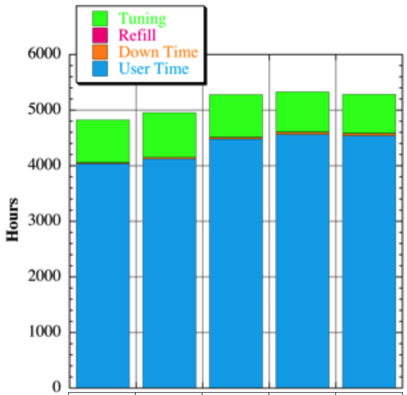
3. Operation Status

1. SPring-8

Figure 1 highlights the operation statistics for the last five fiscal years. In FY2019, the total operation time for the storage ring was 5,271 hours, and 86.1% (4,538 hours) was allocated for user experiments. The user availability of 99.0% and the mean-time-between-failures (MTBF) of 206.3 hours were both close to the past five-year average. The total downtime was 40.5 hours, and almost 42% of that (16.9 hours) was related to natural disasters such as instantaneous voltage drops of the facility power supply due to lightning strikes and earthquakes. The remaining 58% was due to accelerator machine failures such as high-power RF system troubles and sudden drops in the magnet power supplies. Cooling water supply failures were also observed in the magnet and vacuum systems. The flow rate of the water supply system slowly dropped, and the interlock occasionally forced the system to stop.



	FY2015	FY2016	FY2017	FY2018	FY2019
Acc. Operation Time	4817.9	4951.7	5281.6	5329.8	5285.7
SR Operation Time	4804.8	4941.1	5270.4	5316.7	5271.2
Tuning&Study (Acc.&BL)	767.2	803.1	769.6	721.8	701.7
Refill	5.3	3.4	4.6	5.3	5.6
Down Time	16.8	23.1	28.7	43.1	40.5
Mean Time between Failures	202.8	229.2	194.7	168.9	206.3
Achieved User Time	4033.9	4125.5	4478.7	4559.6	4537.9
Planning User Time	4056.0	4152.0	4512.0	4608.0	4584.0
Availability (%)	99.5	99.4	99.3	98.9	99.0

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

We are investigating the reason and plan to replace some devices such as the water pumps. The accelerator has been operational for more than 20 years. Unfortunately, signs of aging accelerator components have been extensively observed. Thus, devising maintenance strategies based on thorough investigations of potential problems is becoming increasingly important until the major machine upgrade, SPring-8-II.

A highlight of FY2019 was our newly developed beam orbit correction using the adaptive feedforward control (AFC). For years, periodic orbit fluctuations have been observed due to twin-helical undulators in BL23 and BL25. The two beamlines are equipped with optical helicity switching, which is excited by the local orbit bump of electrons in the corresponding straight section. We suppose the orbit fluctuations to be cancelled out by the feedforward correction control. Nevertheless, the amount of orbit fluctuation slowly became consequential in user operations due to the gradual deterioration of the feedforward correction. Therefore, we developed the AFC to repeatedly correct the feedforward table every few minutes. Our test operation confirmed that the new control system adequately suppresses the orbit fluctuation (Fig. 2). We plan to apply this new system to user operations in FY2020.

A little over two years ago, user operations began using the newly developed permanent dipole magnet. At SPring-8, several kinds of permanent dipole magnets have been developed specifically for SPring-8-II and other future light sources. To verify the reliability of these magnets in practical operations, we replaced one of the dipole electromagnets in the beam transport from the booster synchrotron to the storage ring with a permanent dipole magnet at the end of FY2017. Since then, not only have user operations occurred without any problems, but stable light has been provided to users without any measurable degradation of the magnet.

In addition to the permanent dipole magnets, we have developed state-of-the-art accelerator components looking toward the future. New beam position monitors (BPMs) based on a modern standard MTCA.4 were installed in the storage ring for testing. These BPMs are currently being used for the feedforward orbit correction at BL23 and BL25. A new digital low-level RF (LLRF) system, which replaced the old NIM-based analog system, has been providing reliable and flexible LLRF operations. Other new components, which are key to SPring-8-II, are also extensively being developed.

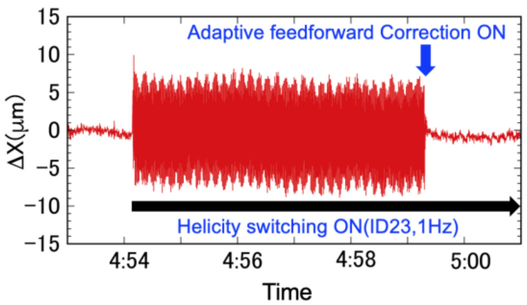


Fig. 2. Horizontal orbit fluctuation due to the helicity switching at ID23.

2. SACLA

Three beamlines, BL1–BL3, have been installed in the Undulator Hall of SACLA. BL1 is a soft X-ray FEL beamline, which is driven by an 800 MeV dedicated linear accelerator. It covers a photon energy range of 20–150 eV. BL2 and BL3 are hard X-ray FEL beamlines with a photon energy range of 4–20 keV and are driven by the 8 GeV SACLA linear accelerator. BL2 and BL3 are switched pulse-by-pulse using a 60 Hz kicker magnet, which enables XFEL multi-beamline operations.

