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

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Abstract

The Photon Factory storage ring (PF-ring) and the Photon Factory advanced ring (PF-AR) continue a stable user operation as a synchrotron radiation source. The MTBF of the PF-ring has been kept at high around 200 h. At the PF-ring, a top-up operation started in April 2009. A rapid-polarization-switching device consisting of tandem polarizing undulators and a new injection system using a pulsed sextupole magnet are being developed. In a dust trapping experiment at the PF-AR, visual observation of luminous trapped dust by using a CCD camera was accomplished recently.

INTRODUCTION

KEK manages two synchrotron radiation sources, Photon Factory storage ring (PF-ring) and Photon Factory advanced ring (PF-AR). The PF-ring is operated at 2.5 GeV to provide photons with the energy from VUV to hard x-ray region. After the upgrade of straight sections in 2005, very narrow-gap in-vacuum undulators have been installed to generate high brilliance hard x-rays [1]. The PF-AR is mostly operated in a single-bunch mode of 6.5 GeV to provide pulsed X-rays. Main parameters of both rings are described in Table 1.

Two rings share an injector linac with the main rings of KEK B-factory, 8-GeV HER and 3.5-GeV LER. The linac has succeeded in a pulse-by-pulse multi-energy acceleration of electron and positron beams [2]. The top-up operation of the PF-ring has been realized as the simultaneous continuous injection to the 3 rings, PF-ring, HER and LER.

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

Parameters	PF-ring	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
Injection energy	2.5 GeV	3.0 GeV
Filling pattern	280/312 or single	single
Stored current	450 or 50 mA Top-up injection	60 mA
Beam lifetime	30 h / 1.3 h	20 h
No. of insertion devices	10	6

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Present status of the PF-ring and the PF-AR and brief introductions on the recent machine developments will be described in this paper.

PF-RING

Table 2: Operational Statistics of PF-ring

	FY2008	FY2009
Total Operation Time (h)	5000	4976
Scheduled User Time (h)	4032	4008
Number of Failures	18	24
Total Down Time (h)	23.8	42.7
MTBF (h)	224	167
MDT (h)	1.3	1.8

Operation statistics

The operation statistics of the PF-ring are listed in table 2. The total operation time is around 5000 h every year. Usually, three months from June to September are a long shutdown period. Reconstruction and annual maintenance of accelerator components or an installation of a new insertion device are conducted in the summer shutdown. About 80 % of the operation time is scheduled for the user operation. The other 20 % is allocated for commissioning, machine developments and regular maintenance tasks. The machine study is scheduled once a week.

Table 3: Classification of Failures of PF-ring

	FY2008	FY2009
RF	5	12
Magnet	3	3
Injection	4	0
Vacuum	0	0
Dust Trapping	0	1
Insertion Device	3	1
Control / Monitor	1	4
Cooling Water	0	1
Safety / Beamline	1	2
Earthquake / Electricity	1	0
Total	18	24

The total number of failures interrupting the user operation is about 20 annually. Beam dumps and any other troubles on the accelerator facility which resulted in closing the beam channels were taken into account as the failures. The Mean Time Between Failures (MTBF) was estimated from the scheduled user time and the number of failures. The Mean Down Time (MDT) was estimated from the total down time including whole time until the beam channel is reopened for the user operation.

The MTBF beyond 200 h was usually recorded at the PF-ring. The high MTBF was a result of the low frequency of beam dumps caused by the RF system. Classification of failures is listed in table 3. Twelve RF failures recorded in FY2009 was exceptionally high in recent years. The increase of the RF troubles was a main reason for the increase of the total number of failures in FY2009.

At the end of the FY2009, a heavy trouble occurred in one of the high-voltage (HV) power supplies for the klystrons. The PF-ring has 4 RF cavities driven by 4 klystrons. We have proceeded with the renewal of the HV power supplies since 2004. Two of them have already been renewed, but the other two are the products before 1989. One of the old power supplies met with the heavy trouble. As a replaceable new HV power supply is already manufactured, it will be installed at 2010 summer shutdown. We are also concerned about an increase of troubles in the low-level RF system comprising many aged electrical modules. A renewal of the low-level RF is the problem which now confronts us.

Top-up operation

A full-time top-up operation started in April 2009. In addition to the improvement of the linac, a pulsed bending magnet to selectively kick the 2.5 GeV electron beam was installed at the end of the linac.

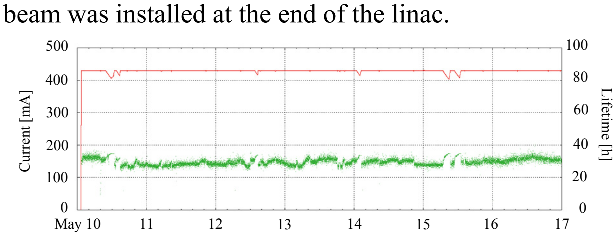


Figure 1: Record of the stored beam current (red line) and the beam lifetime (green dots) for seven consecutive days.

Fig. 1 shows a record of the stored current and the beam lifetime for seven consecutive days in May 2010. The stored current was maintained at 430 mA, slightly less than the usual value because one of 4 RF cavities was suspended by the HV power supply trouble. No beam dumps and no interruptions to the user operation occurred in the week. There are six small current dips of 10 or 20 mA. The injection beam was stopped for a few hours when the linac was exclusively used by other rings' commissioning or at irregular maintenance works. The simultaneous injection to the PF-AR has not been completed. So the top-up injection is interrupted twice a day for the regular PF-AR injection. Typical interruption time by the PF-AR injection is 15 minutes and a decrease of the beam current is about 3 mA typically.

