3 PF-AR

3-1 Summary of Machine Operation

The operation statistics of the PF-AR in FY2005 are summarized in Table 1. The total operation time was 5328 hours, and the failure time was 62.5 hours. The total operation time has been comparable to that of the PF in recent years (Fig. 1). The failure rate is still about twice as high as that of the PF ring, but has been remarkably improved in recent years. The injection frequency of twice a day with an initial beam current of 60 mA was maintained throughout the year. A standard operation mode (two-bunch operation at 5 GeV) for medical applications was established. While no medical applications were carried out during FY2004, the PF-AR was operated in this mode nine times in FY2005.

The special feature of the PF-AR is its operation as a "single-bunch light source". A low single-bunch impurity (the ratio of the electron number in undesirable buckets to that in the prescribed bucket) is essential for effective utilization of single-bunch radiation. An increase in impurity of the single-bunch beam during the storage period is usually a problem in low-energy and/or low-emittance storage rings. However, it is still a crucial and serious issue even for the PF-AR that is neither a low-energy nor a low-emittance machine if a very low impurity of the order of 10^{-8} is required. Therefore, purification of the single-bunch beam is desired at an operation energy of 6.5 GeV. An existing purifier, originally designed to operate at an injection energy of 3 GeV, has been upgraded to enable beam purification at 6.5 GeV. The improved system will be tested soon.

A new in-vacuum type undulator for beamline NW 14A was installed in the west-straight section. Another in-vacuum type undulator will also be installed soon in the west-straight section. Details of these undulators are reported in the previous issue of this report and in the following section.

Table 1 Operation statistics of PF-AR in FY2005.

Operation Time	5328.0 h	
SR Experiment	4578.5 h	85.9%
Beam Development	545.0 h	10.2%
Failure	62.5 h	1.2%
Miscellaneous	142.0 h	2.7%

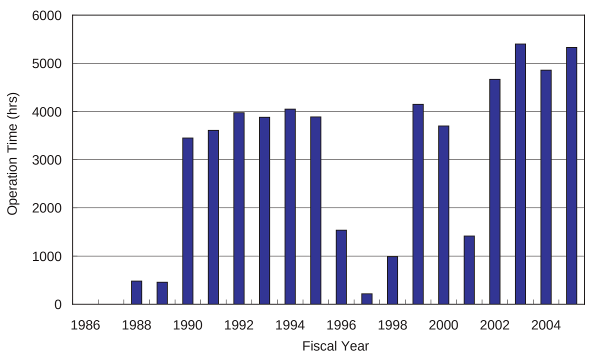


Figure 1
Operation time history of the PF-AR.

3-2 Two New In-Vacuum Type Undulators for the Non-Equilibrium Dynamics Project at the PF-AR

The non-equilibrium dynamics project has been underway for the past few years at the 6.5-GeV PF-AR [1]. For the project the RF sections of the PF-AR were modified to produce free straight sections for insertion devices and to enable the construction of a new beamline AR-NW14A. Figure 2 shows a schematic plan view of the north half of the PF-AR. Two of the four RF cavities located in the west RF section were moved to the east section, and beamline AR-NW14A was constructed for time-resolved X-ray diffraction and XAFS experiments. Two new in-vacuum type X-ray undulators (U#NW14-36 and U#NW14-20) have been constructed. U#NW14-36 has been installed in the lowest of the new straight sections, and U#NW14-20 will be installed in the second-lowest within an RF section.

There were two main requirements for the light source for time-resolved X-ray diffraction and XAFS experiments at AR-NW14A. One was to cover a wide photon-energy region from 5 to 25 keV by several harmonics, and the other was that a narrow energy region from 13 to 18 keV is covered by the first harmonic of

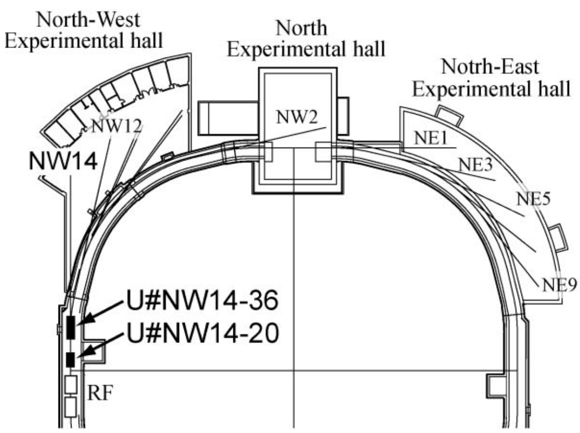


Figure 2
Schematic plan view of the north half of the PF-AR.

