PRESENT STATUS OF THE KEK PF-RING AND PF-AR

Kimichika Tsuchiya#, Seiji Asaoka, Kaiichi Haga, Kentaro Harada, Tohru Honda, Yosuke Honda, Masaaki Isawa, Yukihide Kamiya, Tsukasa Miyajima, Hiroshi Miyauchi, Shinya Nagahashi, Norio Nakamura, Takashi Nogami, Takashi Obina, Toshiyuki Ozaki, Hidenori Sagehashi, Hiroshi Sakai, Shogo Sakanaka, Hiroyuki Sasaki, Yoshihiro Sato, Miho Shimada, Kenji Shinoe, Tatsuro Shioya, Mikito Tadano, Toshihiro Tahara, Takeshi Takahashi, Ryota Takai, Yasunori Tanimoto, Takashi Uchiyama, Akira Ueda, Kensei Umemori, Masahiro Yamamoto,
KEK, Ibaraki, Japan
Hiroyuki Takaki, ISSP/SRL, Chiba, Japan

Abstract

Two synchrotron light sources have been operated at the High Energy Accelerator Research Organization (KEK). One is the 2.5 GeV Photon Factory storage ring (PF-ring) and the other is the 6.5 GeV Photon Factory advanced ring (PF-AR). In this paper, present operational status, recent R&D activities and the future plans will be reported.

INTRODUCTION

Two electron storage rings are currently dedicated to Synchrotron Radiation (SR) research at KEK, and have been meeting a wide variety of needs of SR users. Principal parameters of the PF-ring and PF-AR are listed in Table 1. At the PF ring, the top-up injection system with a pulsed sextuple magnet was established in 2009 [1]. The in-vacuum undulator SGU#15 will be installed in 2013 and three VUV/SX elliptically polarizing undulators (EPUs) will be installed in 2014. Furthermore, upgrade plan towards the top-up injection of the PF-AR is underway. Construction of the straight injection tunnel from linac to the PF-AR has started in April 2013.

Table 1: Main parameters of PF-ring and PF-AR

Parameters	PF-ring	PF-AR
Beam energy (GeV)	2.5GeV	6.5GeV
Circumference (m)	187m	377m
Emittance (nm.rad)	35	293
Beam current (mA)	450(top-up)	60-40(decay)
Beam lifetime (h)	22	22
Critical energy (keV)	4.0	26
Number of insertion devices	11 (3 in-vacuum)	6 (5 in-vacuum)

OPERATIONAL STATUS

The PF-ring is operated at 2.5 GeV to provide photons with the energy from VUV to hard x-ray region and the PF-AR is always operated in a single-bunch mode of 6.5 GeV to provide pulsed X-rays. Both two rings continue stable user operations after the shutdown for the restoration caused by the Great East Japan Earthquake on 11 March 2011 [2]. The operation statistics of the PF-ring and PF-AR are listed in Table2. In 2012, the mean time between failures (MTBF) recovered the usual values before the earthquake in both rings.

Table 2: Operational statistics of PF-ring and PF-AR

	PR-ring		PF-AR	
Fiscal year	2011	2012	2011	2012
Total operation time (h)	4728	4416	4080	4080
Scheduled user time (h)	2832	3792	2904	3672
Number of failures	18	23	49	33
Total down time (h)	14.9	37.6	38.7	29.7
MTBF (h)	157.3	164.9	59.3	111.3
MDT (h)	0.8	1.6	0.8	0.9

DEVELOPMENT

Fast Polarization Switching

We have been developing a fast-polarization-switching source at the B15-16 straight section in the PF ring. The source consists of two tandem APPLE-II-type elliptically polarizing undulators (EPU), namely U#16-1 and U#16-2, and a fast kicker system [3][4]. These two EPUs are designed to obtain soft x-rays in the energy region from 200 eV to 1 keV under various polarization states. The period length of the EPU is 56 mm and the periodicity number is 44.

We can use U#16-1 and U#16-2 as both the usual APPLE-II type EPU and as the adjustable phase undulator (APU). In APU mode, we move the top pair of the magnetic rows longitudinally with respect to the bottom pair, however, the gap is fixed to change the photon energy.

To achieve a fast local bump, five identical bump kickers were installed in a long straight section (B15-16) in the spring of 2008. Figure 1 shows a schematic view of the configuration of the B15-16 straight section. The control system for the fast local bump is developed under the APU circular polarization modes of the EPUs. After the feed-forward correction, the vertical and horizontal

#kimichika.tsuchiya@kek.jp

oscillations are also suppressed within 3μm around the ring with 10 Hz polarization switching. Figure 2 shows an example of beam position measurement by the fast BPMs at the bump. At other beamlines, the fluctuation of the photon beam linked the bump switching is not detected.

