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Beamlines of the biomedical imaging and therapy facility at the Canadian light source – part 3

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ABSTRACT

The BioMedical Imaging and Therapy (BMIT) facility provides synchrotron-specific imaging and radiation therapy capabilities [1–4]. We describe here the Insertion Device (ID) beamline 05ID-2 with the beam terminated in the SOE-1 (Secondary Optical Enclosure) experimental hutch. This endstation is designed for imaging and therapy research primarily in animals ranging in size from mice to humans to horses, as well as tissue specimens including plants. Core research programs include human and animal reproduction, cancer imaging and therapy, spinal cord injury and repair, cardiovascular and lung imaging and disease, bone and cartilage growth and deterioration, mammography, developmental biology, gene expression research as well as the introduction of new imaging methods.

The source for the ID beamline is a multi-pole superconducting 4.3 T wiggler [5]. The high field gives a critical energy over 20 keV. The high critical energy presents shielding challenges and great care must be taken to assess shielding requirements [6–9]. The optics in the POE-1 and POE-3 hutches [4,10] prepare a monochromatic beam that is 22 cm wide in the last experimental hutch SOE-1. The double crystal bent-Laue or Bragg monochromator, or the single-crystal K-edge subtraction (KES) monochromator provide an energy range appropriate for imaging studies in animals (20–100+ keV).

SOE-1 (excluding the basement structure 4 m below the experimental floor) is 6 m wide, 5 m tall and 10 m long with a removable back wall to accommodate installation and removal of the Large Animal Positioning System (LAPS) capable of positioning and manipulating animals as large as a horse [11]. This end-station also includes a unique detector positioner with a vertical travel range of 4.9 m which is required for the KES imaging angle range of $+12.3^\circ$ to -7.3°. The detector positioner also includes moveable shielding integrated with the safety shutters.

An update on the status of the other two end-stations at BMIT, described in Part 1&2 [3,4] of this article, is included. 1PACS Codes: 07.85.Qe, 07.85.Tt, 87.62.+n, 87.59.–e

1. Introduction

The Insertion Device (ID) beamline extends techniques initially tested on the bending magnet beamline [3], including absorption imaging, DEI, [12–13] KES [14–16] and Phase Contrast (PCI) imaging [17–19] in both CT and planar modes, to a higher energy spectrum and for larger samples. The ID beamline can generate monochromatic beams using a set of monochromators. The ID scientific program requires unique high load capacity and large vertical travel range positioning systems. Fig. 1 shows major dimensions and location of the components from the source.

Abbreviations: BM, Bending Magnet; BMIT, Bio-Medical Imaging and Therapy facility; CT, Computed Tomography; DEI, Diffraction Enhanced Imaging (also known as ABI - Analyzer Based Imaging); KES, K-edge Subtraction Imaging; ID, Insertion Device; LAPS, Large Animal Positioning System; MRT, Micro-beam Radiation Therapy; PCI, Phase Contrast Imaging; POE, Primary Optical Enclosure (White beam enclosure); SOE, Secondary Optical Enclosure (Monochromatic beam enclosure)

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2. Source and front end

2.1. Source and front end (BMIT multi-pole (25+2) superconducting wiggler)

The insertion device (see Table 1) and front end are described in detail elsewhere [4–5]. The maximum horizontal photon beam angle is 6.8 mrad, as defined by the Deflection Parameter, K of the wiggler, of which the ID beamline utilizes 4 mrad. The optics hutch prepares the monochromatized beam to be used in the experimental hutch SOE-1. The monochromators prepare a beam-width in excess of 220 mm at the sample location, with an energy range (20–100+ keV) appropriate for imaging studies in small and large animals. The expected brightness of the source is 3×10^{12} ph/s/mrad^2/0.1%bw/mA @ 20 keV.

Due to unique spectral properties of the source special care was required to design the shielding for the hutches [6–9].

