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

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Abstract

The Photon Factory at KEK has been managing two synchrotron radiation sources, the PF-ring and PF-AR, for over 30 years. Although their operation time has been decreasing in recent years for budget reasons, continuous efforts to improve their performance have been made. In this paper, the operational status of these light sources for FY2018 is described. At the PF-ring, a first-generation undulator was renewed with the beamline components. A vacuum chamber for the new undulator was applied the NEG coating on the inner surface. This is the first attempt in Japanese light sources that the NEG-coated chamber is used for undulators. At the PF-AR, the top-up injection using the direct beam transport line was introduced to the user operation for the first time. Since modification of the beam injector LINAC for enabling simultaneous injection to the four different rings (the PF-ring, PF-AR, SuperKEKB HER and LER) was completed, this top-up operation no longer disturbs the operation of the other three rings. A low-energy operation of the PF-AR was also tested to secure more operation time within the limited budget.

PHOTON FACTORY LIGHT SOURCES

The Photon Factory (PF), an accelerator-based light source facility at KEK, operates two storage rings: The Photon Factory storage ring (PF-ring) and the Photon Factory Advanced Ring (PF-AR). As a result of major upgrades and continuous machine maintenance, both rings supply stable synchrotron radiation (SR) to more than 3,000 users per year even though it has been over 30 years since the first light was observed. The PF-ring is a 2.5-GeV electron storage ring and is operated in multi-bunch mode with a stored current of 450 mA. It is also operated in hybrid fill mode, which is composed of a 50-mA isolated bunch and a 400-mA bunch train, for several weeks a year. The PF-AR is a 6.5-GeV electron storage ring and is operated in single bunch mode with a stored current of 60 mA. A full-energy injection using the new direct beam transport (BT) line has been performed since FY2017. The beam injector linac (LINAC) is common to the two light sources and the two rings for the electron-positron collider: SuperKEKB HER and LER. The main parameters of the two light sources are summarized in Table 1.

In the following sections, the operational status of the PF-ring and PF-AR in FY2018 is described, as well as the highlights of their upgrades.

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

	PF-ring	PF-AR
Beam energy (GeV)	2.5	6.5
Circumference (m)	187	377
Emittance (nm rad)	35	293
Harmonic number	312	640
Stored current (mA)	450	60 (Single bunch)
Critical energy (keV)	4.0	26
No. of insertion devices	12	6

PF-RING

Operational Statistics

The operation time of the PF-ring in the past 10 years is shown in Fig. 1. Owing to the remarkable rise of electricity prices after the 2011 Great East Japan Earthquake and the yearly reduction of the operational budget, the total operation time decreased from 5,000 to 3,000 h. After FY2014, however, it was maintained at 3,000 h or more because of efforts to decrease power consumption and increase the facility's income. The achievement rate of the scheduled user time for FY2018 was 99.1%. While the total downtime increased by 12 h compared to FY2017, the failure rate was kept at 1% or less. The mean time between failures (MTBF) was 184 h; therefore, we can say that the PF-ring operation in FY2018 was sufficiently stable. A breakdown of the downtime shows that 69% was due to issues with the magnet power supplies and 28% was due to the RF system. The old power supplies for the quadrupole magnets which caused frequent issues owing to aging was replaced on the FY2018 budget. In addition, the renewal of an old septum duct which caused a serious vacuum leak in FY2015 is also in progress [1]. The new septum duct will be installed to the injection section with a new septum magnet during the 2020 summer shutdown. At the same time, the current injection scheme will be reconsidered and optimized for the low emittance lattice. Since the new injection scheme enables the improvement of the injection rate and the suppression of the stored beam oscillation caused by the injection, it will contribute to the reduction of the radiation dose on the experimental floor and stabilization of the SR intensity.

BL19 Upgrade

The upgrade project of the SR beamline #19 (BL19) is in progress. This project is planned for three years starting in FY2017 and relies on two different budgets. During the 2018 summer shutdown, the removal of an old revolver-type undulator and the installation of a new APPLE-II type

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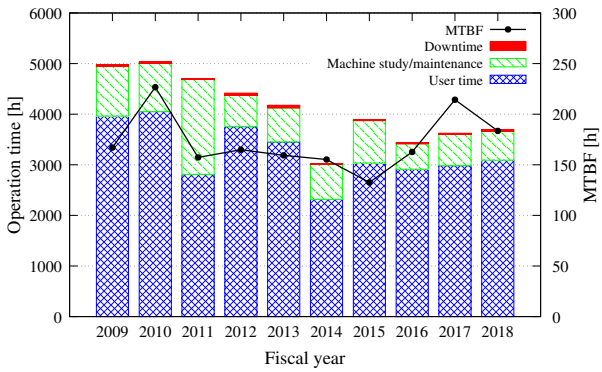

