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Improved performance of an undulator soft X-ray station BL-2A of the Photon Factory in its reduced emittance operation

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The electron beam emittance of the Photon Factory storage ring has been reduced from 130 nm-rad to 36 nm-rad since May, 1998. This improves the brilliance of the synchrotron radiation, especially in the undulator source. The increase in the measured photon flux at a soft x-ray undulator beamline 2A within a very small aperture having the acceptance of 65 μrad (horizontal) × 20 μrad (vertical) is comparable to the calculated one in the photon flux density; the peak intensity of the 5th harmonics at K = 1.7 (2020 eV) becomes ~2.4 times as much as before. On the other hand, a total photon flux in a rather wide area, which can be focused in ~1 mmϕ spot to utilize for most normal experiments, has increased by ~1.5 times.

Keywords: soft x rays; undulator; low emittance; double-crystal monochromator.

1. Introduction

The "Scrap & Build" project of beamlines has been proceeding in the Photon Factory (KEK-PF) in accordance with the "High Brilliance" project of the storage ring (Katoh *et al.*, 1998a, 1998b). The reduction of the electron beam emittance ε increases the brilliance of the synchrotron radiation. For undulator sources, the magnification of the brilliance reaches as much as 10 if the planned lowest emittance (ε = 27 nm-rad) is achieved. At a soft x-ray undulator U#02 (λu = 6 cm), a grazing-incidence monochromator station BL-2B (Yagishita *et al.*, 1992) was reconstructed to BL-2C with varied-space plane gratings (Watanabe *et al.*, 1997) and a double-crystal monochromator station BL-2A (Maezawa *et al.*, 1989, Kitajima *et al.*, 1992, 1996) has been modified. The new layout of BL-2A and the improved performance under the reduced emittance operation are described in this report.

2. New layout of PF-BL-2A

Figure 1 schematically shows the new layout of the beamline 2A. Because the sample position has moved downstream by ~5.5 m to avoid interference with the optical components of the next beamline BL-2C, a cylindrical mirror Mv has been introduced for vertical focusing in addition to another cylindrical mirror Mh for horizontal focusing. Both the mirrors are made by quartz and coated with Ni, and the incident angles are 0.6° to reflect soft x rays under ~6 keV.

To reduce heat loads to the first crystal of the monochromator, the graphite absorber of 1-μm thickness has been replaced by 10-μm one, which is inserted just before the monochromator. This is quite important when we use InSb crystal, whose thermal properties are much worse than Si crystal. With the thicker absorber, the InSb first crystal can withstand the total power without melting. However, there still remains a problem of beam expanding due to the heat loads when the undulator gap is fairly closed so that the weak-field operation is recommended for the use of InSb.

A hutch was constructed to enclose all the components that are placed on the extended line of the center of undulator, which may scatter the bremsstrahlung γ-rays. A 250-mm long lead shield was set just after the monochromator, where the monochromated beam was 20 mm below the straight line. With this radiation shield, the experimenters can access the area for experiments safely during usual operation.

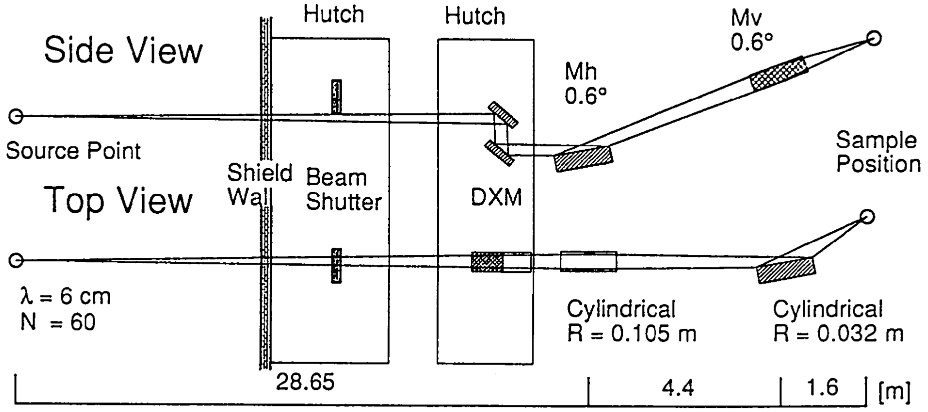

Figure 1

New layout of PF-BL-2A. Soft x rays from the undulator U#02 (λu = 6 cm, N = 60, Kmax = 2.25) are monochromated by the double-crystal monochromator (DXM) and then focused with two cylindrical mirrors (Mh and Mv).

