattering geometry):** In this configuration, a second large area detector will be positioned using the LDDP at a sample-to-detector distance of up to 4 m, spanning an angular range of 3-55 degrees. Figure 2 shows the instrument in this configuration.
3. **Pinhole Ultra-Small XPCS (US-XPCS):** In this configuration the sample will be mounted on the WA-XPCS diffractometer and the detector will be positioned in the 8-ID-I shielded enclosure with a sample to detector distance of up to ~22 m.

6-CIRCLE DIFFRACTOMETER

The WA-XPCS diffractometer will be a large 6-circle diffractometer for accommodating a wide range of samples in a variety of scattering geometries. The diffractometer will have a "split" detector arm with two mounting rails for mounting detectors near the sample as well as supporting flight paths for use with the LDDP. The base positioning table of the diffractometer will have an extension in the downstream direction for mounting large additional pieces of instrumentation, which can be seen in Fig. 3 below.

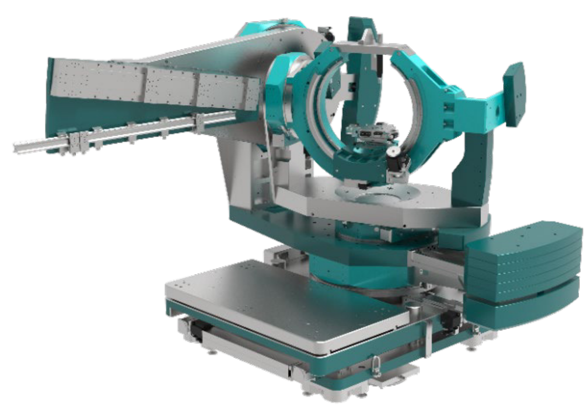

Figure 3: 6-circle diffractometer. Design and 3D model of the diffractometer provided by Huber Diffraktionstechnik GmbH & Co. KG.

LONG DISTANCE DETECTOR POSITIONER (LDDP)

The LDDP provides a versatile platform for mounting detectors up to 4 m away from sample. The LDDP will consist of a large granite base on which sits a combination of motorized stages. The granite base will sit on air casters that allow the LDDP to be coarsely positioned manually within the hutch. Once coarsely positioned, fine alignment of the detectors will be done with the motorized stages. Once in position, the location of the detector on the LDDP relative to the sample will be reported using a laser tracking system.

The air casters for the LDDP will be activated using two manual triggers on the handle of the instrument. The air casters will then lift the base and all of the supported components a minimum of 6 mm off of the floor, allowing free movement around the enclosure.

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Once the instrument has been coarsely positioned, the granite base provides a stable, low-vibration support for the stages and detector. The instrument will support detectors up to 20 kg, and the stages will provide +/-100 mm of travel both vertically and horizontally. The LDDP is shown with a detector positioned at the center of travel in Fig. 4.

Figure 4: Long Distance Detector Positioner. Design and 3D model of the LDDP instrument provided by JJ X-ray

VACUUM FLIGHT PATH ASSEMBLIES

All 3 operating configurations will require the use of a vacuum flight path assembly downstream of the sample environment. When the detector is mounted on the diffractometer, a short pipe will be mounted directly to the detector arm of the diffractometer, along with other components such as anti-scatter slits and a remotely operated filter box. In the long-distance WA-XPCS mode, a flight path assembly will be supported by the second mounting rail of the diffractometer's detector arm, and at the other end a mobile support. For Pinhole US-XPCS, a sample will be placed on the diffractometer and a flight path assembly will be supported by the diffractometer. This flight path will connect to the downstream optical components of the enclosure and will be supported by a, mobile support.

Figure 5 shows an initial concept for the flight path assembly for long-distance WA-XPCS mode. This flight path will contain several removable rigid sections to allow users to place the LDDP, along with its mounted detector, at positions between 2.5 m and 4 m from the sample, across a range of 0-55 degrees horizontally.

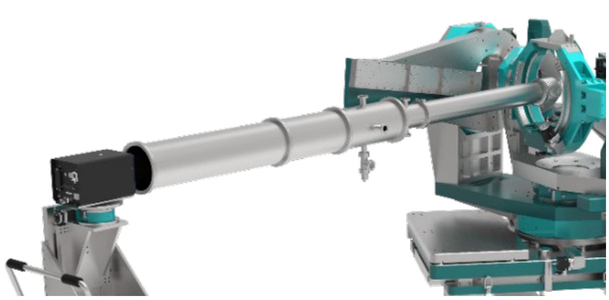

Figure 5: Removable flight path for the LDDP.

LASER TRACKER

The combination of the diffractometer and LDDP provides maximum versatility in detector positioning while preserving space in the enclosure. However, there is not a fixed spatial and angular relationship between a sample mounted in the diffractometer and a detector mounted on the LDDP. To determine this spatial and angular relationship, once the LDDP has been positioned, a laser tracker will be used to determine the location of carefully chosen fixed reflectors on the base of the diffractometer and on the LDDP. This information along with the known motion of the stages on the LDDP and the diffractometer will be used to determine the distance and angle between the sample and the detector. The yellow dots in Fig. 6 show potential locations for mounting laser reflectors. The precise configuration of the reflectors will be optimized once all the components have been installed.

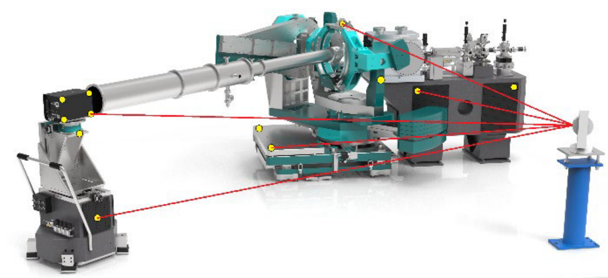

Figure 6: Conceptual schematic showing the laser tracker being used with the diffractometer and the LDDP

CONCLUSION

The APS-U will significantly enhance the coherence properties of the APS x-ray source. XPCS is one of the x-ray techniques that will most directly benefit from the 100-fold increased coherence. To fully realize these benefits, the x-ray instruments must be designed with sufficient functionality and stability to take advantage of them. The WA-XPCS instrument uses a combination of a 6-cricle diffractometer, LDDP, and laser tracker to meet these requirements, while maintaining maximum versatility to adapt to the future needs of the scientific program.

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