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DESIGN AND DEVELOPMENT OF THE ADVANCED DIFFRACTION AND SCATTERING BEAMLINES AT THE AUSTRALIAN SYNCHROTRON

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Abstract

The Advanced Diffraction and Scattering (ADS) beamlines will provide high energy synchrotron X-rays for a variety of different diffraction- and imaging-based experiments at the Australian Synchrotron. A 4.5 T super-conducting multipole wiggler will be used to provide X-rays in the range 50-150 keV, to two experimental endstations. The high power density of the beam requires significant thermal management through the whole beamline from the front end to the endstation. Flexible endstation designs have been developed to facilitate X-ray diffraction experiments on a range of sample types and environments (up to 300 kg). Detector positioning systems have been developed from industrial CNC robots to provide high speed, precise motion over large spatial envelopes.

SOURCE & BEAM CONDITIONING

The SCMPW source for the beamline produces a beam with a central power density of 33 kW/mrad^2, a total power of 45 kW and divergence of 7 × 1 mrad^2. The final beam size required in the beamline is 0.3 × 0.3 mrad^2. The heat load from reducing the beam size this amount was difficult to achieve in the storage ring for the compact front ends at the Australia Synchrotron.

Due to space constraints in the storage ring the beam conditioning was split between the front end and the beamline. Inside the front end a crotch absorber, mask and a diamond filter reduce the beam to 0.85 × 0.75 mrad^2 and absorb 40 kW, as shown Fig. 1. Inside the beamline a secondary mask trims the beam to the final size of 0.3 × 0.3 mrad^2 and a SiC filter absorbs another 0.8 kW of low energy photons. A summary of the beam conditioning is shown Table 1.

The front end mask was designed to absorb only the horizontal fan, to decrease the thermal strain and thereby increase the power absorption capability of the front end mask. A design consisting of 2 × 800 mm flat cooled plates eliminates the need for an aperture throat and reduces the peak strain on the absorber. The mask absorbs a total power of 35 kW with a central power density up to 460 W/mm^2. Figure 2 shows the layout of the mask and the thermal stress under a missteer event.

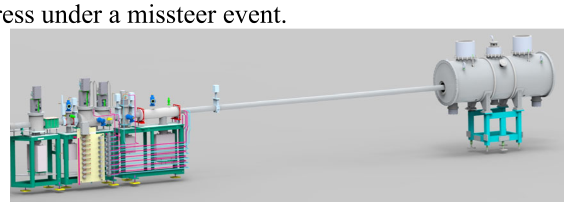

Figure 1: Front end and source in ADS beamlines.

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Table 1: Beam Conditioning in ADS Beamlines

Element	Divergence		Power	
	Vert. (mrad)	Horiz. (mrad)	Absorbed (kW)	Transmitted (kW)
Source	1	7	–	45
CA	0.85	6	2.5	42.5
FE Mask	0.85	0.75	35.4	7.1
Diamond Filter (1.2mm)	0.85	0.75	2.0	5.1
PDS Mask	0.3	0.3	3.5	1.6
SiC Filter (2mm)	0.3	0.3	0.8	0.8

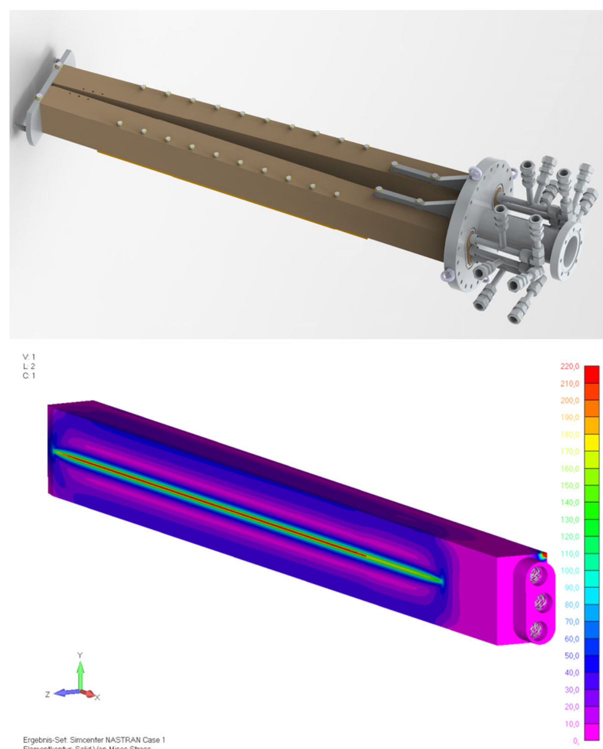

Figure 2: Front end mask (top showing assembly design, lower showing FEA of stress in beam missteer loading (22kW on one half of mask). *Images courtesy of FMB-Berlin*.

ADS-1 BEAMLINE

The primary beamline, ADS-1, will to provide white, pink and monochromatic beam (50-150 keV) to a large end-station located outside the main synchrotron building.

