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RECENT DEVELOPMENT AND OPERATIONAL STATUS OF PF-RING AND PF-AR

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Abstract

Update of the first-generation undulators installed in 1980s is pushed forward at the PF-Ring taking advantage of the extended straight sections reconstructed in 2005. New undulators have been designed as variable polarizing undulators to obtain various polarization states, not only elliptical polarization but also linear (horizontal and vertical) polarization. Three undulators are to be installed by the end of FY2014 for BL02, BL13 and BL28. At the PF-AR, an independent beam transport line from the injector LINAC is being constructed. The Super KEKB which shares the injector LINAC with the PF-Ring and the PF-AR will be commissioned in FY2015. The full energy top-up injection of the PF-AR will be available as a simultaneous injection with the 7-GeV HER, the 4-GeV LER and the PF-Ring not so later than the commissioning of the Super KEKB.

OPERATION STATISTICS

KEK manages two synchrotron radiation (SR) sources, one is a 2.5-GeV VUV/SX ring named Photon Factory storage ring (PF-Ring) and the other is 6.5-GeV hard X-ray ring named Photon Factory Advanced Ring (PF-AR). The SR users more than 3,000 work on about 800 experimental proposals a year.

The PF-Ring is usually operated at 450 mA with top-up injection. The hybrid filling mode of a 50-mA isolated bunch with a multi-bunch train of 350 mA has been introduced by applying the bunch-fill control system developed for the top-up injection.

An advantage of the PF-Ring is stability of the operation. As shown in Table 1, the mean time between failures (MTBF) is kept better than 150 hours every year. In FY2013, there was a 24-hour suspension in order to secure the radiation safety of the construction site near the injector LINAC. This was the main reason why the total down time was much longer compared with previous years.

The total operation and the user time have gradually decreased in these 4 years. The exceptional short user time in FY2011 was an influence of the great East Japan Earthquake. The budget circumstances and rise of the electricity bill are principal factors for the reduction of the operation time. The Photon Factory continues making an effort to keep the user time at least 4000 hours a year to satisfy the SR user's demand.

Table 1: Operational statistics of the PF-Ring

Fiscal Year	2010	2011	2012	2013
Total operation time (h)	5064	4728	4416	4176
Scheduled user time (h)	4080	2832	3792	3504
Ratio of user time (%)	80.6	59.9	85.9	83.9
Number of failures	18	18	23	22
Total down time (h)	29.2	14.9	37.6	52.1
Failure rate (%)	0.7	0.5	1.0	1.5
MTBF (h)	226.7	157.3	164.9	159.3
Mean down time (h)	1.6	0.8	1.6	2.4

Table 2: Operational statistics of the PF-AR

Fiscal Year	2010	2011	2012	2013
Total operation time (h)	4608	4080	4080	3912
Scheduled user time (h)	4032	2904	3672	3478
Ratio of user time (%)	87.5	71.2	90.0	88.9
No. of failures	74	49	33	47
Total down time (h)	73.7	38.7	29.7	99.6
Failure rate (%)	1.8	1.3	0.8	2.9
MTBF (h)	54.5	59.3	111.3	74.0
Mean down time (h)	1.0	0.8	0.9	2.1

The PF-AR has high critical photon energy of 26 keV, and is always operated at a single bunch mode. This ring is convenient for time-resolved activities and high-flux hard x-ray users.

The injection energy of the PF-AR is 3.0 GeV and ramp-up is necessary. We have a plan to accomplish full-energy top-up injection by constructing a new 6.5-GeV beam transport line.

At the PF-AR, the drop of the beam lifetime attributed to the dust trapping [1] is frequently observed. Even though the frequency of the dust trapping is decreasing year by year, this phenomenon is one of reasons why the MTBF of the PF-AR is inferior to the PF-Ring.

UPGRADE OF INSERTION DEVICES

Elliptically polarizing undulators for VUV/SX beamlines

At the PF-Ring, extension of the straight sections for the insertion devices has been accomplished in 2005. By using the extended straight sections effectively, construction of new undulators has advanced for BL16,

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BL02, BL13 and BL28 by replacing the first generation undulators of 1980s. All these undulators are designed as elliptically polarizing undulators (EPU) to obtain various polarization states, not only circular or elliptical polarization but also linear (horizontal and vertical) polarization.

In 2010, two tandem APPLE-II type EPUs, U#16-1 and U#16-2, was installed at the longest straight section between B15 and B16. The 10-Hz polarization switching using the alternating local bump system is working since 2012 [2].

