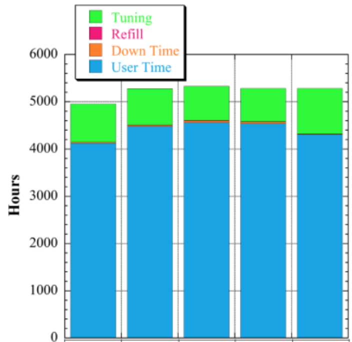
3. Operation Status

1. SPring-8

Figure 1 highlights the operation statistics for the last five fiscal years. In FY2020, the total operation time for the storage ring was 5,274 hours. Originally, 4464 hours was allocated for user operations, but 144 hours out of that was canceled owing to the COVID-19 situation. Thus, 4,320 hours was eventually assigned as user time. The downtime due to machine trouble was 7.4 hours in addition to the planned downtime (3.6 hours) for switching the user operation modes with different filling patterns. The considerably short downtime led to an excellent user availability of 99.7%. More importantly, the mean time between failures (MTBF) of 718.2 hours was achieved by reducing the frequency of machine failures this year. Both the user availability and the MTBF this year were the highest since user operations of SPring-8 started in 1997. For 99.4% of the achieved user time, the stored beam current remained at 100 mA in the top-up operation, where the current stability was kept within 0.1% .



	FY2016	FY2017	FY2018	FY2019	FY2020
Acc. Operation Time	4951.7	5281.6	5329.8	5285.7	5284.6
SR Operation Time	4941.1	5270.4	5316.7	5271.2	5274.8
Tuning&Study (Acc.&BL)	803.1	769.6	721.8	701.7	964.6
Refill	3.4	4.6	5.3	5.6	3.6
Down Time	23.1	28.7	43.1	40.5	7.4
Mean Time between Failures	229.2	194.7	168.9	206.3	718.2
Achieved User Time	4125.5	4478.7	4559.6	4537.9	4309.0
Planning User Time	4152.0	4512.0	4608.0	4584.0	4464.0
Availability (%)	99.4	99.3	98.9	99.0	99.7

Fig. 1. SPring-8 operation statistics for the past five years.

Obviously, the high user availability and the MTBF could become worse in the future due to the degradation of machine components and many other reasons. Recently, signs of aging of the accelerator components have been extensively observed. We therefore keep constructing and executing effective maintenance strategies based on thorough investigations of potential problems until the major machine upgrade, SPring-8-II.

A highlight of recent updates of accelerators in FY2020 was the on-demand full-energy direct beam injection from the 8 GeV linear accelerator of SACLA. The original injection accelerators, the 1 GeV linear accelerator and the 8 GeV booster synchrotron, were shut down at the end of FY2019, in preparation for a next-generation high-quality beam injection for SPring-8-II and the green facility strategy [1]. After several test operations with the new injection setup, we commenced top-up user operations with on-demand full-energy injections of high-quality electron beams from the SACLA linear accelerator. The new injection setup does not change the fundamental light source performance such as brilliance, coherence, and flux, but it greatly helps reduce energy consumption in the facility. The new setup will also be essential for the next-generation light source, SPring-8-II, where an extremely high quality beam injection will be required.

As discussed below in Sect. 2 on SACLA, one of the technical challenges for the new injection is to secure extremely high bunch purities. Some user experiments, such as those for nuclear resonance scattering (NRS) experiments and related works, require a bunch purity of as small as 10^{-8} or even less. In the conventional SPring-8 operation with the original two accelerators, unwilling electrons in the satellite bunches are cleared by the RF knock-out system in the booster synchrotron before injecting to the storage ring. This, however, is no longer possible with direct injection from SACLA. One approach is to produce clear bunches in the SACLA linear accelerator, as discussed later. In addition, we developed a bunch cleaner system, where spurious satellite bunches inside the storage ring are kicked out. Here, it is crucial not to disturb the main bunches for a variety of filling patterns in user operations. The performance of the newly developed bunch cleaner is shown in Fig. 2. An example of bunch purity history in user time was plotted for 12 satellite "empty" buckets behind the main bunch. The operation mode was the H-mode, where a large bunch of 5 mA is isolated in the ring, and bunch trains of the remaining 95 mA are distributed on the other side of the ring. The time

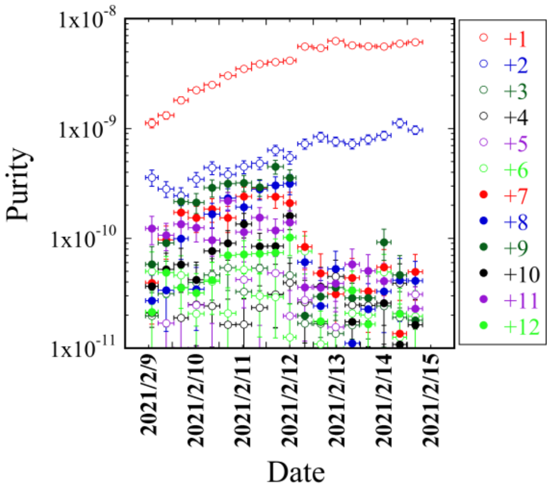


Fig. 2. Example of bunch purity history in user time with the injection from SACLA. The bunch purities of 12 satellite buckets behind the main bunch are plotted in the H-mode.

