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MECHANICAL DESIGN AND CONSTRUCTION OF THE COHERENT X-RAY SCATTERING BEAMLINE AT TAIWAN PHOTON SOURCE

H. Y. Yan†, C. H. Chang, C. C. Chiu, C. Y. Chang, L. Lee, L. J. Huang, C. Y. Chen, J. M. Lin, D. G. Liu, S. H. Chang, and Y. S. Huang,
National Synchrotron Radiation Research Center, 30076 Hsinchu, Taiwan

Abstract

The Coherent X-ray Scattering (CXS) beamline at Taiwan Photon Source has been completely constructed in the end of 2015 and opened for users in the next half year of 2016 successfully. Two In-vacuum Undulators (IU22) with lengths of 3 m and 2 m were used as the Insertion Device (ID) to provide intense synchrotron radiation for the CXS beamline. To achieve the coherent performance, the components setup in the beamline needs to be considered and designed carefully. As no white-beam diamond window was installed in the upstream beamline for the maintenance of coherent beam, a differential pumping mechanism was evaluated to prevent the worse vacuum condition influencing the front end and the storage ring. A single-crystal diamond filter was also adopted to maintain the coherence of x-ray. The protection of bremsstrahlung radiation for this beamline was designed specifically based on the optical layout. This paper will introduce the detailed mechanical design and current status for the CXS beamline.

INTRODUCTION

The Coherent X-ray Scattering (CXS) beamline, which is mainly dedicated to the experimental techniques of the Small-angle X-ray Scattering (SAXS), X-ray Photon Correlation Spectroscopy (XPCS), Coherent Diffraction Imaging (CDI), and so on with its highly coherent beam, is one of the phase-I beamlines at Taiwan Photon Source (TPS). The CXS beamline has been completely constructed and opened for users in 2016. The focused size of 10 x 10 μm^2 at sample with operating energy ranging from 5.6 to 20 keV was also accomplished. The preliminary mechanical design of the CXS beam was reported in [1]. Based on the following suggestion for optimization, the detailed design of the beamline was upgraded. This paper introduces the updated and optimized parts in the following sections, such as the radiation shields, optics, vacuum condition, and thermal analysis. The current status of the CXS endstation is also briefly described.

COMPONENTS SETUP

The latest layout of the CXS beamline and endstation is shown in Figure 1. The components setup in the beamline is mainly divided into several functional parts: The optics, radiation shields, vacuum condition, definition of beam size, monitor of beam position and size, and filter. The similar components for definition of beam size and monitor of beam position and size were introduced in [1-3]. In this section, we focus on the description for optics, radiation shields, and vacuum condition.

Optics

A liquid nitrogen-cooled Double Crystal Monochromator (DCM) manufactured by Kohzu Precision with two sets of crystals, which are Si (111) and Ge (111), was adopted for its mature technique in any sort of hard x-ray beamlines and located at 30.5 m. The crystals can be switched with a wide lateral translation. After reflected by the first and second crystals, the beam path offsets upward by 25 mm.