3. Improved performance under the reduced emittance operation

The electron beam emittance ε of the PF storage ring has been reduced from 130 nm-rad to 36 nm-rad since May, 1998 (Katoh *et al.*, 1998b). This increases brilliance of the synchrotron radiation, especially in the undulator source. Then, how much gain is actually available? To confirm the pure effect of the emittance reduction, the available photon flux was measured with a simplest optics of apertures and monochromator only; i.e., the beam intensities were measured before the two focusing mirrors. The horizontal and vertical positions of the horizontal and vertical apertures, respectively, were adjusted to obtain maximum intensity at a peak of the undulator harmonics. Figure 2 shows a comparison of measured beam intensities in a very small area. The horizontal aperture of 1-mm opening at 15.5 m from the source point accepts ~65 µrad of the beam and the vertical aperture of 0.5-mm width at 25.0 m does ~20 µrad. The peak intensity of the 5th harmonics has reached at ~2.4 times as much as before under this condition.

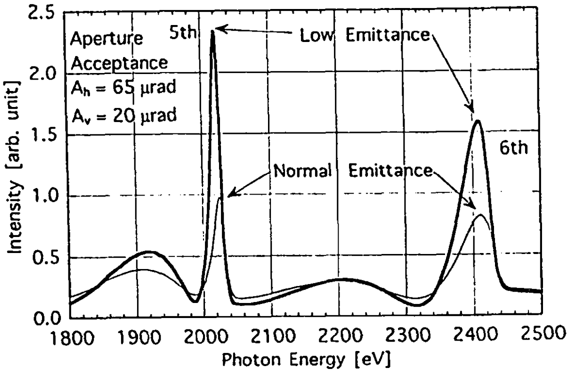

Figure 2

Measured photo-emission current from a nickel plate. Only the center of the undulator radiation (gap = 32.9 mm) was passed by apertures whose acceptances are 65 µrad (horizontal) and 20 µrad (vertical).

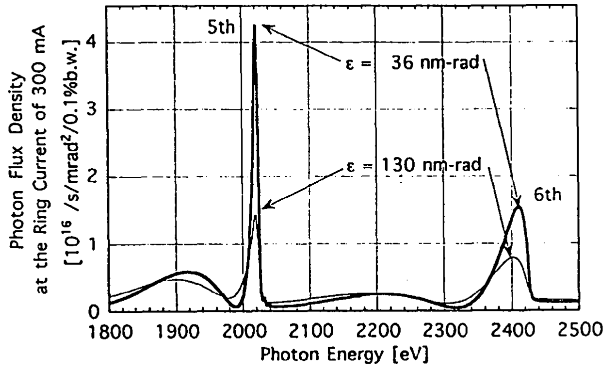

Figure 3

Calculated photon flux density for K = 1.7.

Table 1

Parameters of the PF storage ring at the U#02 source point and the undulator beam till April, 1998 and since May, 1998.

ε is the natural emittance and the X-Y couplings of 2% and 1% are assumed for ε = 130 nm-rad and 36 nm-rad optics, respectively. $\sigma_{x,y}$ is the horizontal or vertical electron beam size and $\sigma'_{x,y}$ is the horizontal or vertical electron beam divergence. $\Sigma'_{x,y}$ is the horizontal or vertical effective beam divergence for a 2020-eV photon.

	ε (nm-rad)	σ_x (µm)	σ_y (µm)	σ'_x (µrad)	σ'_y (µrad)	Σ'_x (µrad)	Σ'_y (µrad)
-Apr.	130	784	112	157	22	158	26
May-	36	422	42	84	8	85	15

This is reasonable in consideration of the beam size and divergence at the U#02 source point listed in Table 1, where the effective source divergences Σ'_x and Σ'_y were calculated for the photon energy of 2020 eV (σ'_P = 13 µrad). Please note the size of photon is negligibly small (σ_P = 3.7 µm for E_P ~ 2020 eV) compared with the electron beam size, i.e., Σ_x and Σ_y are almost the same as σ_x and σ_y, respectively. These values are sufficiently small even in the higher emittance mode compared with the beam sizes at the apertures expanded by the beam divergences. Accordingly, the merit of downsizing of σ_x and σ_y is not effective in the measured intensity and the photon flux density rather than the brilliance can be compared. In fact, the spectral features are well reproduced by the calculated photon flux densities shown in Fig. 3.

On the other hand, a total photon flux in a rather wide area of 260 µrad^h × 80 µrad^v has become ~1.5 times as much as before. This can be focused to ~ 1 mmϕ by the two mirrors and the absolute photon flux reaches ~ 2 × 10^{11} photons/s at the peaks of the undulator harmonics.

The energy resolution depends only on the crystal properties for such a small beam divergence of Σ'_y so that essentially it does not change by the emittance reduction. Actually, measured spectrum of Ar gas at Ar *K*-edge looks no difference with the previous data. The previously reported dip in the first absorption peak of SO_2 at sulfur *K*-edge (Kitajima, 1996) is not reproduced and may be artificial.

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