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For monochromatic beam modes a Transfocator is used to input a tunable collimating beam to a cryogenically-cooled double crystal Laue monochromator (DCLM),

The Transfocator has water cooled lenses with a copper mask and integrated aluminium filter. The Transfocator consists of Al and Be lenses arranged in pneumatically actuated cassettes. The cassettes shall have 1, 2, 4, 8, 16 & 32 Be lenses and 32 and 64 Al lenses. The lens material is polycrystalline Be or Al and each lens has a radius of curvature of 200 µm, a web thickness of <50 µm and an aperture size of 0.8 mm. With the expected lens layout the Transfocator can collimate photons up to 110 keV and produce low divergent beam up to 150 keV.

A cryogenically cooled DCLM (shown in-situ in Fig. 3) is utilised in the ADS-1 beamline to select energies. The DCLM shall be a bent vertical fixed exit double Si 111 crystal Laue system and cover the energy range 50 keV to 150 keV with an energy resolution within $1 \times 10^{-2} < \Delta E/E < 2 \times 10^{-4}$. Each crystal shall be capable of being spherically bent using a bender mechanism. The beam shall be incident on the concave side of the bent crystals and both the (111), (220) and (113) planes shall be accessible. The first and second crystals shall be asymmetrically cut at $\chi = -35° \pm 0.02°$ and the V_{perp} directions shall be $(\bar{1}10)$ to ensure that the (113) planes can be accessed by a 29.2° pitch rotation of the crystals.

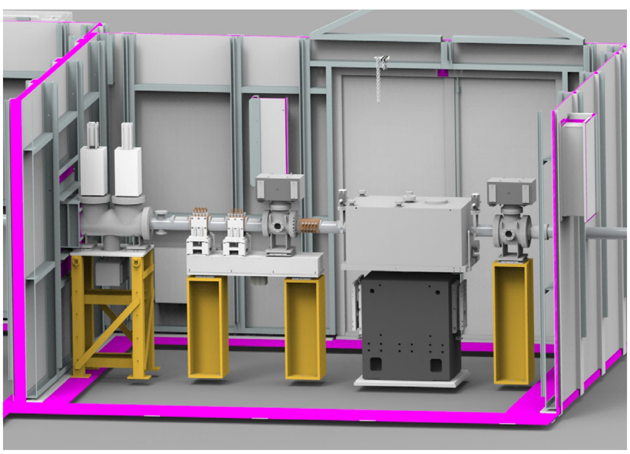

Figure 3: Second optics hutch showing DCLM, slits and shutters.

The endstation of ADS-1 is designed to be flexible and will enable; rapid powder diffraction, energy dispersive diffraction, white/pink beam Laue diffraction, high speed imaging and combined imaging and diffraction. The ADS-1 endstation will have the full experimental capabilities and flexibility, and accommodate both small and large samples up to 300 kg.

A large gantry robot (shown in Fig. 4) will position up to 4 detectors on 2 arms in a spatial envelope of $2.5 \times 0.3 \times 6$ m^3 with 20 µm precision. The gantry robot has been adapted from a CNC machine application and allows for high speed operation (>1000 mm/s) with payload masses up to 250 kg. The detector housing in this design will incorporate radiation shielding to protect the detectors during operation and when not in use.

The detectors will be interchangeable and will allow for future expansion of detector types available for experiments. The initial detector types will be; hybrid pixel and amorphous silicon detectors for monochromatic diffraction; indirect scintillator-based CCD imaging detectors and novel, state-of-the art Energy Dispersive detectors. The high speed and dual arm positioning system allows for quick transitions between different detector types and sample to detector distances for multi modal experiments.

The sample goniometer has a modular configuration and will allow small and large samples and environments up to 300 kg, to be positioned in the beam. A tomography stage will be available to users for samples up to 50 kg. The travel range of the sample goniometer is shown in Table 2.

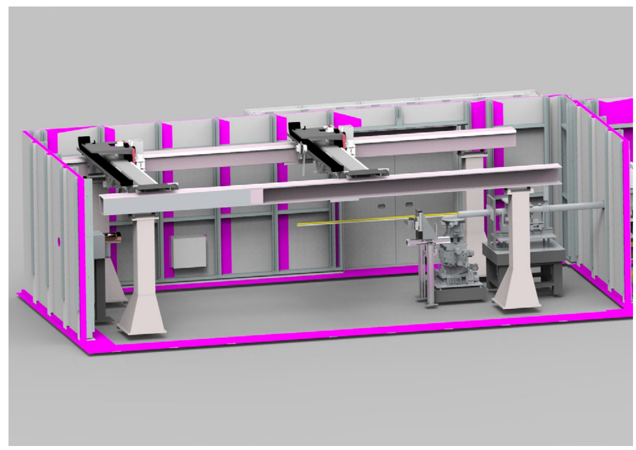

Figure 4: ADS-1 endstation.

