STATUS OF THE PHOTON FACTORY

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Abstract

The present status of two synchrotron light sources, the PF and the PF-AR storage rings at KEK, is presented. An upgrade project of the PF storage ring was successfully completed in 2005. Through this upgrade, four short-straight sections were newly created, and ten existing straight sections were extended. Two short-gap undulators were then installed in the new sections, and were commissioned. Further improvements, including a top-up operation, are in progress. The other PF-AR is a unique single-bunch hard X-ray source. During 2005-2006, two in-vacuum undulators were successfully commissioned.

INTRODUCTION

The High Energy Accelerator Research Organization (KEK) manages two synchrotron light sources [1], the Photon Factory (PF) storage ring and the Photon Factory Advanced Ring (PF-AR). The principal parameters of both rings are shown in Table 1. The 2.5-GeV PF storage ring was commissioned in 1982 as one of the major synchrotron radiation (SR) sources in the world, and it has been operated very well. The PF ring has been upgraded three times (see Table 2). Through the series of upgrades, the PF ring has become competitive [2] with other intermediate-energy third-generation light sources. We report in the next section the latest upgrade, the recommissioning, and the prospect for further improvements. The other 6.5-GeV PF-AR (see Table 3), initially named the TRISTAN Accumulator Ring, was commissioned in 1984 as a booster for the TRISTAN 30-GeV e^+e^- collider. It was converted to a dedicated SR source in 1998, and was largely upgraded in 2001. The third section describes recent improvements and operational status of the PF-AR

PF STORAGE RING

Upgrade

We carried out an upgrade project [3, 4] of the PF storage ring from March to September, 2005. This project aims at creating more space for advanced insertion devices. We refurbished the magnet lattice of about two-thirds of the ring as shown in Fig. 1. This upgrade resulted in creation of four short-straight sections of 1.4 m each, as well as extension of existing 10 straight sections.

Table 1: Principal parameters of the PF and the PF-AR storage rings.

	PF	PF-AR
Beam energy	2.5 GeV	6.5 GeV
Circumference	187 m	377 m
Natural emittance	35 nm·rad	293 nm·rad
RF frequency	500.1 MHz	508.6 MHz
Energy loss per turn	0.4 MeV	6.66 MeV
Injection energy	2.5 GeV	3 GeV
Typical number of bunches	280	1
Initial stored current	450 mA	60 mA
Beam lifetime (at initial cur.)	30-40 hrs	15-20 hrs
Number of insertion devices	9	6

Table 2: Brief history of the PF storage ring.

Year	Event
1982	Commissioned.
1986	Upgraded to lower emittance (460 → 130 nm·rad).
1997	Upgraded to lower emittance (130 → 36 nm·rad).
2005	Upgraded (extensions in straight sections) [3, 4].

Table 3: Brief history of the PF-AR.

Year	Event
1984	Commissioned as the TRISTAN injector.
1986	Parasitic SR usage started.
1998	Converted to a dedicated light source.
2001	Upgraded (beam current and lifetime) [5].

In these sections, we replaced quadrupole magnets to thinner ones, and moved them closer to bending magnets. We also renewed the beam ducts in these sections [6], and reconstructed thirteen beamline front-ends [7] so that we accommodated them both to the new lattice and to coming new IDs. We also reinforced septum magnets for injection, renewed our control system to an EPICS

(Experimental Physics and Industrial Control System)-based one [8], and installed a transverse bunch-by-bunch feedback system [9].

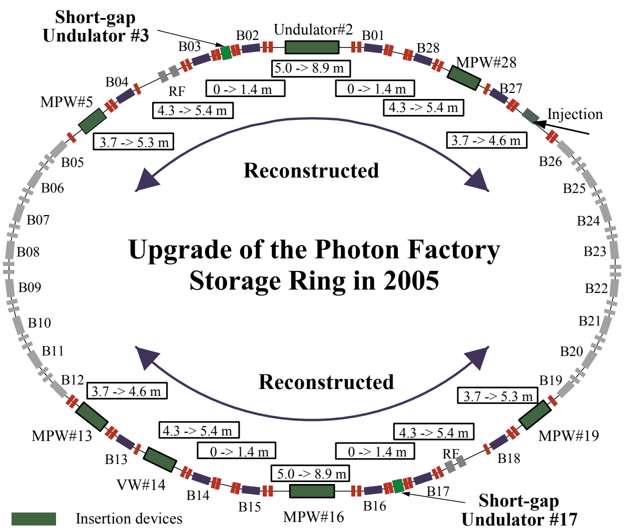

Figure 1: Upgrade of the PF storage ring in 2005.