interval between the main bunch and the bunch trains is 1486 ns. We measured the number of electrons captured in the 12 buckets behind the main bunch that are supposed to be empty. As shown in Fig. 2, the bunch cleaner started kicking out spurious electrons on 12 Feb. at 4 pm. It was demonstrated that the bunch cleaner improved the bunch purities to higher than 10^{-10}, except for the first two buckets behind the main bunch. So far, these two adjacent buckets are not required to be cleaned up, but we may improve the bunch cleaner so that these buckets are also cleaned.

2. SACLA

The initially expected user time was 5,000 hours at least, but the actual operating time for user experiments was 3,252 hours because of the COVID-19 pandemic. Since the SACLA linear accelerator has started to be used as a full-time injector of SPring-8 in addition to XFEL operation, robust and reliable operations are required more than before. A backup power supply for a kicker magnet, which is a critical apparatus for beam injection, was installed in FY2020 (Fig. 3).

Fig. 3. Backup power supply of the kicker magnet installed in the SACLA klystron gallery.

2.1 Beam injection to the SPring-8 storage ring

The default injector of the SPring-8 storage ring was changed from a twenty-five-year-old injector system to the SACLA linear accelerator in September 2020 [2]. The old injector system, which consisted of a 1 GeV linear accelerator and an 8 GeV synchrotron booster, was shut down in March 2021.

At SPring-8, an electron bunch charge purity of 10-8-10-10 is typically requested for time-resolved experiments, such as NRS. However, during the beam injection from SACLA, it turned out that a small number of electrons were injected to unintended empty bunches. We found that some trailing electrons after the main beam were decelerated by an L-band accelerator and re-accelerated by a 476 MHz cavity in the SACLA injector. As a result, the trailing electrons went back and forth between the L-band accelerator and the 476 MHz cavity, and hence, they were injected to the storage ring with a delay of the round-trip time. This caused the unintended beam injection and the degradation of the bunch purity. The blue dotted line in Fig. 4 shows a beam current signal measured between the L-band accelerator and the 476 MHz cavity. The decelerated electrons are observed about 9 ns after the main beam, and they have opposite polarities because of their opposite directions of movement.

In order to clean up the trailing electrons, an electron sweeper was introduced in the SACLA injector, where the trailing electrons are kicked out by pulsed electric fields (red solid line in Fig. 4). In addition, an electron bunch knockout system was installed in the storage ring, in which RF fields are applied to empty bunches and remove residual unwanted electrons. Together with the use of energy slits at the beam transport line, a bunch purity of 10^{-10} is routinely attained during the user time.

2.2 BL1 undulators

BL1 is a soft X-ray FEL driven by an independent 800 MeV linear accelerator and three undulators are installed. In FY2019, demagnetization was observed for the first undulator. In March 2021, the magnetic field correction was carried out to recover the undulator performance. Since the permanent magnets of the other two undulators were also expected to be damaged, the last undulators of BL2 and BL3 were moved to BL1 to replace the second and third undulators. As a result, the FEL pulse energy that had been sluggish around 10 J has been successfully recovered to 50 J at 100 eV.

It is known that the present undulator length of 5 m is very large for the 800 MeV electron beam and the transverse electron beam envelope does not match the undulator natural focusing, which led to the demagnetization. We are currently planning to renovate all undulators with a length of 1.5–2 m.

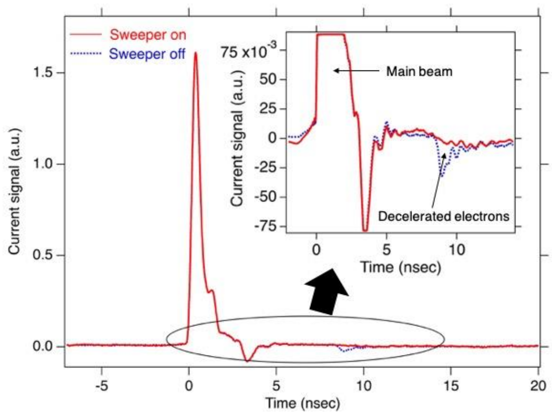


Fig. 4. Current signals observed by a current monitor installed between the L-band accelerator and the 476 MHz cavity. The red solid and blue dotted lines show the signals with the sweeper on and off, respectively.

Takahiro Watanabe[*1], Shiro Takano[*1], and Toru Hara[*2]

[*1] Light Source Division, JASRI

[*2] RIKEN SPring-8 Center

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[1] http://www.spring8.or.jp/ja/news_publications/press_release/2021/210823/ (in Japanese).

[2] Hara, T. et al., (submitted) Phys. Rev. Accel. Beams.