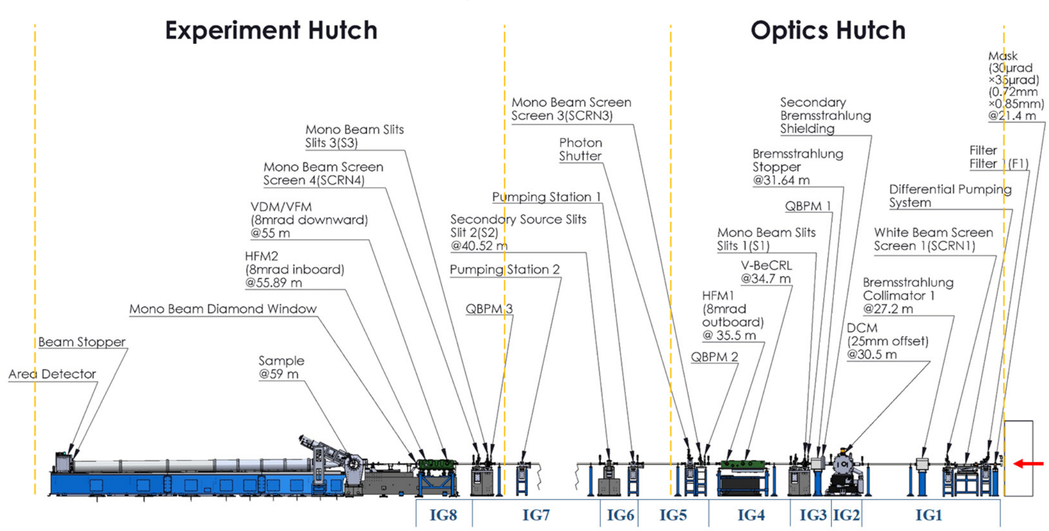

Figure 1: The layout of the CXS beamline and endstation.

† yan.hy@nsrrc.org.tw

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The first focusing system consists of the Vertical-Beryllium Compound Refractive lenses (V-BeCRL) and the first Horizontal Focusing Mirror (HFM1), which are located at 34.7 m and 35.5 m respectively. The V-BeCRL has 8 changeable lenses for adjusting the focal length, an in-vacuum hexapod taken as the adjustable base, and an in-vacuum long translation in the beam direction. The HFM1 is adjusted by 3 atmospheric vertical jacks and 2 in-vacuum lateral translations. The beam path deflects outboard by 8 mrad after reflected by the HFM1.

The second focusing system consists of the Vertical Deflection Mirror (VDM), Vertical Focusing Mirror (VFM), and the second Horizontal Focusing Mirror (HFM2). The VDM/VFM and HFM2 are located at 55 m and 55.89 m respectively. The VDM and VFM are switchable for different focusing mode. The motion control of the VDM/VFM and HFM2 is the same as that of the HFM1. The beam path deflects downward and inboard both by 8 mrad after reflected by the VDM/VFM and HFM2. The first and second focusing system were all manufactured by FMB Oxford.

Radiation Shields

A bremsstrahlung collimator, a bremsstrahlung stopper and a mono-beam photon shutter with definite sizes were developed to sufficiently collimate and intercept the bremsstrahlung radiation from the ID source. Tungsten alloy blocks covered with 100 mm-thick polyethylene (PE) in the bremsstrahlung collimator and stopper shown schematically in Figure 2 were formed in ratchet shape along the beam direction and with 12.7 x 12.7 mm^2-square aperture for beam passing. The chamber of the bremsstrahlung stopper has a bypass pipe to enhance the vacuum conductance while that of the bremsstrahlung collimator does not for the differential pumping design. The mono-beam photon shutter with a 7 mm-thick and 60 x 60 mm^2-square lead plate was used to block the direct beam effectively. The protective methods of the 1.2 m-thick ratchet wall in the downstream front end was also designed carefully using blocks of lead and PE with definite sizes [4]. The bremsstrahlung ray tracing for the CXS beamline is illustrated in Figure 3.

Furthermore, a well-aligned aperture with an inner diameter of 6 mm was installed in the downstream of the experiment hutch to prevent the mono beam from hitting the inner wall of the transporting pipe exposing to the experimental hall.

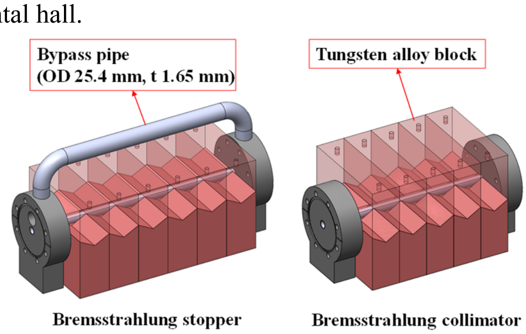

Figure 2: The schematic drawing of the tungsten alloy blocks assembled in the bremsstrahlung collimator and stopper.