For the other polarization modes and the transition states of the EPUs, we confirmed that feed-forward correction worked well with the same accuracy as in the circular polarization mode. We could use the same data table for feed-forward correction in all APU symmetric modes of the EPUs. The fast polarization switching operation at 10 Hz was started successfully in April 2012 at the PF-ring. Experiment users can change the photon energy and the polarization state of both U#16-1 and U#16-2 independently at any time during the fast polarization switching operation and during static operation.

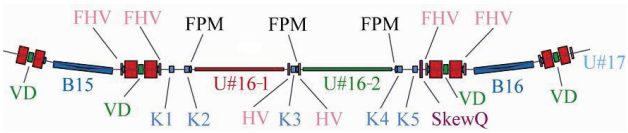


Figure 1: Schematic view of the configuration of the B15-16 straight section.

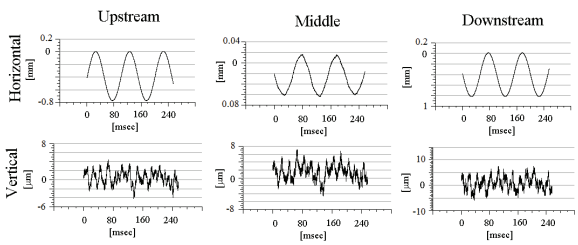
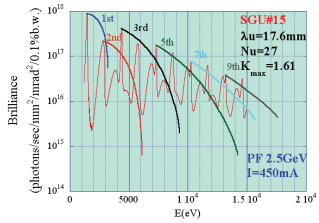


Figure 2: Example of the beam position measurement by the fast BPMs at the bump.

FUTURE PLANS

A New Short Gap Undulator (SGU#15)

After the reconstruction to upgrade of the PF storage ring, four 1.4m-long straight sections have been created for short gap undulators (SGU) with a period length of less than 20 mm [5]. We constructed three SGUs in an in-vacuum configuration for the X-ray light source with energy around 10 keV. The minimum gaps are both 4 mm and the operation of these SGUs is stable under the top-up operation of the PF ring. For the last remaining straight-section, B14-15, we are planning to construct a new SGU#15 as a light source for both the small- angle X-ray scattering experiments and the XAFS experiments. The period length of the SGU#15 is 17.6 mm and the number of periods is of 27. The photon energy region of the SGU#15 is wide, from 2 keV to 15 keV. To cover the all this entire energy region, the higher harmonics of undulator radiation will be used up to the 9th higher harmonics. Figure 3 shows a calculated spectrum of the SGU#15 and a photograph of the SGU#15 during the magnetic measurement. The magnetic adjustments for SGU#15 have been completed in autumn of 2012 sufficiently. We will install the SGU#15 in the PF ring in summer of 2013 after the vacuum commissioning.



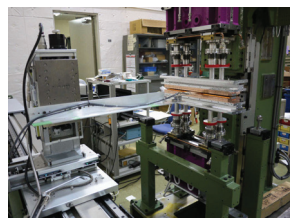


Figure 3: Calculated spectrum of the SGU#15 and a photograph of the SGU#15 during the magnetic measurement.

Table 3: Basic Parameters of the New IDs in the PF Ring

Name	U#02-2	U#13	U#28
Period length (mm)	160	76	160
Number of periods	17	47	22
Maximum Bx/By (T)	0.33/0.33	0.34/0.68	0.33/0.33
Type of undulator	EPU	EPU	EPU

Renewal Project of the Undulators for the VUV-SX Beam lines

At the PF ring, the reconstruction to upgrade of the straight sections for the insertion devices has been accomplished in 2005. As the result of the reconstruction, the lengths of the every straight section were extended. As an attempt to utilize the extended straight section effectively, we are constructing three new undulators for BL02, BL13 and BL28, which will be called U#02-2, U#13 and U#28, respectively. All these undulators are designed as elliptically polarizing undulators (EPUs) to obtain various polarization states, not only circular (left-handed and right-handed) polarization but also linear (horizontal and vertical) polarization.

For BL02, we plan to move the existing undulator (U#02) to the downstream of the B01-B02 straight section, and install a new undulator (U#02-2) tandem at the upstream of U#02. We will use U#02 and U#02-2 exclusively to obtain photons over a wide energy region at the single beamline. The photon energy region of U#02 is from 400 eV to 2 keV and the target energy region of U#02-2 is from 15 eV to 300 eV with the first harmonic radiation of EPU. The period length of U#02 and U#02-2 are 60mm and 160 mm, respectively.

We renewed the present undulators for BL13 and BL28 to utilize the extended straight section as possible. U#13 has the period length of 76mm and the target photon energy region of U#13 is from 50 eV to 1.5 keV under various polarization states. U#28 has same parameters as U#02-2 except the total length. Table 3 shows the designed parameters of the new undulators. We will

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construct these three undulators by fiscal 2013 and install them in the PF ring step by step during 2014.

New PF-AR Transport Line

In April 2013, construction of a new beam transport line (BT) for the PF-AR has started at KEK. This new BT will enable 6.5 GeV full energy injection and top-up operation. The construction completion is scheduled for January 2016.