Table 2 Basic parameters of U#NW14-36 and U#NW14-20 in the PF-AR ring (E=6.5 GeV, I=50 mA).

Name	Period length (mm)	Number of period	Maximum B (T)	Maximum Gap (mm)	Minimum Gap (mm)	Magnetic structure
U#NW14-36	36	79	0.83	40	10	Pure Halbach
U#NW14-20	20	75	0.63	40	8	Pure Halbach

undulator radiation. U#NW14-36 was designed to satisfy the first requirement and U#NW14-20 the second. Table 2 shows the basic parameters of U#NW14-36 and U#NW14-20. The undulators were constructed employing the same in-vacuum technology [2, 3] by which several undulators have already been constructed at the PF-AR. A pure Halbach-type magnet arrangement was adopted with a period length of λ_u=36 mm and a period number of N=79 (for U#NW14-36), and λ_u=20 mm and N=75 (for U#NW14-20).

The period lengths of the devices were selected to cover the 5 to 25 keV photon-energy region with up to the fifth harmonic during 6.5-GeV operation of the PF-AR for U#NW14-36 [4], and to cover the 13 to 18 keV energy region with the first harmonic for U#NW14-20.

The magnet material selected was a Nd-Fe-B alloy with a remanent field of B_r=12.0 kG and a coercivity of iH_c=28 kOe (NEOMAX35VH manufactured by NEOMAX Co. Ltd.). Since the material for the magnet blocks is porous, these blocks were coated with a 5-μm-thick TiN film for vacuum sealing. They were embedded in a holder of oxygen-free copper, and attached on a pair of magnet-mounting beams made of Al. Figure 3 shows photographs of part of the magnet arrays. Each magnet block was mounted in its copper holder individually for U#NW14-36. Two magnet blocks were clamped in one copper holder for U#NW14-20.

Both faces of the magnet arrays were covered with a thin (60-µm) copper-plated nickel foil to avoid heat problems caused by the electric current induced by the electron beam. Be-Cu foils 180 µm in thickness were inserted as RF contactors between the ends of the magnet arrays and the Q duct of the PF-AR.

The gap between the magnet arrays can be changed using a translation system composed of ball screws and linear guides. The scanning speed of the magnet gap is 30 mm/min. We have developed EPICS (Experimental Physics and Industry Control System)-based control systems for these undulators, similar to those used for other new undulators in the PF [5, 6] and in the PF-AR [3].

These two undulators will be operated exclusively for the same beamline. When one undulator is under operation, the gap of the other undulator will be opened to its maximum limit to avoid mixing of the radiation.

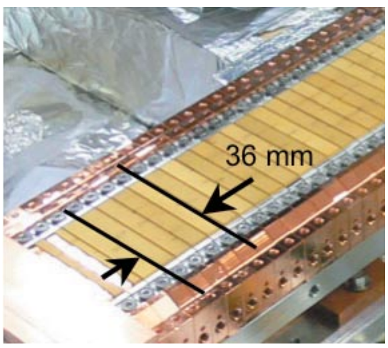
The arrangement of the magnet blocks was determined by the simulated annealing method [7] to minimize the calculated magnetic field integral in the vertical and horizontal directions over the whole undulator. This determination was made on the basis of measured field data for each magnet block. The field data were obtained using a rotating coil system [5, 6], set along the longitudinal axis of the magnet blocks.

The actual field optimization of the undulators was performed based on precise field measurements in the vertical and horizontal directions, which were made using a 2-dimentional Hall-probe system. Two Hall probes were oriented in the vertical and horizontal directions in a temperature-controlled copper holder. The temperature of the Hall-probe system was maintained at 30 ± 0.01°C by a micro-oven mounted inside the holder. The Hall-probe system has a total thickness of 2 mm, and was developed during the construction of the very short-period undulator SGU#17 at the Photon Factory [6]. It can be used to perform very accurate field measurements of a gap as narrow as 3 mm.