Figure 1: New elliptically polarizing undulator U#02-2 (near side) installed with the existing planar undulator U#02 (far side) in the long straight section.

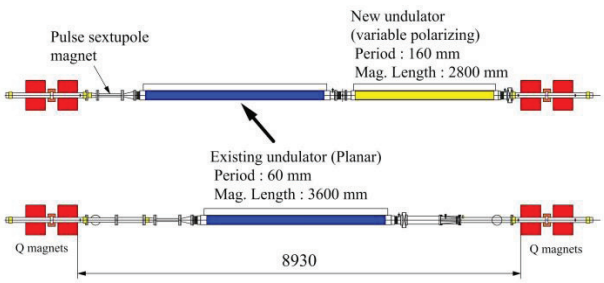

Figure 2: Change of the placement of undulators at the long straight section between B01 and B02.

In March 2014, we reconstructed the other longest straight section between B01 and B02. The distance between the quadrupole magnets of both ends is 8.93 m. We have moved the existing planar undulator U#02 of 3.6 m in length to downstream of the straight section, and the new EPU (U#02-2) of 2.8 m in length (Fig.1) was installed at the upstream of U#02 as shown in Fig. 2. The pulsed sextupole magnet [3] used for the top-up injection has been installed at the downstream end of this straight section.

Two undulators, U#02 and U#02-2, are used to obtain photons over a wide energy region at the single beamline. U#02 of 60-mm period supplies photon in the 400 eV to 2 keV range and U#02-2 of 160-mm period supplies photon in the 15 eV to 300 eV range with the first harmonic radiation of EPU [4].

Two more EPUs are almost ready for installation for BL13 and BL28. We are going to install these two EPUs by the end of FY2014. U#13 has the period of 76 mm and the magnetic length of 3.6 m. The target photon energy region is from 50 eV to 1.5 keV under various polarization states. U#28 has the same period and the same photon energy range as U#02-2 and has a longer magnetic length of about 3.5 m.

In-vacuum undulators for X-ray beamlines

In 2013 summer, we installed the fourth short gap undulator (SGU) for BL15 of the PF-Ring. The period length of the SGU#15 is 17.6 mm and the number of periods is 27. The photon energy region is wide from 2 keV to 15 keV. In order to cover the wide energy region, the higher harmonics of the undulator radiation is used up to 9th higher harmonics.

SGUs were constructed in an in-vacuum configuration for the X-ray light source with energy around 10 keV [5]. The minimum gap of all SGUs is 4 mm, compatible with the top-up operation of the PF-Ring.

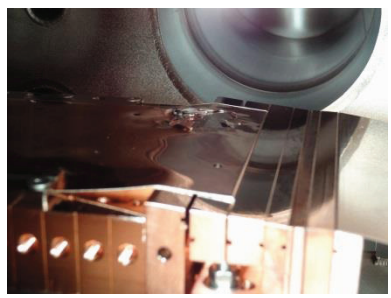

Figure 3: Damage found on the cover foil of the short gap in-vacuum undulator SGU#17.

In November 2013, we experienced the first trouble on the SGU. An irregular vertical orbit distortion due to an artificial mistake gave damage on the copper foil covering the magnetic array of SGU#17. After a beam abortion occurred by the vacuum system fail due to an abnormally high pressure, the injection efficiency deteriorated obviously for a gap narrower than 6 mm. It was found that a prat of the copper foil melted and there was a hole of about 20 mm in diameter near the upstream end of the magnetic array as shown in Fig. 3. Fortunately there was no damage on the magnetic array itself, the SGU#17 could be repaired by replacing the foil on site in March 2014.

Vacuum condition of the elliptically polarizing undulator

Figure 4 shows the cross section of the vacuum duct made of stainless steel for U#16-2. The length of the beam duct is 2.85 m (Fig. 5). The vacuum ducts for all elliptically polarized undulators were produced in a similar design.

The vertical aperture of the beam path is 15 mm to tolerate the undulator gap of 21 mm for U#16. 15 mm is the smallest vertical aperture in the PF-Ring except for the magnetic gap of the in-vacuum undulator.

In the side chamber, non-evaporable getter (NEG) modules of SAES St-707 are equipped with two sputter ion pumps (SIP, 100 l/s). Nominal pumping speed of the NEG modules is 3700 l/s for H_2 and 1450 l/s for CO.

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We have two tandem undulators and the connecting pipes that accommodate fast steering magnets for the alternating local bump system. The total length of the 15-mm beam path amounts to 8.5 m. On the top and bottom of the beam path, 50 mm thick copper was plated to reduce the resistive wall impedance.