Table 2: ADS-1 Goniometer Motion Envelope

Subassemblies	Axes	Range	Repeatability
Tomography	X	±25 mm	0.002mm
	Z	±25 mm	0.002mm
	RY	∞	10 µrad
Intermediate	Y_{fine}	20 mm	0.002 mm
	Y_{coarse}	100 mm	0.01 mm
	X	±50 mm	0.002mm
	Z	±50 mm	0.002mm
Permanent	RZ	±5°	20 µrad
	RX	±5°	20 µrad
	RY	0-360°	20 µrad
	X	100 mm	0.01mm
	Y	30 mm	0.01mm

ADS-2 BEAMLINE

The second ADS beamline, ADS-2, will take a 5° deflected beam from a cryogenically-cooled side-bounce Laue monochromator (SBM) (shown in Fig. 5). The deflected beam is focussed using a mirror and delivered to the endstation.

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The monochromator houses 3 crystals operating in Laue geometry that vertically translate into the beam. The silicon crystals in the monochromator have a triangular form factor with an optical thickness of 3mm. The crystals select the energies 45.3, 74.0 and 86.8 keV with a bandwidth of 2.9×10^{-3} using reflection from the 111, 220 and 311 planes respectively. The heat load on the SBM crystals is the most significant driver of beam size and filtration due to their upstream location. A set of SiC filters is immediately upstream of the SBM with multiple filter thicknesses to manage power. A high efficiency cooling design enables the SBM crystals to absorb up to 300 W of power with a power density of 110 W/mm2.

A vertical focussing mirror is used on ADS-2 to focus the beam and reduce the intensity of higher order harmonics. The multilayer mirror has 3 stripes of (Ni/B_4C, Au/B_4C & Pt/B_4C) suitable for he monochromated beam generated by the SBM (45.3 keV to 86.8 keV) with each stripe 10 mm wide. The substrate is $1100 \times 50 \times 40$ mm with stripes that translate laterally into the beam.

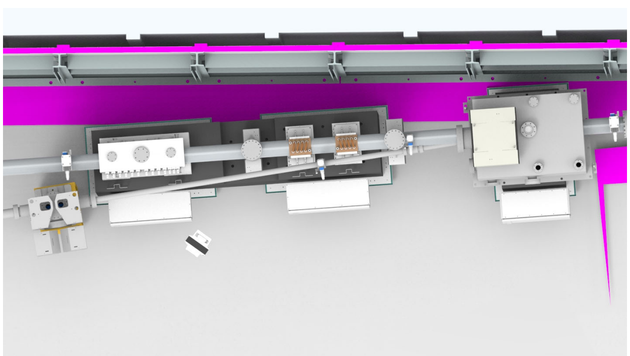

Figure 5: Branchline from SBM.

The monochromatic ADS-2 endstation utilises a modular sample goniometer and another high travel range detector positioning system to enable in-situ, high throughput powder & single crystal diffraction.

The sample goniometer has a modular construction with a permanent alignment base upon which different experiment specific goniometers may be mounted. The alignment base can translate vertically 20 mm with +/- 25 mm horizontal travel across the beam axis. 600 mm travel along the beam axis will allow access to the varying focal points from the upstream mirror. A capillary spinner and single-crystal kappa goniometer will be available for users and will mount to the alignment base.

A gantry style robot (shown in Fig. 6) will position 2 detectors in a 0.6 x 0.3 x 4 m^3 spatial envelope with 20 µm precision. Incorporating a similar concept to the motion system in ADS-1 endstation, the gantry robot has been adapted from a CNC machine application and allows for high-speed operation (>1000 mm/s) with payload masses up to 250 kg

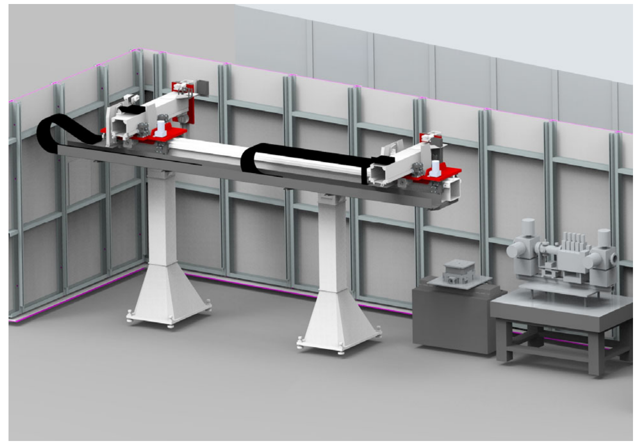

Figure 6: ADS-2 endstation.

CONCLUSION

The ADS beamlines are the fifth and sixth beamlines being built within the Australian Synchrotron/ANSTO BR–GHT program. The Australian Synchrotron is a 3 GeV machine designed to operate continuously 24 hours per day, 7 days per week, providing ≥ 5000 user-beam hours annually. The ADS beamlines project encompasses design, procurement, build/installation and commissioning phases. The beamline will commence user operations in July 2023.

The Advanced Diffraction and Scattering (ADS) beamlines will provide high energy X-rays to the Australian and New Zealand synchrotron User communities for dedicated diffraction and imaging experiments. A range of new and traditional white and monochromatic beam techniques will fulfil an important role for the materials, engineering, energy and Earth science communities particularly when coupled to a broad range of sample stages and environments. The resulting in-situ capability will be a powerful feature of the ADS beamlines.