Recommissioning

The PF storage ring was recommissioned on September 20, 2005. We could successfully store the beams within five days, and could achieve a target beam current of 450 mA on September 30. After vacuum conditioning with beams, user operations resumed on October 18, 2005. From November 22, we reduced a frequency of injections from three to two times a day due to an improvement in the beam lifetime. The progress in vacuum conditioning after the recommissioning is reported in [6].

New Insertion Devices

In the newly created short-straight sections, we installed two short-period short-gap undulators, SGU#17 [10] and SGU#3, of in-vacuum type. The first short-gap undulator, SGU#17, has a period length of 16 mm, a number of periods of 29, and a maximum magnetic field of 0.92 T at a magnet gap of 4 mm, respectively. The other SGU#3 has very similar parameters but a different period length of 18 mm. The brilliance of the undulator radiation from the SGU#17 is shown in Fig. 2. These short-gap undulators can provide brilliant hard X-rays of up to 15 keV using up to the seventh-harmonic radiation at the beam energy of 2.5 GeV. To this end, the field errors of these undulators were corrected very carefully. In order to achieve very short magnet gaps, the vertical betatron function was squeezed to 0.4 m at the center of the undulator. The SGU#17 was successfully commissioned in October, 2005, and then, it has been operated very well with a minimum gap of 4 mm. The other SGU#3 was installed in the summer of 2006, and it was commissioned in October, 2006.

Operational Status and Accelerator Study

We annually operated the PF storage ring for about 5,000 hours during the last six years except in 2005.

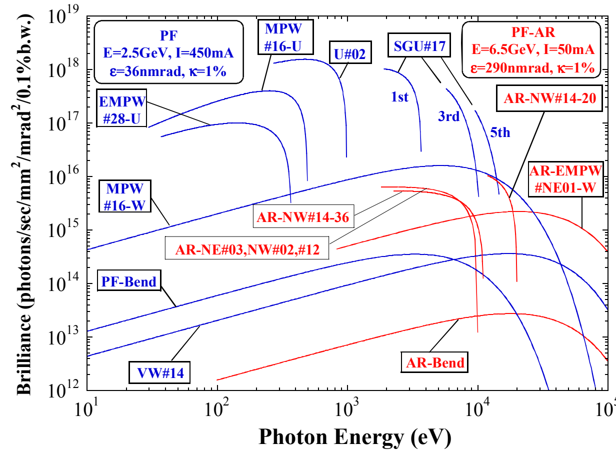

Figure 2: Brilliance of the synchrotron radiation available at the PF (blue traces) and the PF-AR (red) storage rings.

Approximately 16-19% of the operation time was used for accelerator study and tune-up. Failure time was about 0.5% of the total time during past four years. Detail operational statistics were summarized in [1].

We have currently 22 beamlines (BLs) for users including nine BLs from insertion devices (IDs). The number of registered users of the Photon Factory surpasses 2,500, and annual visits for experiments are 23,000 persons·days.

We have actively carried out accelerator physics studies. For example, the determination of non-linear resonance parameters [11], the development of various unique SR monitors [12], and the observation of quadrupolar tune shifts [13], are worthy of special mention.

Developments in Progress

Taking full advantage of the straight-section upgrade, we plan to renovate some conventional IDs to advanced ones. As the first step of this strategy, we plan to install a fast-switching elliptically-polarizing source in an 8.9-m straight section, while retiring a multipole wiggler, MPW#16. This device [14] will comprise a pair of APPLE-type undulators in tandem, and a fast orbit-bump system for selecting one of the photon beams from two undulators. One of the undulators is under construction.

