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X-ray absorption beamline at the Mitsubishi compact storage ring

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Beamline #5 (BL#5) at the Mitsubishi compact storage ring (MELCO-SR) is a beamline designed to perform X-ray absorption experiments in the 1–5 keV energy range. MELCO-SR is a racetrack-type storage ring with compact superconducting magnets, which is operated at 600 MeV, mainly for X-ray lithography experiments. As the ring is set in a shield wall of 2 m thickness, a point just outside the shield wall of BL#5 is located at 6.8 m from the source point. A small toroidal mirror, located inside the shield wall at 3.4 m from the source, focuses the beam vertically and horizontally onto the 7.3 m point. This simple optical configuration allows us to bring the source point outside of the shield wall, and to collect about 10 mrad horizontally and maintain small footprints on the monochromator crystal. A new 'Cowan type' monochromator, located at 7.4 m from the source and selected for simplicity of design and for stability, will provide a bright high-resolution and stable X-ray beam for use in the X-ray spectroscopy of electronic materials in MELCO.

Keywords: beamlines; source images; toroidal mirrors; shield walls.

1. Introduction

Synchrotron radiation sources provide opportunities for advancements in X-ray spectroscopy of materials, owing to the high flux and the energy tunability available (Agarwal, 1991). In order to take full advantage of these opportunities, the optical design of the beamline requires utmost care to utilize as much flux as possible and to optimize the beam size and beam divergence as small as possible at a monochromator crystal.

The Mitsubishi compact storage ring (MELCO-SR) is a racetrack-type storage ring with compact superconducting magnets (Nakanishi *et al.*, 1992), which is operated at 600 MeV, mainly for X-ray lithography experiments. Fig. 1 shows a plan view of the facility. The flux curve of the ring is compared with that of UVSOR in Okazaki in Fig. 2. As the magnets produce high magnetic fields of 3.5 T, the critical energy of the ring is

$$\varepsilon_c \text{ [keV]} = 0.665E^2 \text{ [GeV] } B \text{ [T]} = 0.84 \text{ keV},$$

which is not only optimized for X-ray lithography, but also suitable for X-ray spectroscopy in the 1–5 keV energy range. On the other hand, the ring is located in a shield wall of 2 m thickness; a point just outside the shield wall around beamline #5 (BL#5) in Fig. 1 is at a distance of 6.8 m from the source point. This distance is relatively short compared with larger synchrotron radiation facilities; however, it is still too long for sufficient flux to be accepted by crystals of limited size in a monochromator. The approximate vertical opening half-angle of the radiation at the critical energy is

$$1/\gamma = m_e c^2/E = 0.85 \text{ mrad}.$$

If we take the full width of the source emittance, the vertical beam size at the point just outside the shield wall will be 11.5 mm, which is too wide to be accepted by a monochromator crystal at lower angles. Taking less width of the vertical source emittance will reduce the beam size on the monochromator crystal, but also reduce the flux available. To overcome these problems, we adopted a new but very simple optical design for the beamline.

In this paper we describe the optical concepts and ray-tracing results of BL#5 at MELCO-SR, designed to perform X-ray absorption experiments in the 1–5 keV energy range.

2. Optical design

The optical layout of BL#5 at MELCO-SR is shown in Fig. 3. A small toroidal mirror, located at 3.4 m from the source, focuses the beam vertically and horizontally onto the focal point located at 7.3 m from the source. Therefore, the mirror allows us to image the source to a point outside of the shield wall. If no focusing optics are used, the vertical acceptance of the beam should be 0.1 mrad in order to optimize the beam size at the monochromator position, practically 7.4 m from the source. The mirror enables us to use the full width of the beam emittance of

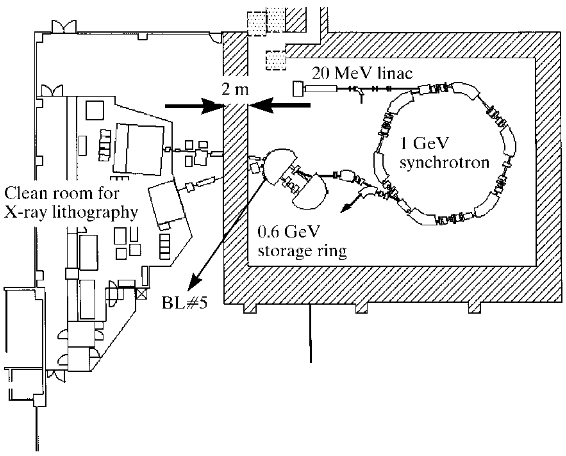

Figure 1
Plan view of MELCO-SR.

