# Construction of an Elliptically Polarizing Undulator (U#19) at the Photon Factory

We are constructing a new elliptically polarizing undulator (U#19) as a light source for soft X-ray scattering, spectroscopy and scanning transmission X-ray microscopy (STXM) experiments. U#19 is an EPU with an APPLE-II-type magnetic arrangement to obtain various polarization states. We designed U#19 to utilize the extended straight section as much as possible. The target photon energy region of U#19 is from 100 eV to 2 keV under various polarization states.
We installed U#19 in the ring in the summer of 2018 and its operation for user experiments was successfully begun during the autumn operation of the ring.

We have renewed the undulators for the vacuum ultraviolet and soft X-ray (VUV-SX) light source renewal project after the reconstruction of the Photon Factory (PF) [1]. Step-by-step, we constructed five elliptically polarizing undulators (EPUs): U#02-2, U#13, U#16-1, U#16-2, and U#28 for the beamlines BL-02, BL-13, BL-16, and BL-28, respectively. For the remaining beamline BL-19, we are constructing U#19 as a light source for soft X-ray scattering, spectroscopy, and STXM experiments. U#19 is the fourth EPU with the APPLE-II-type magnetic arrangement [2] to obtain various polarization states. **Table 1** shows the basic parameters of the EPUs at the ring.

**Table 2** shows the characteristic parameters of U#19. The target photon energy region of U#19 is from 100 eV to 2 keV under various polarization states. **Figure 1(a)** shows the calculated spectrum of U#19. The basic design of the mechanical system to move the gap and the magnet rows of U#19 is the same as that of the previous APPLE-II-type EPU (U#13). **Figure 1(b)** shows a photograph of U#19 after assembling the magnet arrays.

**Table 1:** Basic parameters of the EPUs at the PF ring

| Name | Period length (mm) | Number of periods | Maximum By, Bx (T) | Photon energy region (eV) | Type of EPU | Installation year |
|---|---|---|---|---|---|---|
| U#16-1 & 2 | 56 | 44 | 0.6, 0.38 | 200–1000 | APPLE-II | 2008, 2010 |
| U#02-2 | 160 | 17 | 0.33, 0.33 | 30–300 | six movable rows | 2014 |
| U#13 | 76 | 48 | 0.68, 0.34 | 50–1500 | APPLE-II | 2015 |
| U#28 | 160 | 22 | 0.33, 0.33 | 30–300 | six movable rows | 2015 |
| U#19 | 68 | 55 | 0.71, 0.46 | 100–2000 | APPLE-II | 2018 |

**Table 2:** Characteristic parameters of U#19

| Magnetic block size (mm) | Magnet material | Maximum magnetic force Fx, Fy, Fz (kN) | Gap operation range (mm) |
|---|---|---|---|
| 40×40×17 | Nd-Fe-B (NEOMAX-S49CH) | 42.6,17.5, 43.5 | 24–150 |