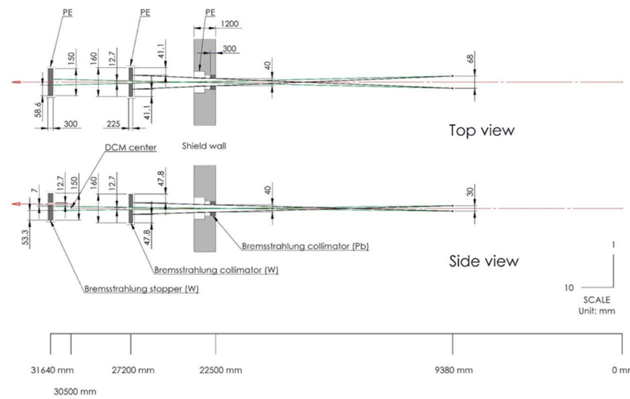

Figure 3: The drawing of bremsstrahlung ray tracing for the CXS beamline at TPS.

Vacuum Condition

Except for the DCM, vacuum condition of all sections in the beamline, which was divided by the gate valves and diamond window into 7 sections as shown in Figure 1, was designed below 10^{-9} torr for the purpose of protecting the optic mirrors from carbonization. After the baking process during construction, the goal of the defined vacuum level was achieved successfully. Moreover, two penning gauges of the fast closing valve in the front end were installed in the IG1 and IG7 sections individually, and their trigger setpoint of pressure was set at 10^{-4} torr to protect the vacuum in the front end when abnormality of vacuum in the beamline occurred. The fast closing valve can shut fastly in 0.01 second when one of the penning gauges triggers.

To keep the coherence of X-ray beam, there is no white-beam diamond window installed in the upstream section of the beamline. The front end and storage ring may be easily influenced by worse vacuum in the beamline due to no pressure isolation. Consequently, a differential pumping mechanism was designed to reduce vacuum conductance between the front end and DCM, which has a pressure of 3 x 10^{-7} torr when the liquid nitrogen system did not operate. Based on the theory for molecular flow in a long round tube, Equation (1) describes the calculation for a large difference in pressure between two vacuum systems:

$$W = \frac{L}{12.1d^3} = \frac{P_1 - P_2}{P_2 S_2} \quad (1)$$

Symbols W, L, d, P_1, P_2, and S_2 mean the gas flowing impedance, length of the round tube, inner diameter of the round tube, pressure on the gas-in side, pressure on the pumping side, and pumping speed of the pumping side respectively. Evaluation of differential pumping between the filter and DCM is illustrated in Figure 4. The actual pressure in the filter is 2 x 10^{-10} torr, and therefore the goal for differential pumping is nearly achieved.

However, the operating pressure of the CXS endstation is around 0.1 torr, which has very large vacuum difference from that of the beamline. A mono-beam single-crystal diamond window with a thickness of 100 µm and a rectan-

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gular aperture of 4 mm x 6 mm was used to isolate the vacuum incompatibility and also able to maintain the coherent beam.

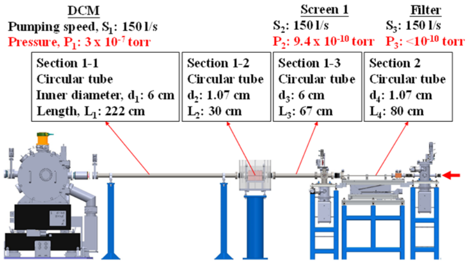

Figure 4: The evaluation of differential pumping between the filter and DCM.