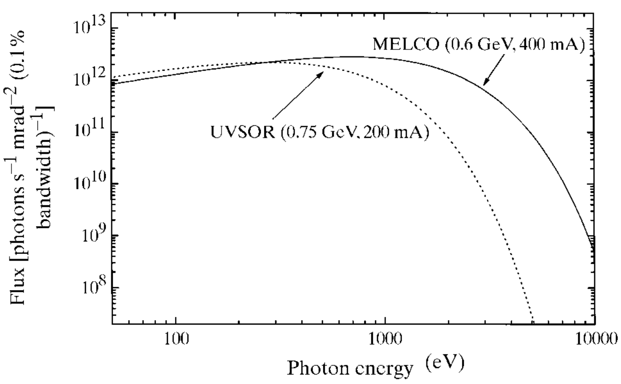

Figure 2
Spectral flux curve of MELCO-SR with that of UVSOR in Okazaki.

0.85 mrad. We can also adopt a wider horizontal acceptance of up to 6 mrad, compared with that without any focusing optics of 1 mrad. Therefore, this simple design provides more than 30 times as much flux as that without a mirror. A new 'Cowan-type' double-crystal monochromator (Jones *et al.*, 1995) is located 7.4 m from the source point. A vacuum sample chamber with channeltrons and other X-ray detectors is located 8.5 m from the source point for X-ray absorption experiments.

This virtual source point outside the shield wall can introduce other optical designs. For example, if two mirrors with the same surfaces are located before and after the monochromator, we can collimate the beam onto the monochromator crystal, and focus the source image on the sample point with unit magnification, like beamline 9.3.1 at the Advanced Light Source (Perera *et al.*, 1995). Compact storage rings sometimes do not have a shield wall between the ring and the experimental area. However, even in such cases, putting a mirror before the monochromator will benefit both the flux and the energy resolution.

The focusing properties of a mirror must satisfy Coddington's equations,

$$1/u + 1/v = 2/R\sin\theta,$$

$$1/u + 1/v = 2\sin\theta/\rho,$$

where u and v are objective and image distances, R and ρ are the major (tangential) and the minor (sagittal) radii, respectively, and θ is the glancing incidence angle. Setting u = 3.4 m, v = 3.9 m and θ = 12 mrad, the calculated radii for the mirror are R = 325 m and r = 0.047 m.

Because of the limitation of the space inside the shield wall, the length and the width of the mirror are defined to be 30 cm and 4.5 cm, respectively. The following ray-tracing simulation will show that the above sizes are sufficient for our purpose.

3. Ray-tracing simulation

The ray-tracing simulation program *SHADOW* (Lai & Cerrina, 1986) is based on the propagation of randomly generated rays of equal amplitude, weighted with appropriate distribution functions. To model the bending-magnet source for BL#5, 5000 pseudo-random (Monte Carlo) rays are generated in real and momentum space. In the plane normal to the radiation emission direction, a Gaussian spatial distribution is assumed. The photon beam dimensions are

$$\sigma_h = 0.54\,\text{mm}, \quad \sigma_v = 0.46\,\text{mm}.$$

Table 1
Source description of MELCO-SR.

Random source	
Generated total	5000 rays
Source assumed	Tridimensional
Source spatial characteristic	Gaussian
	σ_X: 0.54 × 10^{-3} m; σ_Z: 0.46 × 10^{-3} m
Depth	Synchrotron source
Source emission characteristics	
Distribution type	Synchrotron
Distribution limits	X: 6.0 mrad; Z: 0.5 mrad
Magnetic radius	0.593 m
Beam energy	0.585 MeV
Beam emittance	ε_X: 6.9 × 10^{-7} mrad; ε_Z: 2.76 × 10^{-8} mrad
Distance from waste	X = 0, Z = 0
Polarization used	SR TOTAL
Source photon energy distribution	BOX DISTR
Photon energy	1000–5000 eV

The parameters used in generating the MELCO-SR source are tabulated in Table 1. Ray tracing of this system for an acceptance of 6 mrad × 0.5 mrad radiation was performed.

