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OPERATIONAL STATUS OF PHOTON FACTORY LIGHT SOURCES

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Abstract

At PF-ring, the injection section has been reconstructed with the replacement of a septum magnet and aged beam ducts in FY 2020, and several upgrading plans are underway in parallel. At PF-AR, we are constructing a GeV-range test beamline. The bremsstrahlung photons generated by a thin carbon wire are brought to a copper target to generate electron-positron pairs. A sufficient test beam can be expected when the target wire touching halo of the stored beam, and the test beam can be used simultaneously with the synchrotron radiation experiments. The operating times of the storage rings, which have been decreasing year by year in recent years, will be substantially restored in FY 2021.

OPERATIONAL STATUS

The Photon Factory of KEK is operating two light source rings, PF-ring and PF-AR [1]. PF ring is a 2.5 GeV storage ring, which delivers a wide range of photons from the vacuum ultraviolet to hard x-rays for forty SR beamlines equipped with six variably polarizing undulators and four in-vacuum short gap undulators. PF-AR is a high-energy 6.5 GeV ring to deliver x-rays for eight beamlines equipped with a variably polarizing undulator and five in-vacuum undulators. PF-AR is characterized by the all-time single-bunch operation at a large bunch current of 50 mA.

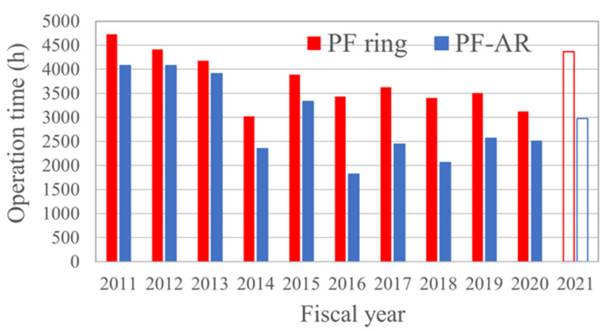

Figure 1: Operation times of PF-ring and PF-AR over ten years.

The annual operation times of both rings over ten years are shown in Fig. 1. In March 2011, the Great East Japan Earthquake struck us, and since then, the operation times have been decreasing year by year due to declining budget and rising electricity costs. The budget increase was approved, the operating time is expected to increase 40% compared to the previous year for PF-ring and about 20% for PF-AR for FY 2021. We expect to be able to maintain these recovered operating times in the future.

Table 1: Operation Statistics of PF-Ring

Fiscal Year	2017	2018	2019	2020
Total operation time (h)	3624	3408	3504	3120
Scheduled user time (h)	3000	2832	3064	2584
Ratio of user time (h)	82.8	83.1	87.4	82.8
No. of failures	14	17	20	15
Total down time (h)	16.6	28.4	59.9	158.4
Failure rate (%)	0.6	1.0	2.0	6.1
MTBF (h)	214.3	166.6	153.2	172.3
Mean down time (h)	1.2	1.7	3.0	10.6

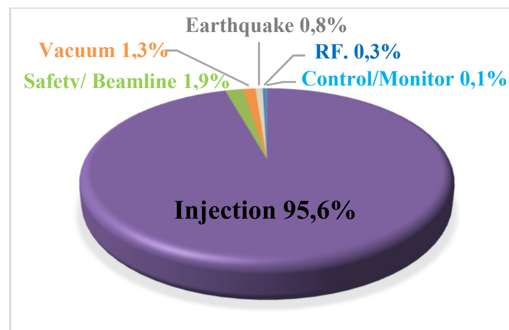

Figure 2: Breakdown of the failure time in FY 2020 for PF-ring.

Table 2: Operation Statistics of PF-AR

Fiscal Year	2017	2018	2019	2020
Total operation time (h)	2448	2064	2568	2520
Scheduled user time (h)	2136	1608	2112	2112
Ratio of user time (h)	87.3	77.9	82.3	83.8
No. of failures	55	25	8	14
Total down time (h)	24.7	26.4	12.3	168.1
Failure rate (%)	1.2	1.6	0.6	8.0
MTBF (h)	38.8	64.3	264.0	150.9
Mean down time (h)	0.4	1.1	1.5	12.0

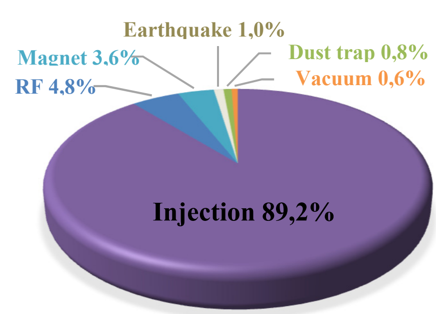

Figure 3: Breakdown of the failure time in FY 2020 for PF-AR.

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The operation statistics of both rings are summarized in Table 1 and Table 2. Breakdown of the failure time in FY 2020 for PF-ring and PF-AR is shown in Fig. 2 and Fig. 3, respectively.