A top-up operation project of the PF ring is underway. To share the injector beams with the KEK B-factory, the 8-GeV injector linac will be improved so that it can change an electron-beam energy from pulse to pulse, and can deliver the beams to the PF and the KEKB nearly simultaneously. We have remodelled our beam-transport line, and optimized an injection bump for minimizing coherent beam oscillations. After some remaining works, the top-up operation will be realized step by step.

PF-AR

Outline

The PF-AR is a unique 6.5-GeV "single bunch" light source which can provide high-flux hard X-ray pulses. High beam currents of up to 60 mA with a single bunch allow us to reconcile pulse X-ray experiments with the other experiments requiring high-flux X-rays. A layout of the PF-AR is shown in Fig. 3. There are seven beamlines including five BLs from IDs. The PF-AR is a pioneer facility where the first in-vacuum undulator [15] was developed. Since then, we have installed five in-vacuum undulators in the PF-AR for hard X-ray production.

The PF-AR was largely upgraded [5] in 2001, where all vacuum chambers were replaced, and many other improvements were carried out. This upgrade resulted in high beam currents and long beam lifetime (15-20 hrs) of today.

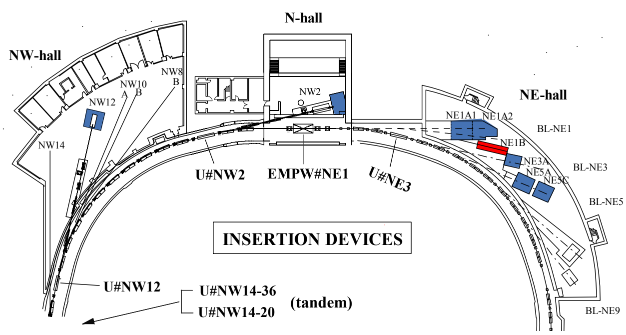

Figure 3: Layout of the PF-AR. A part of the ring, where the beamlines are located, is shown.

Operational Status

We annually operated the PF-AR about 5,000 hours after the upgrade in 2001. The total operation time in FY2005 was 5,328 hours, where an interruption of operations was 1.2% of total time. Under usual operations, the beams were injected twice a day, while we sometimes provided special two-bunch, 5-GeV operations for clinical users.

New Insertion Devices

Funded by the ERATO Non-Equilibrium Dynamics Project, two in-vacuum undulators [16], U#NW14-36 and U#NW14-20, were installed in the summers of 2005 and 2006, respectively, for the beamline AR-NW14A. These undulators were designed for time-resolved X-ray diffraction experiments and for XAFS experiments. They were installed in the same west straight-section in tandem, and are used exclusively. The former undulator, U#NW14-36, has a period length of 36 mm and a number of periods of 79, and it can provide wide-energy photons of 5-25 keV with up to the fifth harmonic radiation. The other U#NW14-20 has a period of 20 mm and 75 periods, and it can provide photons of 13-18 keV with the first harmonic. The brilliance of SR from these undulators is shown in Fig. 2. These undulators were successfully commissioned in the autumns of 2005 and 2006, respectively.

Accelerator Study

A novel beam-injection scheme [17] using a pulsed quadrupole magnet, instead of using several kicker magnets, was proposed. This scheme was successfully demonstrated at the PF-AR.

FUTURE PROJECT

We had a series of intensive discussions with user scientists and with other accelerator scientists in Japan about how the future Photon Factory should be. We came to a conclusion that we should immediately start R&D for the future light source which is based on the Energy Recovery Linac (ERL). In April 2006, KEK formed an inter-departmental "ERL project office", and started R&D for the ERL-based future light source. The future project of the Photon Factory is described in [18].

CONCLUSIONS

The upgrade of the PF storage ring was successfully completed in 2005. This resulted in the creation of much available space for new insertion devices, and for renovating old IDs to advanced ones. Two short-gap undulators were newly installed, and were commissioned successfully. Through the series of upgrades, the PF storage ring has become competitive to other intermediate-energy third-generation sources. The delivered user hours and the reliability of operations are comparable to the best of its class in the world [2].

The other 6.5-GeV PF-AR has annually been operated for about 5,000 hours with high reliability. Two in-vacuum undulators were commissioned during 2005-2006.

ACKNOWLEDGMENT

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