As shown in Fig. 1, the beam lifetime is always monitored. Bunch-by-bunch feedback systems for the transverse and longitudinal directions are equipped to suppress the coupled bunch instabilities. In the longitudinal direction, however, quadrupole-mode oscillation is observed. The RF phase modulation technique is jointly used to stabilize the fluctuation of the quadrupole-mode oscillation. As the beam lifetime of the PF-ring is mainly limited by the Touschek effect, variation of the beam lifetime can be a measure of the status of the beam instability.

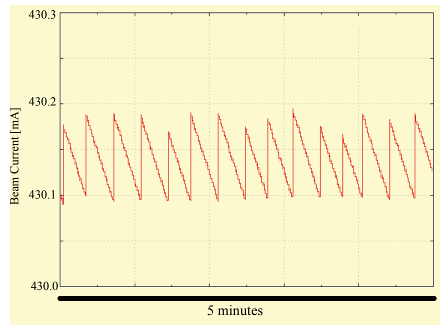


Figure 2: Five-minute record of top-up injections.

Fig. 2 shows a record of each injection for 5 minutes when the injection was tuned well. The injection is controlled to send a single beam request to the linac when the stored current becomes lower than a set value, 430.1 mA in this case. The RF bucket to be injected is selected by the bunch filling control system to maintain a flat filling pattern [3]. There were 15 injections during 5 minutes in the Fig. 2. The average interval was 20 s and the average injected current was about 0.08 mA/pulse.

Injection using Pulsed Sextupole Magnet

Figure 3: Pulsed sextupole magnet (yellow) installed in the PF-ring.

A new injection scheme using a single pulsed quadrupole magnet instead of a conventional pulsed bump produced by dipole kicker magnets was firstly demonstrated at the PF-AR [4]. Next, an injection using the pulsed sextupole magnet (PSM), shown in Fig. 3, has been successful at the PF-ring [5]. The PSM is thought to be suitable for the top-up injection because the disturbance to the stored beam can be very small.

A new pulsed power supply that provides a short pulse has been manufactured to realize a single turn kick of the

PSM. Using the new power supply, the pulsed sextupole injection system is being tuned up. Practical use in the top-up operation will be started in the autumn 2010.

New Polarization Switching Device

A rapid-polarization-switching source is being developed at the PF-ring. It consists of two variably polarizing undulators and a fast local bump system using five identical bump kickers. The first model of the polarizing undulator and the bump kickers were already installed in 2008. The second undulator is under construction and will be installed in the summer 2010 [6].

In order to realize a specification of the switching frequency 10 Hz, the studies to control the local bump and to suppress the orbit leakage outside the local bump are in progress [7].

PF-AR

Table 4: Operational Statistics of PF-AR

	FY2008	FY2009
Total Operation Time (h)	4969	5063
Scheduled User Time (h)	4344	4392
Number of Failures	40	41
Total Down Time (h)	41.7	91.0
MTBF (h)	109	107
MDT (h)	1.0	2.2

Operation statistics

The total operation time of the PF-AR is almost the same as the PF-ring. Because of the large wake field in the multi-cell RF cavities, storing the multi-bunch beam is difficult. So the PF-AR is exclusively operated at a single-bunch mode.

Table 5: Classification of Failures of PF-AR

	FY2008	FY2009
RF	4	8
Magnet	2	2
Injection	9	1
Vacuum	0	2
Dust Trapping	15	16
Insertion Device	0	0
Control / Monitor	1	1
Cooling Water	3	4
Safety / Beamline	5	7
Earthquake / Electricity	1	0
Total	40	41

The total number of failures was larger than that of PF-ring, and the MTBF of the two years was about 100 h.

The failure peculiar to the PF-AR is a sudden drop of the beam lifetime caused by dust trapping. This interrupts the user operation at about 15 times annually. The scheduled user time amounted to 26 weeks a year, and then the average rate of the interruptions due to dust trapping is slightly more than every two weeks. The dust trapping is very rare at the PF-ring, and it disturbed the user operation only once during the two years as shown in table 3.

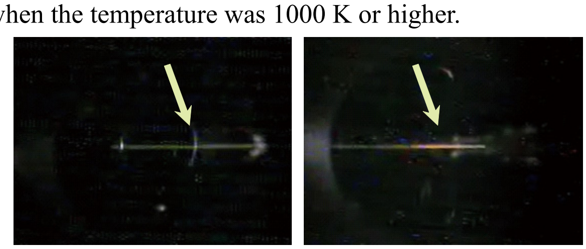
Beam dumps caused by the RF system were less than 10. Though the RF system is basically unchanged from the PF-AR commissioning at 1983, high MTBF related to the RF system is still maintained.

Most failures classified to the injection were troubles related to the strong beam instability at the injection energy. The number of injection troubles was largely reduced in FY2009.

Visual Observation of Dust Trapping

The PF-AR has been suffering from sudden lifetime drop phenomena attributed to dust trapping. The distributed ion pump (DIP) installed in the bending chamber was recognized as one of the main sources of dust particles. Now all the DIPs are suspended during the user operation, but the dust trapping phenomena are still remained though its frequency has been reduced.

We made an experiment to prove various types of discharge in the beam ducts can be dust sources. Using the movable electrodes installed for the experiment, we confirmed that the discharge created by the electrode was followed by the dust trapping, and also succeeded in a visual observation of luminous dust streaking in front of CCD cameras [8, 9]. An example image of the visually observed trapped dust is shown in Fig. 4. The trapped dust was assumed to be at high temperature owing to the interaction with high energy electron beam. It was estimated that the black-body radiation from the dust particle of a few μm in diameter can be bright enough when the temperature was 1000 K or higher.



Camera B Camera A

Figure 4: Trapped dust was visually observed using CCD cameras.

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