Figure 1: Operation time of the PF-ring in the past 10 years.

elliptically polarizing undulator were performed [2]. A 4.1-meter long aluminum vacuum chamber whose inner surface is coated with a Ti-Zr-V Non-Evaporable Getter (NEG) thin film was used for the new undulator [3]. This is the first time in Japanese light sources that the NEG-coated chamber is used for undulators. The reduction of the vacuum pressure in the chamber is in agreement with predictions from simulations and evolves favorably so far. Although the optical system and the spectrometer installed downstream of the undulator are not of special configurations, the scanning transmission X-ray microscopy (STXM) is normally installed at the end of the beamline, and the user can obtain high-resolution STXM images. The start-up and tuning of these BL19 components have started in November 2018, and they will be available to the user in the first operation period of FY2019. Figure 2 shows a photo of the new undulator installed in the ring tunnel.

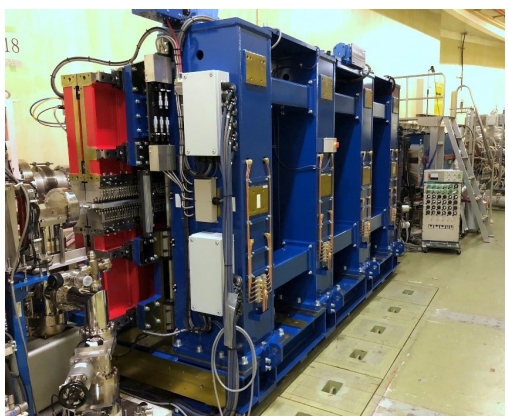

Figure 2: New APPLE-II type undulator installed for the BL19.

PF-AR

Operational Statistics

The operation time of the PF-AR in the past 10 years is shown in Fig. 3. The total operation time of the PF-AR since FY2014 has aimed to achieve 2,000 h because its operation requires an electricity budget approximately twice the one of the PF-ring. The scheduled user time in FY2018 was 1608 h, and its achievement rate was 98.4%. While the number of failures significantly decreased since the problem of accidental discharges of the injection kickers installed at the end of the direct BT line was solved, the total downtime was almost the same as that of FY2017. The failure rate and MTBF were 1.6% and 64 h, respectively. These are normal values for the PF-AR. A breakdown of the downtime shows that 75% was due to issues with the RF system, 14% was due to the injection devices, and 8% was due to sudden beam loss caused by dust trapping. The old programmable logic controllers in high-voltage power supplies for klystrons, which were manufactured in 1988 and became difficult to maintain, were renewed in the 2018 summer shutdown. In addition, beam dumps caused by the temperature interlock of cables for extracting and damping the higher order modes (HOMs) in acceleration cavities frequently occurred in FY2018. The cause of the heating of the HOM cables is considered to be the aging and deterioration by radiation. All of the 70 HOM cables will be replaced during the 2019 summer shutdown.

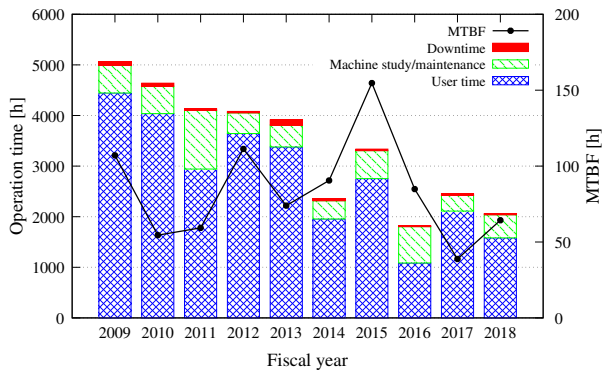

Figure 3: Operation time of the PF-AR in the past 10 years.

First Introduction of Top-up Injection

The user operation of the PF-AR has continued with a 6.5-GeV full-energy injection using the direct BT line completed in FY2016 [4]. In FY2017, the upgrade of the operation interlock system, the radiation survey during the injection with the main beam shutters of the SR beamlines opened, and the improvement of the injection rate with the magnet gap of the insertion devices closed were also completed. In parallel with the preparations required for the introduction of the top-up injection, the DC magnets of the LINAC were replaced with pulsed ones to switch the injection parameters for the four different rings to pulse-by-pulse [5]. Since this large modification of the LINAC was completed on schedule in the 2018 summer shutdown, the user operation of both light sources was since performed with the top-up injection. This is the first time that the PF-AR introduces the top-up injection to its user operation. This injection of the PF-AR does not disturb those of the other three rings since the injection parameters are switched within the minimum injection period of 40 ms. Although the beam dump or loss caused by accidental discharges without any triggers of the three

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injection kickers was a matter of concern [1], it was resolved by stopping the use of the suspected problematic injection kicker and injecting beams with the other two only. Figure 4 shows the stored current for one week during user operation, before and after introducing the top-up injection. This top-up injection has contributed to reducing the frequency of the re-injection for recovering the sudden drop of the beam lifetime caused by dust trapping and to stabilizing the user operation.