3. POE-3 (second optics hutch)

The main components [10] within the second optics hutch are: filter assembly, tertiary photon slits, (X-ray wire beam positioning monitor – optional), fixed mask with bremsstrahlung collimator, beryllium window, CT monochromator, DEI monochromator, KES monochromator or beam expander, in-vacuum bremsstrahlung and white beam stop which terminates the white beam 48 m from the source, Kapton window, tiltable optics table with a set of filters and shutters, (monochromatic beam chopper – optional) and a moveable shielding assembly with a vertical travel range of 0.7 m (see Table 2) with two sets of safety shutters. The tiltable table needs to provide a 550 mm vertical travel range with a tilt capability of $-7°$ to $+7°$ (with respect to the horizontal) and ~230 kg load capacity.

The bremsstrahlung and white beam stop design is unique as it needs to stop the direct beam which has been transmitted through the various transmission monochromator crystals. This beam stop is located downstream of the KES monochromator (see Fig. 1) and it needs to be small enough vertically to allow the CT, DEI and KES monochromatic beams to pass. The CT beam vertical center is 15–25 mm above the white beam level and the DEI beam is 10 mm above the CT mono beam level. The bremsstrahlung beam stop safety performance was modeled [9] and as a result a recommendation for additional local shielding was made and implemented. It is critical to have very precise control of the position of the beam-stop and to have a fail-proof holder design.

There are several high capacity ion pumps installed to deal with outgassing from the filters, slits, monochromators and beam-stops. The vacuum section of POE-3 is isolated from air by the last optical component, the Kapton window.

Table 2
POE-3 Moveable shielding assembly loads, ranges and accuracy specifications.

Parameter	Value
Total mass	2650 kg (5850 lb)
Mass of moving structure	2030 kg (4475 lb)
Vertical translation stage travel range	679 mm
Travel velocity	up to 1.33 mm/second
Resolution (V)	20 μm

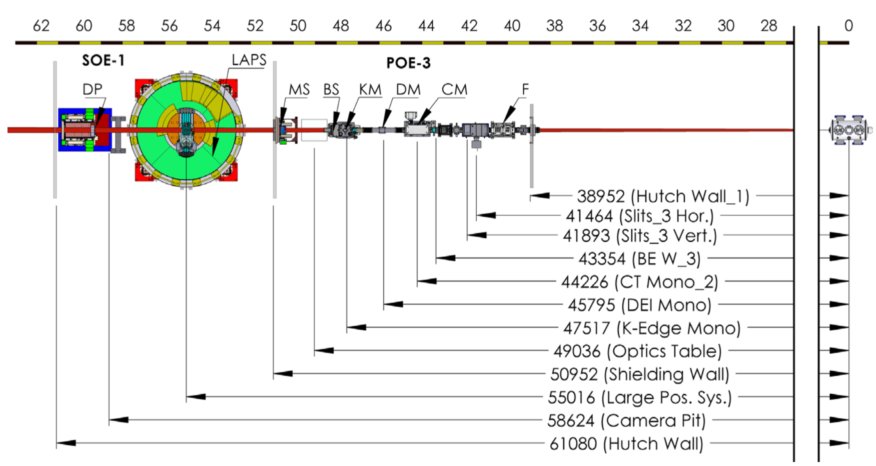

Fig. 1. 05ID-2 Beamline - distance from the source of main components in POE-3 and SOE-1 hutches (F - filters, CM - CT mono, DM - DEI mono, KM - KES mono, BS - Beam Stop, MS - Moveable Shielding, LAPS, DP - Detector Positioner).

Table 1
Wiggler specifications.

Magnetic field, B_0	4.3 T maximum
Period length, λ_0	4.8 cm
N_f	12.5 full-field periods (25 full-field poles)
N_h	1 half-field period (2 half-field poles)
Deflection parameter, K	19.3 maximum (K/γ~3.4 mrad)
Critical energy, E_C	24 keV maximum
Radiative power	30.1 kW (500 mA, 2.9 GeV) ~13.3 kW accepted into the beamline by the aperture
Horizontal /vertical aperture	50 mm (H) / 10 mm (V) (wiggler liner opening)
Horizontal /vertical divergence	4 mrad (0.23°) (H) / 0.2 mrad (41.2") (V)
Photon range / energy	0.6–0.1 Å / 20–100+ keV
Photon brightness	3×10^{12} ph/s*mA*mrad^2*0.1%BW @ 20 keV
Source size parameters	441 μm (σ_x) x 16.6 μm (σ_y)
Peak power density	211.2 W/mm^2 @ 10 m (500 mA, 2.9 GeV)