A low number of beam dumps characterizes PF-ring, and the MTBF has been recorded to be well over 100 hours. On the other hand, the MTBF of PF-AR was only about 50 hours until FY 2018. It is mainly because the PF-AR required acceleration from 3 GeV to 6.5 GeV after accumulation instead of full-energy injection. Another reason was the frequent lifetime drops caused by dust trapping [2]. In FY 2018, the full-energy injection was enabled by constructing the direct beam transport line [3] from the injector linac, and it became customary to keep the stored current constant by top-up injection. We can see the effect of these improvements evidently in the operation statistics. The number of failures has been significantly reduced in FY2019 and FY2020. The MTBF has been recorded to be equal to or longer than that of the PF-ring.

We have also started the low energy operation at 5 GeV as a new operation mode for PF-AR from FY 2019. The electricity cost of the high energy PF-AR is putting pressure on the budget, so the purpose of introducing the low energy operation was to save the electricity consumption and secure the operating time.

At the end of FY 2020, a heavy failure of the pulse bend power supply caused the first cancellation of the scheduled user time in years. The pulse bend works at the bottom of the injector linac to distribute the injection beam to PF and PF-AR. Both rings suspended the operation for a few days, so the total failure time of them exceeded 150 hours for the last fiscal year.

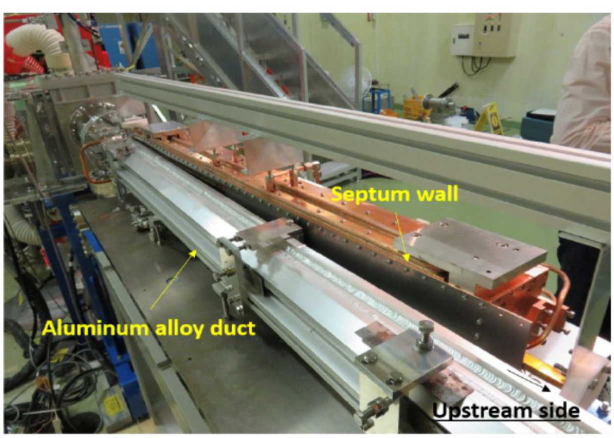

Figure 4: Reconstruction work of a septum magnet and beam ducts of the injection section of PF-ring.

UPGRADE OF PF-RING

Reconstruction of the Injection Section

The PF ring has been in operation since 1982, and most of the accelerator components have been upgraded with modifications to achieve low emittance or enhancement of the straight sections. The only things that had not been updated since 1982 were the bodies of the bending magnets and the vacuum ducts of the injection section. In the vacuum of the injection section, there was a vacuum leak from a cooling water path receiving the synchrotron radiation power, and the operation was continued for several years with insufficient cooling.

In FY 2020, we finally updated the injection section replacing a septum magnet and aged beam ducts with a cooling water leak [4]. As shown in Fig. 4, the new septum magnet was installed in the atmosphere. The injection beam passes through a thin Inconel-made beam duct inserted between the poles of the septum magnet and is injected into the storage ring through an air gap. The beam duct of the storage ring was made of aluminum alloy, and the cooling water path was installed on the atmospheric side to avoid the risk of leakage in the future.

In the reconstruction, the injection scheme was also changed to reduce the distance between the injection beam and the kicker bump orbit from 15 mm to 9.85 mm. It enabled the injection with a smaller initial amplitude for the injected beam. We are trying to improve the injection efficiency and minimize the stored beam disturbance at the top-up injection.

Ongoing Upgrading Plans for PF-Ring

For PF ring, several upgrading projects are ongoing in parallel. The first one is to upgrade the beam position measurement (BPM) system and to stabilize and speed up the associated orbit feedback system. The second is to replace the aged quadrupole and sextupole power supplies and to achieve enhancement of the beam emittance. The other is the introduction of a digital RF control system. These upgrades are planned to be completed within the next two years.

NEW TEST BEAMLINE OF PF-AR

A topic on the PF-AR is the construction of a test beamline. It is a plan to deliver GeV-range electrons for developing detectors of particle physics. The Fuji test beamline in the KEKB Factory shut down, so it has a high demand from the physics community. The start of service of the test beamline is planned for 2021.

The test-beam laboratory will be constructed in the south experimental hall of PF-AR. The overall layout is shown in Fig. 5. A thin wire target is placed just upstream of a bending magnet of PF-AR, where the γ-rays produced by collisions with stored beams are converted into electron-positron pairs by a copper converter installed at the end of the bending magnet chamber. The beamline, which leads electrons to the test beam area, has a simple configuration with one bending magnet and seven quadrupole magnets placed at the same level in front of and behind the bending magnet, aiming to transport electrons with minimal loss. A new mezzanine floor has been constructed in the south experimental hall to house the beam shutter, quadrupole magnets, and the laboratory space.