2-1. Beam injection to the SPring-8 storage ring

Since October 2018, electron beam injection to the SPring-8 storage ring has been tested. In FY2019, two C-band RF units (four accelerator structures) were added to the SACLA linear accelerator to increase the maximum beam energy by 250 MeV. This addition helps realize a stable beam injection at 8 GeV by keeping two or three spare RF units.

For the beam injection, the electron bunch is directed to XSBT (XFEL to Synchrotron Beam Transport) at the end of the SACLA linear accelerator (Fig. 3). The bunch charge is about 200 pC. To fill the empty storage ring (0 mA stored current) to 100 mA current takes about 10 minutes with a beam injection of 10 Hz. Then top-up injection maintains the 100 mA stored current.

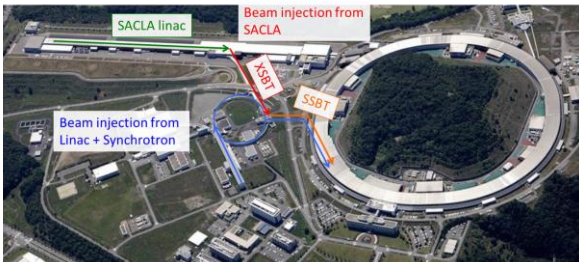


Fig. 3. Beam transport for injection (XSBT and SSBT).

The destination of the electron beam of SACLA is controlled by a table, which lists the beam destinations for the next one second. The future beam destinations are transmitted to all RF units and a kicker magnet through reflective memory. Then they operate with the preset parameters for each destination [1,2]. When the beam injection is requested from the storage ring, the table is replaced by the one containing XSBT as a destination for the beam injection.

In FY2019, all the necessary control and timing systems were developed and tested. Figure 4 shows the storage ring current during the beam injection and top-up operations. An injection efficiency of 95–100% was confirmed. Although the XFEL operation is halted during 10 Hz injection, the top-up injection can be performed in parallel with an XFEL operation.

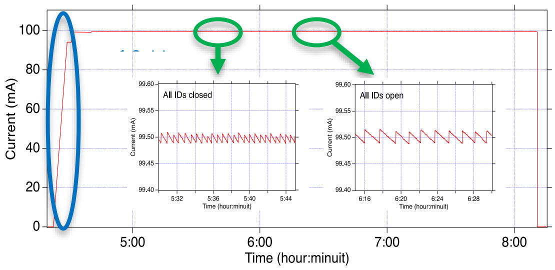


Fig. 4. Top-up beam injection from SACLA.

The first beam injection for three weeks was initially scheduled during SPring-8 user operation in February 2020, but was postponed to FY2020 due to electron gun cathode trouble as its lifetime was shorter than expected.

2-2. Automatic optimization of SACLA

To improve the efficiency of accelerator tuning, automatic XFEL optimization tools were introduced. In FY2019, software using a Gaussian process regression was developed. It is now used by operators for daily XFEL tuning (Fig. 5). However, we continue to develop more advanced and intelligent methods based on machine learning such as DQN.

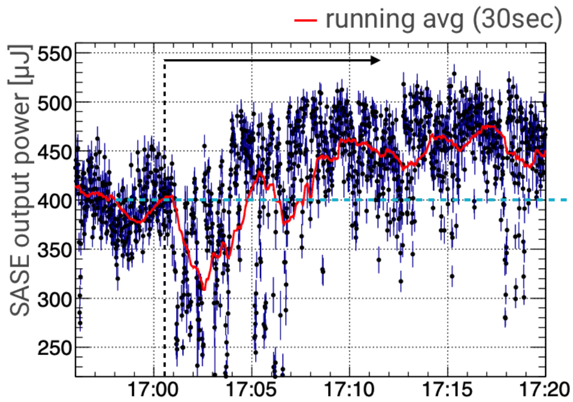


Fig. 5. SACLA accelerator parameter tuning by a Gaussian process regression.

2-3. BL1 undulator demagnetization

The laser output of SACLA BL1 gradually decreased in FY2019. During the winter shutdown period, the magnetic field of the first undulator segment was remeasured, and demagnetization was found for the whole undulator over 5 m (Fig. 6). As an immediate measure, we decided to move the undulator horizontally by 5 mm to avoid the demagnetized area. Additionally, we developed plans to install a vertical collimator in front of the undulator section.

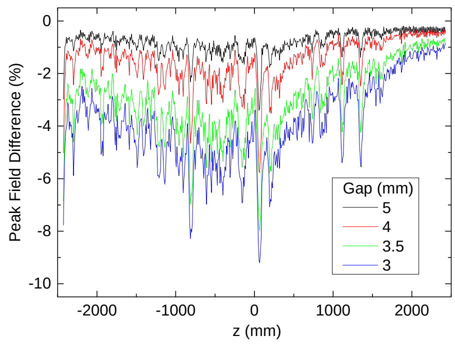


Fig. 6. Demagnetization observed for the first undulator segment of BL1.

Although the laser output power was partially recovered by the horizontal shift of the undulator magnets, the undulators will need to be replaced in the near future. Since the undulator length of 5 m is too long for the 800 MeV electron beam and the transverse electron beam envelope does not match the undulator natural focusing, which led to the demagnetization, the length of the new undulator segments will be shortened to 1.5–2 m.

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References:

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[2] T. Fukui et. al., in *Proc. of IPAC2019*, *Melbourne*, May 2019, 2529 (2019).