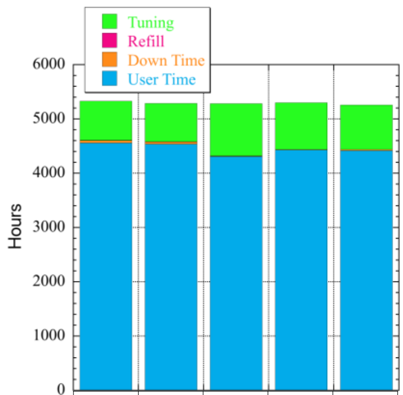
3. Operation Status

1. SPring-8

Figure 1 highlights the operation statistics for the last five fiscal years. In FY2022, the total operation time for the storage ring was 5,300 hours; 4,440 hours was allocated for user operations. The downtime due to machine trouble was 19.7 hours in addition to the planned downtime of 4.3 hours for switching the user operation modes with different patterns. The considerably short downtime led to an excellent user availability of 99.5%. In recent years, we have emphasized the importance of the mean time between failures (MTBF) for user experiments. As a result, we achieved MTBFs higher than 100 hours in these years by suppressing the frequency of machine failures. In FY2022, we obtained an MTBF of 232.4 hours.



	FY2018	FY2019	FY2020	FY2021	FY2022
Acc. Operation Time	5329.8	5285.7	5284.6	5300.2	5259.3
SR Operation Time	5316.7	5271.2	5274.8	5300.2	5259.3
Tuning&Study (Acc.&BL)	721.8	701.7	964.6	860.2	819.3
Refill	5.3	5.6	3.6	3.1	4.3
Down Time	43.1	40.5	7.4	10.0	19.7
Mean Time between Failures	168.9	206.3	718.2	553.4	232.4
Achieved User Time	4559.6	4537.9	4309.0	4426.9	4416.0
Planning User Time	4608.0	4584.0	4464.0	4440.0	4440.0
Availability (%)	98.9	99.0	99.7	99.7	99.5

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

Since the user time operation of SPring-8 with full-energy direct beam injection from the 8 GeV linear accelerator (linac) of SACLA started in 2020, the new injector has provided stable and reliable beam injection to the storage ring. The new injection setup from the SACLA linac will be essential to the future upgrade plan, SPring-8-II, where high-quality beam injection will be required from the viewpoint of beam dynamics. In addition, the new injection setup is already beneficial to the current accelerator operations, because we can save much power consumption without running the conventional 1 GeV linac and 8 GeV booster synchrotron.

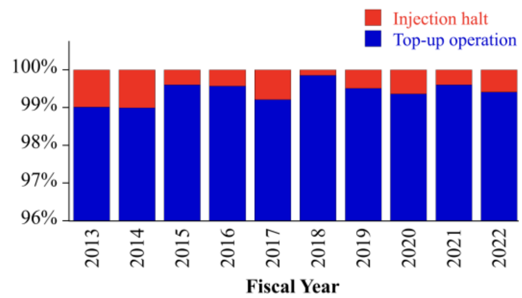


Fig. 2. SPring-8 top-up operation statistics for the past ten years.

In FY2021, 99.6% of the achieved user time (4416.0 hours) was operated in the top-up mode with a stored beam current of 100 mA. The top-up operation availability is kept at the same or even better level than with the original beam injection setup by the 1 GeV linac and 8 GeV booster synchrotron, as indicated in Fig. 2. The injection from the SACLA linear accelerator in FY2020 and 2022 resulted in the availability of around 99.5%, which is slightly better than the average value in FY2012 to 2019.

The high operation statistics such as the operation availability, MTBF, and the top-up operation availability could become worse anytime. In particular, signs of aging of the accelerator components have been extensively observed in recent years, so we have developed and implemented maintenance strategies based on thorough investigations of potential problems. Although these treatments have so far worked well, it is obviously necessary to completely renew most of the components before a major machine failure occurs.

A new insertion device (ID) capable of switching the polarization states between left-handed circular, right-handed circular, horizontal, and vertical polarizations (LCP, RCP, HP, VP) has been constructed. This will replace the existing ID operating in BL17SU, which is composed of both electromagnet and permanent-magnet arrays; since 2020, its capability, such as the wavelength tunability and available polarization, has been largely limited because of a malfunction found in one of the electromagnet coils (water leakage). The new ID, which has a magnetic period of 120 mm and is referred to as “H8U120”, is based on a Helical-8 undulator concept proposed in 2011 [1] and has the advantage that the HP and VP are available with much less heat load than those of conventional elliptically polarized undulators.

The construction of H8U120 started in 2021, and assembling the mechanical components and evaluating the magnetic array finished in July 2022 [2]. Figures 3(a)–3(e) show the magnetic performance of H8U120 at the minimum gap of 20 mm. Figure 3(a) shows the distributions of the horizontal magnetic fields in three different modes of operation, measured by scanning a Hall probe. Blue, green, and red lines correspond to the clockwise (CW), counter-clockwise (CCW), and figure-8 modes, in which LCP, RCP, and HP/VP are generated. Figure 3(b) is the same as 3(a), but for the vertical magnetic field, which is common to the three operation modes, and thus, only one result is shown as the black line. Figures 3(c), 3(d), and 3(e) show the electron trajectories projected on the transverse plane in the CW, CCW, and figure-8 modes, which were calculated using the magnetic distributions shown in Figs. 3(a) and 3(b). The electron moves along a CW helix, CCW helix, or figure-8-like orbit in each mode, respectively.