Using the Hall-probe system has allowed optimizing the kick angles of the electron beam at individual magnetic poles and minimizing the optical phase errors at the magnetic poles. The adjustment procedure was made by (1) exchanging the magnet units where the deflection is large, and (2) insertion of the magnet chips into holders of the magnet blocks.

Figure 4 shows typical results of the field adjustments in terms of the electron orbit in U#NW14-36 and U#NW14-20. The final deflection and deviation of the

(a)



(b)

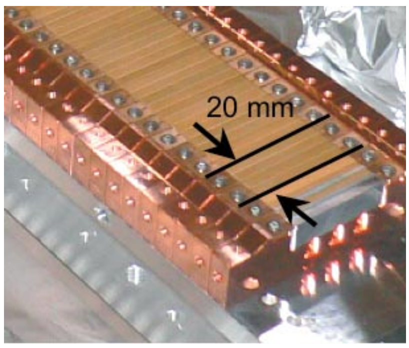


Figure 3
Photographs of the magnet arrays of (a)U#NW14-36 and (b)U#NW14-20.

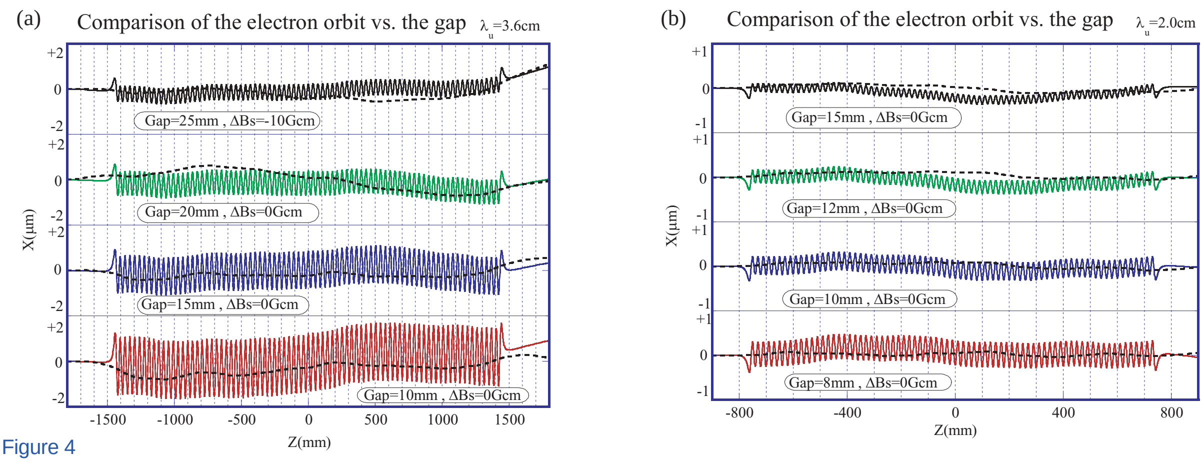


Figure 4
Results of the field adjustment of (a)U#NW14-36 and (b)U#NW14-20. The solid cruve shows the horizontal electron orbit and the dotted curve shows the vertical orbit.

electron orbit were found to be satisfactorily small both in the horizontal and vertical directions.

The root-mean-square errors of the optical phases were as small as 4 degrees for U#NW14-36 and 3.2 degrees for U#NW14-20. The effects of the field errors on the spectral properties were found not to be significant; the brilliance of the 5th harmonic for U#NW14-36 is maintained at 89% of the ideal (no errors) brilliance.

A combination of non-evaporable getter (NEG) pumps and sputter ion pumps (SIPs) was employed for the pumping system of the vacuum chambers. The pumping speeds provided by the NEG pumps and SIPs for U#NW14-36 are 5000 l/s and 480 l/s, and those for U#NW14-20 are 4000 l/s and 240 l/s. Baking at 120°C for 48 hrs resulted in ultimate pressures of 1.5×10^{-8} Pa for U#NW14-36 and 2×10^{-8} Pa for U#NW14-20.

U#NW14-36 was installed in the PF-AR in the summer of 2005 following vacuum commissioning, and operation began satisfactorily for experiments in autumn 2005. The vacuum commissioning of U#NW14-20 was completed in March 2006 following magnetic measurements and adjustments. The U#NW14-20 will be installed in summer 2006, with its operation starting from autumn 2006.

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