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NCD-SWEET BEAMLINE UPGRADE

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Abstract

The SAXS/WAXS Experimental End sTation (NCD-SWEET) at ALBA Synchrotron has undergone major improvements in three main areas, beam performance, SAXS detector data quality and beamline operability, in order to perform state-of-the-art SAXS/WAXS experiments. A new channel-cut monochromator system has improved the beam quality and stability, with current vibration amplitudes under 1% of the beam size. Two sets of refractive beryllium lenses have been installed for focussing the beam. One of the sets allows to microfocus the beam size. Besides this, the former SAXS CCD detector has been replaced by a single-photon counting pixel detector, a Piltatus3 S 1M. In the end station, a full redesign of the mechanical elements with sub-micron resolution movements together with the installation of new equipment has been completed, resulting in an improved beamline configuration, and a faster and safer rearrangement of the flight tube length. New upgraded configuration also allows for GISAXS experiments. Finally, other auxiliary improvements have been done in areas like radiation protection, air conditioning, health and safety, cable management, electronics and control.

INTRODUCTION

The NCD-SWEET beamline is dedicated to Small Angle X-ray Scattering (SAXS) and Wide Angle X-ray Scattering (WAXS) experiments at ALBA Synchrotron. SAXS experiments provide structural and dynamics information from coherently scattering entities within sample at a longer length-scale (up to several hundreds of nm). E.g. large molecular assemblies, fibres or higher order structures of proteins and polymers can be explored by this technique. WAXS technique explores structure at shorter length scales on the order of Angstroms. In addition, one of the objectives of the upgrade of beamline was to make it suitable for Grazing-Incidence Small-Angle Scattering (GISAXS) experiments which are being implemented at present.

The End Station of the beamline includes the last downstream section of beam conditioning optics, a sample environment, two detectors (SAXS and WAXS) and a flight tube on rails that permits changing the camera length and minimizing the air gap between the samples and the SAXS detector (Fig. 1).

Following some years of operations of NCD beamline, Scientific Advisory Committee suggested to perform an upgrade of the beamline in order to improve its performance. After review process by a panel of experts as well as internal discussions, a major project was developed in order to achieve the state-of-the-art for SAXS/WAXS experiments at the beamline. Present paper discusses this multidisciplinary project including all of the changes made and features added to the beamline.

Figure 1: NCD-SWEET End Station.

BEAM PERFORMANCE

In the past, NCD beamline experienced poor beam stability due to undesired vibration in the double crystal monochromator system. In order to resolve this stability issue, the former double crystal monochromator (DCM) system has been replaced with a new channel-cut system while keeping the vacuum vessel, Bragg angle goniometer and other interfaces (Fig. 2). As a result, stability has improved substantially with current vibration amplitudes under 1% of the beam size instead of 39% before the change.

Figure 2: Channel-cut monochromator system.

In addition, two sets of refractive beryllium lenses have been installed for focussing the x-ray beam. One set is located in the Optics Hutch section of the layout while the second in the End Station of the beamline. The latter enables achieving microfocus beam size at the sample position (although with the associated loss in the flux). Addition of these beryllium lenses allows for switching between the existing toroidal-collimating mirror optics

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and refractive lens optics. Consequently, the most suitable focussing configuration can be chosen depending on user.

SAXS DETECTOR DATA QUALITY

The former SAXS detector ADSC Q210R suffered a total malfunction in 2015 and was replaced with an aging ADSC Q310r kindly provided by ESRF. As a part of the upgrade project, this last detector was replaced with a new single-photon counting pixel detector Piltatus3 S 1M. This new detector has considerably improved the operation reliability of the beamline and data quality.

A new positioning table (Fig. 3) was designed and built for housing the SAXS detector, in replacement of the previously used support. This positioning table, enabling vertical, lateral and pitch movements, is based on the in-house developed "skin" concept design which provides high stability and excellent resolution performances [1]. Table consists of a sturdy granite block, two movable lateral plates driven by ball screws with linear guides actuated by stepper motors. Both lateral plates are linked together by a top plate articulated by flexure hinges, providing vertical and pitch motions. Another motion system with similar mechanics is added on top of the previously described one, providing lateral movement. Granite block functions as a stable and stiff reference for the rest of the mechanics. Ball screws have low axial clearance in order to assure good repeatability while linear guides are slightly preloaded for stiffness purposes. Metrology tests of the table movements showed submicron resolution and notable repeatability values (see Table 1). Finite element analysis (FEA) was performed in order to study the structural and vibration behaviour of the system (Table 2).

Figure 3: SAXS detector and flight tube in the End Station.

The SAXS detector table is able to accommodate up to two detectors for any x-ray detector currently available on the market by only changing the interface between the table and the detector.

In addition, the original WAXS detector support has been totally redesigned. The newly designed system permits ninety degrees of roll movement and includes insertion movement to adjust the detector position with respect to the sample. The active imaging area of the detector is tilted a 30 degrees fixed angle with respect to the vertical plane of the sample.