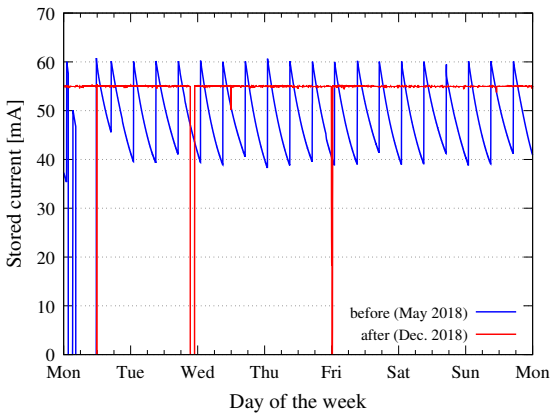

Figure 4: Stored currents of the PF-AR before and after introducing the top-up injection. The current is maintained at 55 ± 0.1 mA after the introduction, while it is topped up three times a day to 60 mA before. The current drops in the figure are due to beam dumps caused by machine issues or re-injections for recovering the sudden drop of the beam lifetime.

5-GeV Test Operation

The operation time of the PF-AR in recent years is much less than the target value of 3,000 h because its operational cost is twice the PF-ring one, as described above. In order to improve this situation, a test operation with a lowered beam energy from 6.5 GeV to 5 GeV was conducted for a week. The power consumption of the 5-GeV operation is expected to be around 60% of the 6.5-GeV operation. When the beam energy is lowered, the beam injection for the PF-AR becomes incompatible with the PF-ring because a setting of the DC bending magnet commonly used with the PF-ring at the end of the LINAC has to be changed. Therefore, a pseudo top-up operation was performed using a sequence program to change the BT magnet setting every three minutes. The decrease in the stored current of the PF-ring during the PF-AR injection is below 0.1% which is a level sufficient for the user operation. Figure 5 shows the SR spectra measured at the sample position of the SR beamline NW10A, whose light source is a bending magnet. The vertical axis indicates the photon flux at the stored current of 50 mA. The flux rapidly decreases in the high-energy region of more than 14 keV and becomes half of the 6.5-GeV operation one at around 27 keV. However, it exceeds the calculated estimation at all energies. This is because the SR vertical beam size at the optical slit of the beamline decreases with the electron beam energy and emittance. The data below 14 keV also include higher order SRs. Such a decrease in the photon flux in the high-energy region can be compensated by an increase of the stored current, the extension of the measurement time, or the use of the higher order SRs. In FY2019, however, we plan to conduct the 6.5-GeV operation at a set ratio since some SR beamlines need high-energy X-rays of 50 keV or more. In the later part of the test operation, it was observed that the beam lifetime became short continuously and, then, the beam loss rate exceeded the injection rate. The investigation of the cause of this phenomenon will be an important issue in the next operation.

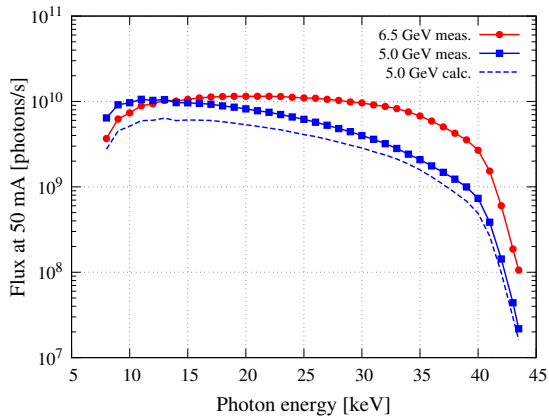

Figure 5: Comparison of SR spectra at NW10A between the 6.5-GeV and 5-GeV operations. The dashed line shows the calculated estimate.

SUMMARY

The operational status of the PF-ring and PF-AR for FY2018 was described. The PF-ring operation was continued stably. The upgrade of the SR beamlines and renewal of aging devices proceeded successively. At the PF-AR, the top-up injection, which was the final goal of the construction of the direct BT line, was introduced to the user operation for the first time. The energy saving operation, which decreased the beam energy from 6.5 GeV to 5 GeV, was also tested to secure more operation time within the limited budget.

A project to improve the beam emittance of the PF-ring by modifying its arc section is under consideration. The beam emittance with the new lattice is expected to be improved from the current value of 35 nm rad to 5.7 nm rad.

ACKNOWLEDGEMENTS

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