The constructed H8U120 was installed in the storage ring in the summer shutdown period (Aug. 2022) and has been operated without any problem.

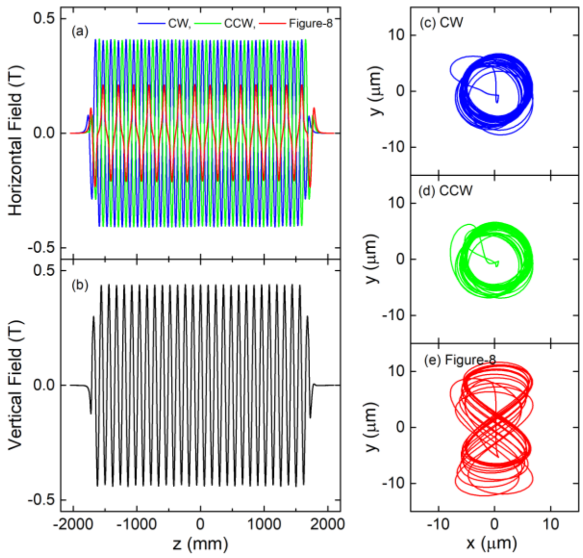


Fig. 3. Magnetic performance characteristics of the constructed H8U120 in three modes of operation: (a,b) horizontal and vertical field distributions, and (c–e) trajectories projected on the transverse plane.

2. SACLA

In SACLA, there are three FEL beamlines: BL1, BL2, and BL3. BL2 and BL3 are X-ray FELs and

BL1 is a soft X-ray FEL. BL1 is equipped with a dedicated 800 MeV linear accelerator originally constructed as a prototype accelerator named SCSS. In FY2022, the total user time for the X-ray beamlines (BL2 and BL3) was 4,770 hours with 97.7 % beam availability and 1,322 hours for BL1 with 99.1 % beam availability.

Since 2020, the linear accelerator of SACLA has also served as a low-emittance injector of the SPring-8 storage ring. The old injector, consisting of a 1 GeV linear accelerator and an 8 GeV synchrotron, was shut down in 2021 to save 5 MW of electricity. In the meantime, ensuring the operation reliability of SACLA becomes more crucial, as it provides the electron beam to both SACLA and SPring-8.

During the summer shutdown period of 2022, a newly developed 476 MHz RF source based on solid-state amplifiers was installed in the injector section (Fig. 4). The previous inductive output tube (IOT) and the new RF source are now connected to the 476 MHz RF cavity through an RF switch. The solid-state amplifier source is the default and the IOT serves as a backup.

In terms of the electron gun, a CeB_6 cathode needs to be replaced once or twice a year. Previously, it had been necessary to break the gun vacuum for cathode replacement, resulting in a downtime of a few days. In 2022, a new system was introduced, in which the entire gun tank, including the cathode, can be swapped without breaking the gun vacuum (Fig. 5). This improvement has significantly reduced the cathode replacement time to just half a day and also allows for fast recovery from unexpected gun troubles.

Fig. 4. New 476 MHz RF source based on solid-state amplifiers.

Fig. 5. New electron gun swapping system.

A machine learning (ML) optimizer has been utilized for accelerator tuning at SACLA since 2020, and it has become an indispensable tool for XFEL operation. Figure 6 illustrates the XFEL intensity development during a machine startup. The accelerator was initially adjusted manually and then the ML optimizer was employed to increase the XFEL intensity. It took about 70 minutes to recover the intensity. Figure 7 shows an example of spectral brightness optimization using a high-resolution single-shot spectrometer. In 2022, this spectrometer was introduced to BL2 in addition to BL3.

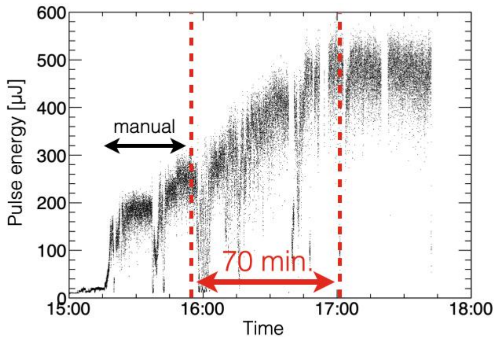


Fig. 6. XFEL pulse intensity development during a machine startup.

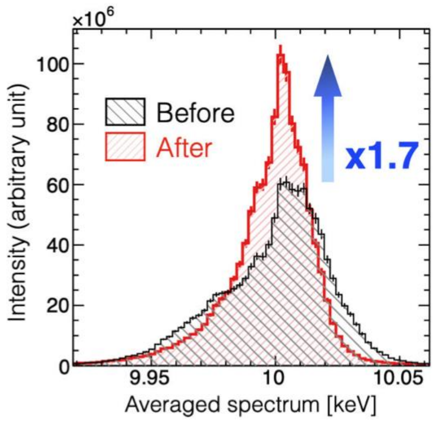


Fig. 7. Averaged XFEL spectra measured by a high-resolution single-shot spectrometer before and after ML tuning.

Watanabe Takahiro[*1], Takano Shiro[*1], Takashi Tanaka[*1, *2] and Hara Toru[*2]
[*1]Accelerator Division, JASRI
[*2]RIKEN SPring-8 Center

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[2] Tanaka, T. et al. (2023). *J. Synchrotron Radiat.* **30**, 301.