Fig. 4 shows the image plane (the sample chamber position) computed by the program, neglecting the figure errors of the mirror. The r.m.s. beam dimensions at the image plane, shown in Fig. 4, are σ_h = 3.0 mm and σ_v = 2.0 mm, compared with the source dimensions above. The footprint of the beam was completely within the mirror surface, and the total lost rays were only 9.6% of the initial rays. Considering that the imaging plane is not the imaging plane of the mirror, we can expect a good image quality and high flux at the sample position. A small beam size on the monochromator crystals will provide a high energy resolution and enable the use of small crystals like YB_{66}, which is the only crystal covering the 1–2 keV energy region, but has only a 20 × 10 mm size available.

4. Conclusions

We have designed a beamline at MELCO-SR, covering the 1–5 keV photon energy range with high flux and good energy resolution at the sample point. The beamline is now at the

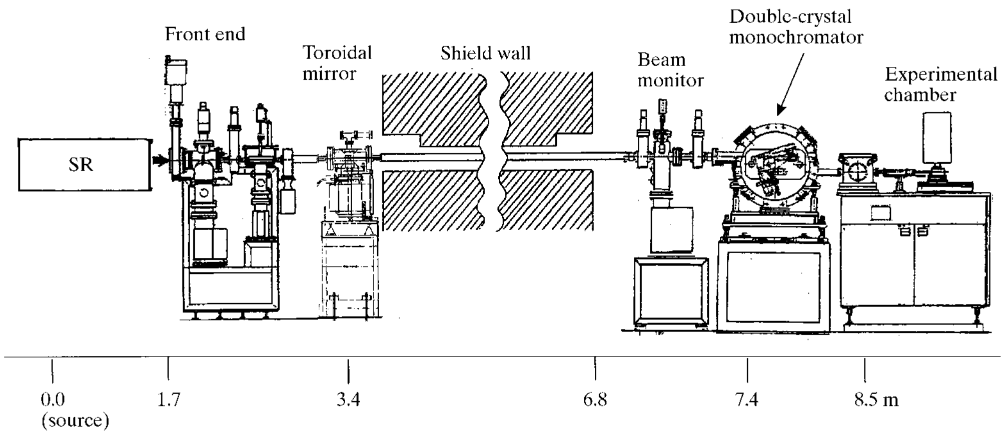

Figure 3
Optical layout of BL#5 at MELCO-SR. In the figure, SR = synchrotron radiation. Not to scale.

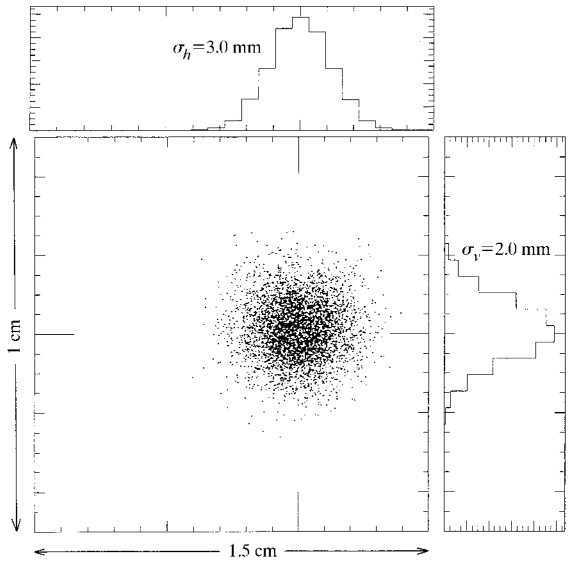

Figure 4
The beam image at the sample point computed by *SHADOW.*

commissioning stage; it will soon provide a bright good energy resolution and stable X-ray beam for use in the X-ray spectroscopy of electronic materials in MELCO.

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