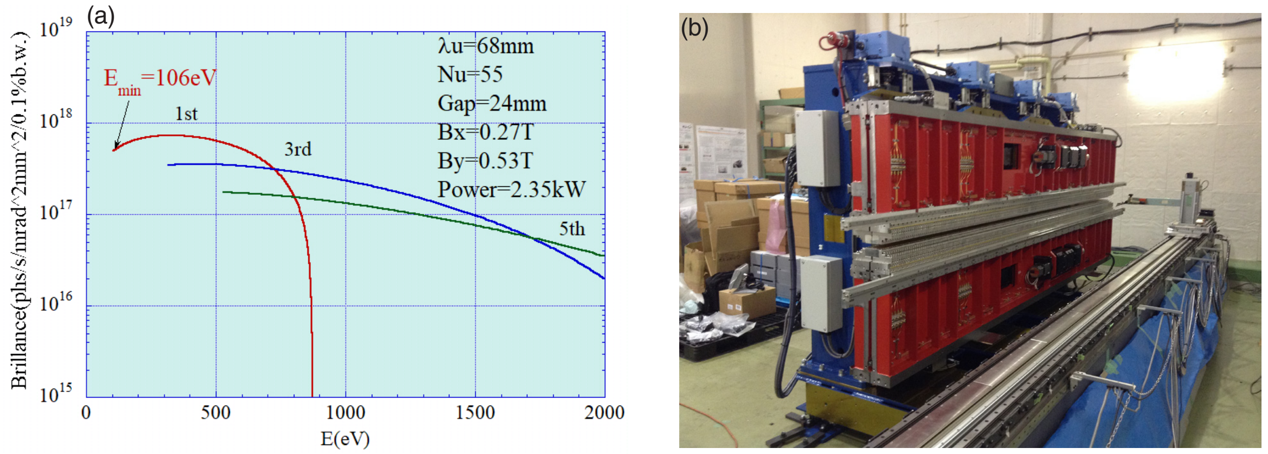


**Figure 1: (a)** Calculated spectrum of U#19 in the elliptical polarization mode (By/Bx = 2), **(b)** Picture of U#19

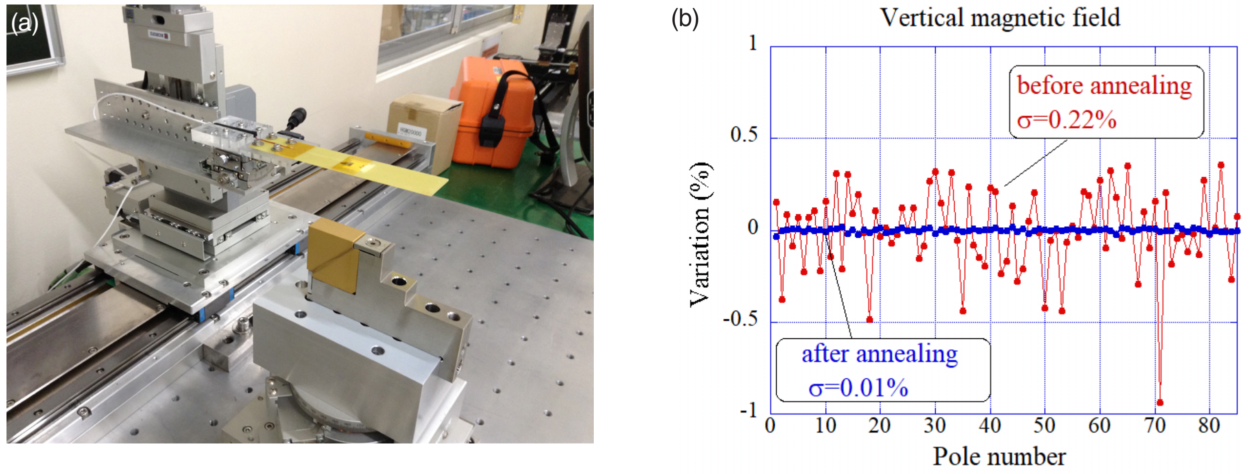


**Figure 2: (a)** Measurement setup for individual magnetic blocks along the beam axis. **(b)** Distribution of the first integrals of the magnetic field every half period along the z-axis at individual magnetic poles compared before and after the sorting simulation in the horizontally linear polarizing mode. The variation from the average value is expressed.

For the magnetic adjustments of the EPUs at the PF, we have developed a practical method of determining an excellent initial arrangement of the magnetic arrays [3]. In this method, the longitudinal magnetic field distribution of each magnet is measured with a high spatial resolution using a Hall probe system that moves along the beam axis. We measured the vertical and horizontal fields simultaneously. **Figure 2(a)** shows the setup used for this measurement. The total number of measured magnets was 920. We optimized the initial arrangement of the magnet arrays by analyzing the superposition of all distribution data. The simulation results for U#19 are summarized in **Fig. 2(b)**. We optimized the magnetic arrangement in the horizontal polarizing mode and the vertical polarizing mode simultaneously. We compared the properties of the superposed magnetic field distribution at the calculated arrangement of the magnets and the case of the initial state. In the initial state, we set the magnetic blocks randomly. The figures show the results of the first integral distributions of the magnetic field every half period along the z-axis at the individual magnetic poles.

For the operation of all APPLE-II-type EPUs (U#16-1 & 2, U#13, and U#19) at the ring, we control our EPUs as adjustable phase undulators (APUs) by individually shifting the four magnetic array rows [4, 5]. We control the photon energy by shifting the upper pair of the magnet rows longitudinally with respect to the lower pair or by shifting the right pair of the magnet rows with respect to the left pair; however, the gap is kept fixed [1, 6, 7]. The COD caused by changes in this APU mode is clearly small compared to the usual variable-gap mode. The APU mode offers a highly useful feature for the operation of EPUs as it allows the polarization state and photon energy to be controlled without spectral degradation or the large disturbance of the electron beam caused by changing the gap of the EPU.

The U#19 vacuum chamber is made of aluminum alloy (A6060-T6), and its inner wall is coated with a non-evaporable getter (NEG) thin film. The beam channel has an elliptical aperture; the vertical opening of 15 mm is required by the beam dynamics and the horizontal opening of 90 mm is identical to those of the adjacent chambers. The external height of the chamber is 20 mm because the minimum gap of the magnet arrays is 24 mm, and the 0.6-mm-thick flat wires are placed at the top and bottom of the chamber.

## REFERENCES

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