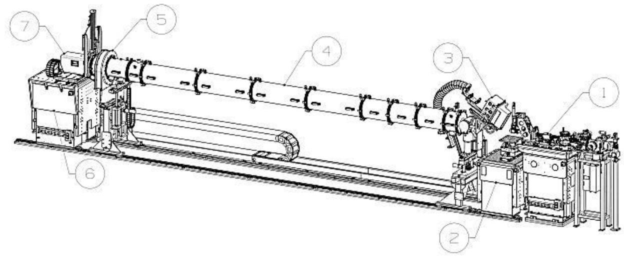

Figure 4: End Station parts breakdown. (1) BCO, (2) sample table, (3) WAXS detector, (4) flight tube, (5) beamstops, (6) SAXS detector table, (7) SAXS detector.

BEAMLINE OPERABILITY

Apart from the changes and modifications in the individual elements of the layout within the End Station (Fig. 4), the one significant is the change of SAXS modus operandi. Originally, SAXS detector was at fixed position while sample environment (and WAXS setup) was translated along the x-ray beam for different flight tube lengths. After years of operations it was concluded that this mode of operations is detrimental to the performance of the beamline by complicating the switching between different configurations of the SAXS experiments and reducing versatility of the beamline. New modus operandi involves translation of the SAXS detector assembly for different flight tube configurations, while sample environment platform is mostly stationary.

Table 1: Table Metrology Results

	Range	Resolution	Repeatability
SAXS Detector Table			
Vertical	300 mm	0.313 µm	5.934 µm
Lateral	515.5 mm	0.781 µm	0.859 µm
Pitch	±7 mrad	0.78 µrad	-
BCO			
	Range	**Resolution**	**Repeatability**
Vertical	90 mm	0.125 µm	2.016 µm
Lateral	40 mm	0.313 µm	0.598 µm
Pitch	±9.2 mrad	0.125 µrad	0.702 µrad
Yaw	±14.6 mrad	0.313 µrad	1.259 µrad
Sample Table			
	Range	**Resolution**	**Repeatability**
Vertical	200 mm	0.195 µm	1.225 µm
Pitch	±87 mrad	0.27 µrad	2.063 µrad

When the End Station is considered (Fig. 1), support structures of the main element have been replaced by new designs. A new beam conditioning optics (BCO) table [2] and new sample table have been built and metrology tested (Table 1). The sample table permits vertical, and pitch movements, and the table consists of a granite block, two lateral plates driven by ball screws with linear guides actuated by stepper motors. Both lateral plates are linked together by a top plate articulated by tapered roller bearings. The BCO assembly includes a fast shutter, a set

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of commercial guard slits, a diagnostic unit comprising three filters and a four-quadrant transmissive photodiode and finally a set of refractive beryllium lenses for micro focussing of the beam.

A set of commercial translation stages have been integrated on the top of the sample table for precise positioning of elements (Fig. 5). These stages permit vertical, lateral, pitch and yaw fine adjustments. Two motorized beamstops have been installed downstream in the flight tube. The first one is a tungsten cylinder block with a photodiode incorporated inside [3] provided with X-Y positioning motion, while the second is a tungsten rod with lateral motorization. All of these improvements, apart from enhancing the original SAXS-WAXS capability, make the End Station suitable for GISAXS experiments.

An originally installed vacuum delay line system has been removed from the optical layout in the End Station, increasing the maximum length of the flight tube. The new configuration of the End Station with a stationary sample and a moving SAXS detector, along with other safety and usability enhancements has reduced the time required to change the flight tube length by 18h. Additionally, a new safety shutter has been installed in the downstream kapton window assembly of the flight tube.

Table 2: FEA Results

	Max. Stress	Max. Deformation	1st Mode of vibration
SAXS Table	10 MPa	100 µm	28.9 Hz
BCO Table	20 MPa	45 µm	59 Hz
Sample Table	17.5 MPa	78 µm	45.7 Hz

AUXILIARY PROJECTS

The fulfilment of all the requirements of the main project has required large developments in other important areas of the beamline. The switch to a channel-cut monochromator system has compelled an update of some radiation protection shielding elements and required installation of a new bremsstrahlung radiation stop.

Besides, the cryocooler for the liquid nitrogen cooling of the monochromator, originally positioned inside the Optics Hutch, has been moved outside of the hutch with a new chicane for cryogenic hoses. This solution has improved safety by dropping the nitrogen concentration and decreasing vibration sources inside the Optics Hutch.

New air conditioning equipment has been installed in the roof of the Experimental Hutch with an air sock distribution system in order to control the uniformity of temperature inside the hutch.

General work on the cable management and electronics has been performed with all new equipment, including a main cable chain in the End Station in order to relieve cables during camera length changes. And finally, the integration of all of the new equipment has involved general changes in the control system of the beamline, especially in the equipment protection system.

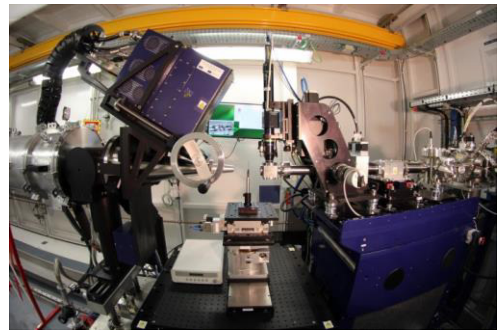

Figure 5: Sample environment in the End Station.

CONCLUSIONS

In summary, the NCD-SWEET beamline has undergone major improvements in beam performance, SAXS detector data quality and beamline operability, as well as developments in other auxiliary areas. All the described works, carried out during implementation of the project, enable beamline to perform state-of-the-art SAXS/WAXS experiments and implement GISAXS technique.

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