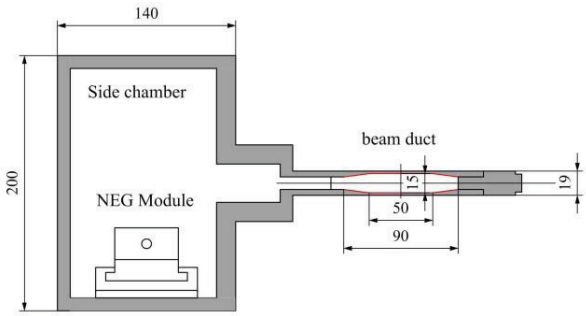

Figure 4: Cross section of the vacuum duct for U#16.

Figure 5: The vacuum duct for U#16-2 in preparation. The full length is 2.85 m.

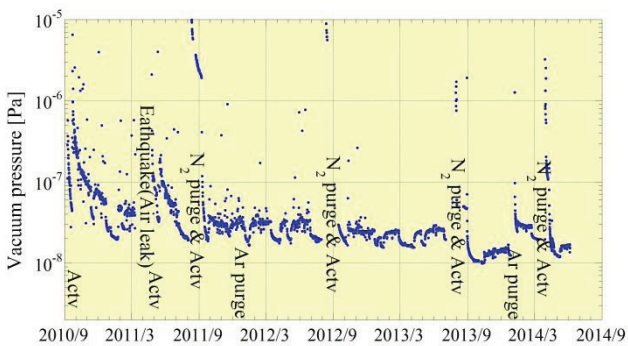

Figure 6: Vacuum pressure of U#16-2 for four years. Repeated activations of the NEG modules are shown as "Actv" in the drawing.

Figure 6 shows the vacuum pressure of the U#16-2 after installed in August 2010. The pressure is measured by Bayard-Alpert ionization gauge attached to the side chamber. During the first 5-month beam operation from October 2010 to February 2011, the pressure decreased promptly to the 10^{-8} Pa range. Unfortunately, the great earthquake and a blackout of several weeks at March 2011 brought the air leak. After recovering from the accidental air leak, the vacuum duct was always purged by dry nitrogen or argon gas when vacuum work was necessary. The re-activations of the NEG modules were always carried out after the dry nitrogen purges. We omitted the activation after the argon purges. Every re-activation well restored the pumping speed and little deterioration observed in the outgassing rate after the dry nitrogen purge.

From October 2012 to July 2013, the beam operation continued without a re-activation for approximately one year. The NEG pump modules held their pumping speed and the pressure was kept at almost constant around 2 or 3 X 10^{-8} Pa.

The pressure has decreased year by year, and it is stable just above 1 X 10^{-8} Pa at 3 years or more passed from the installation, and only a slight difference is observed with or without the beam.

DIRECT BEAM TRANSPORT FOR PF-AR

Construction of the direct beam transport (BT) line for the PF-AR advances now. The BT tunnel shown in Fig. 7 was almost completed by the end of FY2013. As the new BT line will be able to pass 6.5-GeV electron, the full-energy injection is enabled for the PF-AR.

A simultaneous continuous injection to the PF-Ring and the two main ring of KEKB has been already realized. But the PF-AR is excluded because it uses a common BT with the 8-GeV HER. By obtaining an independent BT line, the top-up injection of the PF-AR will be realized simultaneously with the other three storage rings.

The installation of the accelerator components for the BT line and the reconstruction of the injection part of the PF-AR storage ring will be accomplished in FY2015 in parallel with the commissioning of the Super KEKB.

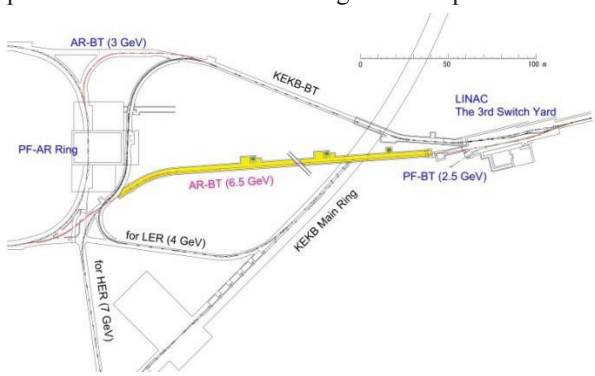

Figure 7: Construction of the direct beam transport tunnel for the 6.5-GeV electron from the injector linac to PF-AR.

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