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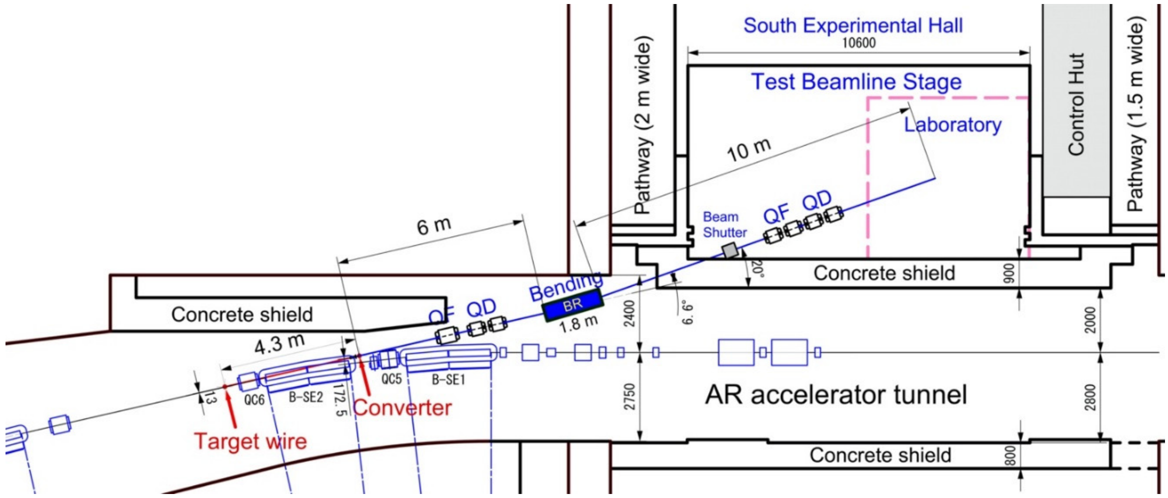

Figure 5: Overall layout of the PF-AR test beamline.

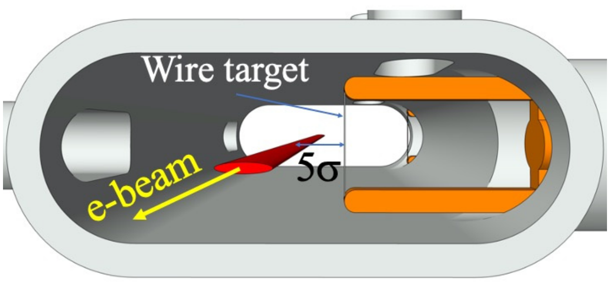

Figure 6: Perspective view of the target wire insertion mechanism.

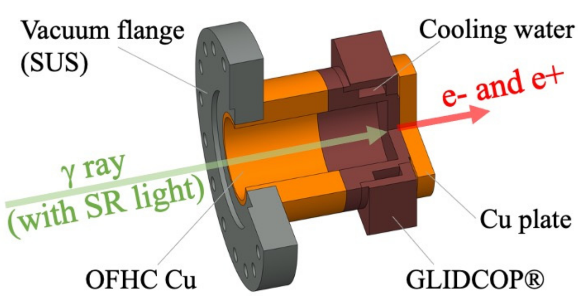

Figure 7: Water cooled Cu converter.

We plan to use the test beamlines and the synchrotron radiation experiment simultaneously, rather than time-sharing. In order to minimize the disturbance to the synchrotron radiation experiment, a thin wire will be inserted at a distance of 5σ outward from the beam orbit. Here, σ is the horizontal beam size of the stored beam. The beam halo will interrupt with the thin wire. In this arrangement, it is confirmed by simulation that several thousand energy-selected electrons are available at the test beam laboratory. The only effect to the synchrotron radiation use is a 10% decrease of the beam lifetime, which the top-up injection can cover without any difficulty. The actual insertion depth of the wire will be continuously controlled to maintain the predetermined beam lifetime.

A perspective view of the target wire insertion mechanism is shown in Fig. 6. As a backup, two wires can be inserted. Since the synchrotron radiation is also incident on the wire, we carefully analyze its temperature rise. The temperature of the radiated area depends on the thermal conductivity and thermal radiation. We carefully determine the thickness and material based on the simulation results. We are also paying attention to the heat load by the wakefield of the large bunch current. A water cooling is prepared for the wire holders. The material of the wire is assumed to be carbon. Specifically, we are considering the use of carbon nanotube (CNT) yarn of 0.1 mm thick.

A copper-made converter is shown in Fig. 7. Water-cooling is essential as the synchrotron radiation power is incident in addition to the γ-rays we need. We have investigated by simulation the dependence of the electron yield on the thickness of the copper plate. If necessary, the converter thickness will be adjusted by replacing the Cu plate after the start of the experiment.

SUMMARY

At Photon Factory, the operating time of the storage rings, which have been decreasing in recent years, will be substantially restored from FY 2021. At the end of FY 2020, cancel of the user time occurred for the first time in several years due to a failure of the pulse-bend magnet. The injection scheme was renewed in 2020, and several upgrading projects are underway in parallel for PF-ring. For PF-AR, a new test beamline will be available in 2021.

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