THERMAL ANALYSIS

Thermal analyses were evaluated by the finite element method to verify the performance of white-beam components in the beamline. The maximum calculated power after the slits in front end with a 24 x 29 μrad^2 aperture is 84 W. The mask is the first white-beam component in the beamline for the prevention of beam missteering and designed with a 30 x 35 μrad^2 aperture. The thermal analysis is based on the assumption that energy is absorbed by the mask entirely. The single-crystal diamond filter with a thickness of 200 μm and a round aperture of 6 mm is the second white-beam component and used to absorb unnecessary energy. The diamond foil was brazed in a holder, and then the holder was assembled with the copper cooling bar. The calculated absorbed power is 27 W when the beam transmits through the center of the diamond foil. Thermal analysis is unnecessary for the liquid nitrogen-cooled DCM thanks to its wide application and experience on this level of power density. The result of thermal simulation shown in Figure 5 presents the design of these white-beam components are applicable.

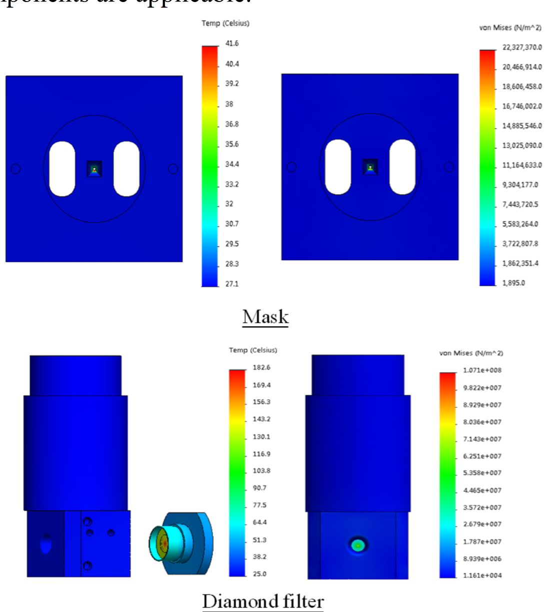

Figure 5: The result of thermal simulation representing the temperature and thermal stress for the mask and diamond filter.

BRIEF DESCRIPTION OF THE CXS ENDSTATION

The CXS endstation begins from the mono-beam single-crystal diamond window in the downstream beamline and consists of the slits 1, slits 2, attenuator, measurement unit of beam intensity, fast piezo shutter, sample, 12 m-long pipe section, beam stopper, area detector and its motor-actuated platform respectively. The sample position is adjusted by a 3-axis stage for its horizontal and vertical directions. The 12 m-long pipe section for the experiments of small angle can reset the distance between sample and area detector from 2 m to 12 m semi-automatically. The goniometer system for the experiments of wide angle was installed nearby the sample and capable of tilting up to 35 and 45 degrees from the horizontal when the in-vacuum area detector was at a distance of 2 m and below 1.75 m away from the sample respectively. The tests of vacuum and movement for the goniometer system was also verified. The layout and on-site view of the CXS endstation is shown in Figure 6.

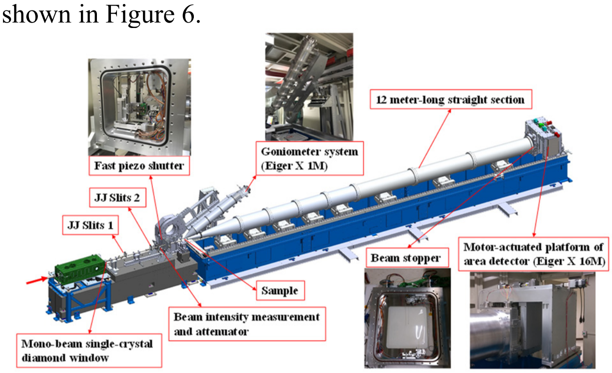

Figure 6: The layout and on-site view of the CXS endstation.

CONCLUSION

The CXS beamline at TPS has been completely constructed and opened for users, and the performance has been also achieved basically. The radiation shields and vacuum condition performed expectedly as well as the differential pumping design. The white-beam components were evaluated by thermal analysis in advance and also verified on-site. The status of the CXS endstation is briefly presented, and some functional expansion is ongoing for more experimental opportunity in the future.

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