At present, injection energy for the PF-AR is 3 GeV and the beam energy is ramped up to 6.5 GeV after accumulation of the beam current of 60mA. The beam injection is done twice a day and it takes about 15 minutes for each injection. So far the PF-AR used the common BT with the KEKB (8 GeV electron) as shown in Fig. 4. During the PF-AR beam injection, the BT was optimized for the PF-AR and the KEKB beam injection was waiting.

A fast switching injection with 50 Hz from the KEK LINAC to the three rings, the PF-ring (2.5 GeV) and the KEKB LER (3.5 GeV) / HER (8 GeV), has been already realized. In the upcoming the SuperKEKB project, the estimated beam lifetime is as short as 10 minutes, so the fast switching injection to the PF-AR is required by the start of the physics run at the SuperKEKB in January 2016. Therefore, the new BT is separated from the SuperKEKB BT at the end of the KEK LINAC using a pulsed bending magnet as shown in Fig. 4. The separated beam for the PF-AR passes through a new tunnel, about 200 m long, and injected the PF-AR.

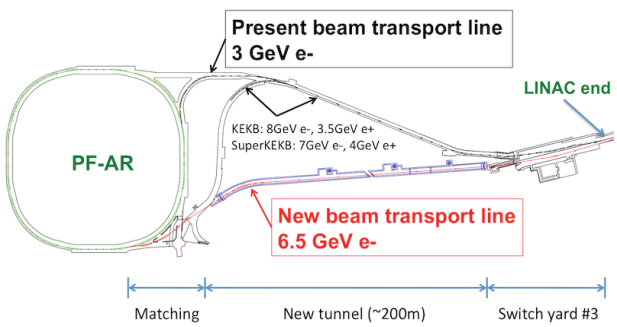

Figure 4: New beam transport line (red) for the PF-AR. A black line show the present beam transport line. A blue area is a new tunnel.

The construction schedule of the new BT is shown in Fig. 5. The tunnel construction was started in April 2013, and will be completed in FY2013. The construction of infrastructure (cooling water, etc) will begin in April 2014 and end in December 2014. The PF-AR will be operated until July 2016 and shut down for about five months. The removal of the old BT and installation of the new BT will be scheduled in this shut down period. The magnets used in the old BT will be reused for the new BT. The commissioning of the new BT is scheduled for January 2016.

Optics parameters (betatron functions, dispersion functions, and beam sizes) from the end of the KEK LINAC to the injection point of the PF-AR are shown in Fig. 6. Solid (blue) and broken (red) lines correspond to the horizontal and vertical parameters, respectively. The optics parameters of the new BT and the PF-AR are matched at the injection point of the PF-AR. The normalized emittance is assumed to be $100\times10^{-6}\,\pi$ m•rad and the energy spread to be 10^{-3} with uniform distribution. After upgrade of the KEK LINAC, these parameters will be improved to $20\times10^{-6}\,\pi$ m•rad and 2×10^{-4}, respectively.

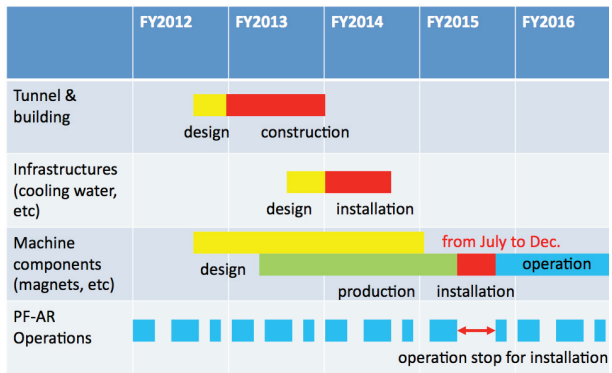

Figure 5: Construction Schedule of the PF-AR new transport line.

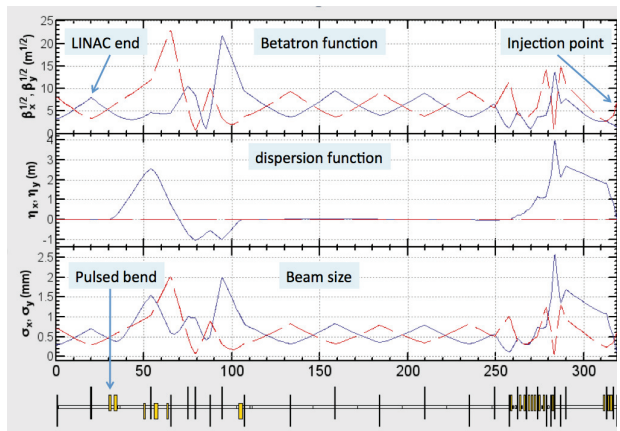

Figure 6: Optics from the end of the KEK LINAC to the injection point of the PF-AR. Blue and red lines represent the horizontal and vertical parameters, respectively.

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