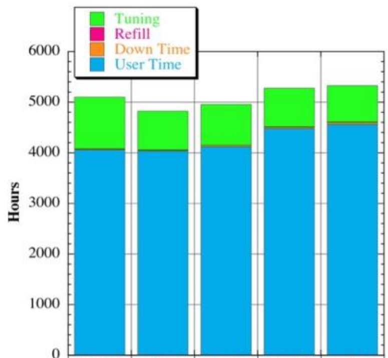
3. Operation Status

1. SPring-8

Operations statistics for the last five fiscal years are shown in Fig. 1. In FY2018, the total operation time for the storage ring was 5317 hours, 85.8 % of which (4560 hours) was allocated for user experiments. Although user availability was more than 99% until FY2017, it slightly decreased in FY2018 to 98.9%. Consequently, the mean-time-between-failures (MTBF) for these five years including FY2018 was estimated to be 192 hours, a bit lower compared with the years before FY2018 (>200 hours).

Most of the downtime (~1.1%) resulted from machine failures related to electromagnet and radio-frequency (RF) devices. Notably, in FY2018, there were nine downtime incidents resulting from electromagnet-related failures. In some cases, water hoses for electromagnets broke down due to aging, including radiation damage, and a large amount of water leaked into the accelerator tunnel. The power supplies for the electromagnets also deteriorated, causing three additional downtime incidents. These failures provide evidence of the aging and deterioration of accelerator components after more than twenty years of operation, highlighting the importance of thoroughly investigating possible problems with old devices and performing preventative maintenance to avoid major machine failures.



	FY2014	FY2015	FY2016	FY2017	FY2018
Acc. Operation Time	5099.3	4817.9	4951.7	5281.6	5329.8
SR Operation Time	5080.7	4804.8	4941.1	5270.4	5316.7
Tuning&Study (Acc.&BL)	1019.3	767.2	803.1	769.6	721.8
Refill	5.1	5.3	3.4	4.6	5.3
Down Time	17.1	16.8	23.1	28.7	43.1
Mean Time between Failures	163.2	202.8	229.2	194.7	168.9
Achieved User Time	4057.8	4033.9	4125.5	4478.7	4559.6
Planning User Time	4080.0	4056.0	4152.0	4512.0	4608.0
Availability (%)	99.5	99.5	99.4	99.3	98.9

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

Another highlight for FY2018 was our installation of a new digital low-level RF (LLRF) system based on modern compact digital technology, MTCA.4. One of the underlying strategies for the SPring-8-II project is to upgrade certain components prior to the major upgrade so that we can smoothly and effectively upgrade other main parts. Accordingly, the LLRF system has been upgraded in a step-by-step manner in recent years. This caused some of the increase in downtime in FY2018 due to the process of running the new LLRF system for practical user operations.

On-demand, high-quality beam injection from the SACLA linac to the storage ring is another key development that we are working on [1]. Although it will not substantially improve or degrade the light source performance for users, it is essential to SPring-8-II because high-quality beam injection is required for the newly designed low-emittance ring. In addition, it will help to reduce the operations costs by allowing us to shut down both the existing 1 GeV linac and the booster synchrotron. Hardware preparation and beam commissioning are now underway. The first test user operation with the new injection setup is planned for the end of FY2019. A full transition from the existing injection setup to the new platform is expected to commence soon after.

We have commenced test user operations using a 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. We have proposed new magnet designs and tested magnets in test benches to address most of the challenges we have faced (*e.g.,* magnetic field tunability and the temperature dependence of permanent magnet materials) [2]. At the end of FY2017, we replaced one of the dipole electromagnets in the beam transport from the booster synchrotron to the storage ring with a permanent dipole magnet for verifying reliability in practical operations. As a result, we smoothly resumed operation of the beam transport without any problems following the replacement, and since then (for more than one year) we have not observed any measurable demagnetization of magnets or any other degradation to beam operations.

Fig. 2. Permanent dipole magnet installed in the beam transport from the booster synchrotron to the storage ring at the end of fiscal year 2017.

2. SACLA

In FY2018, SACLA provided more than 6000 hours of operation time for user experiments. The undulator hall at SACLA can accommodate five undulator beamlines – so far, three beamlines (BL1, BL2, and BL3) have been installed. BL1, a soft X-ray beamline covering a photon energy range from 20 to 150 eV, is driven by an 800 MeV dedicated linear accelerator [3]. The accelerator of BL1 was moved from a former test facility at SACLA, originally called SCSS, and independently operated from the SACLA main linear accelerator. BL2 and BL3, hard X-ray FEL beamlines with a photon energy range from 4 to 20 keV, are driven by an 8 GeV SACLA main accelerator. BL2 and BL3 are switched pulse-by-pulse using a 60 Hz kicker magnet. All three beamlines can be operated in parallel, allowing three user experiments to be performed concurrently. Figure 3 shows a schematic layout of the facility.

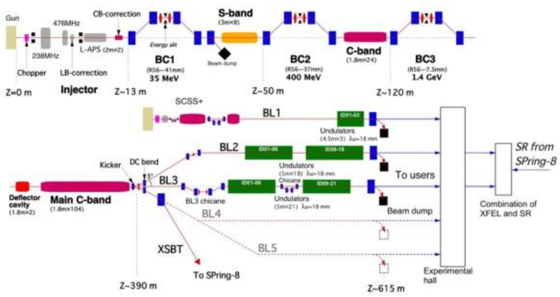


Fig. 3. Schematic layout for SACLA.

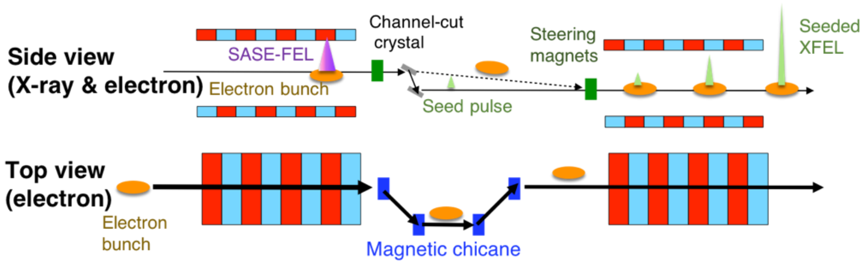


Fig. 4. Schematic configuration for reflection type self-seeded XFEL.

3-1. Reflection type self-seeded XFEL

In BL3, reflection type self-seeded XFEL operations started in June 2018. The self-seeded XFEL was developed to improve the randomly changing spiky spectra and longitudinal coherence of the SASE pulses. In the self-seeding operation, the undulator section is divided into two, and a magnetic chicane and a crystal are installed between the two parts. The SASE pulse emitted from the upstream undulators is monochromatized with the crystal and amplified in the downstream undulators. The transmission type self-seeded XFEL was first proposed at DESY and demonstrated at LCLS, which uses coherent forward Bragg reflection trailing the transmitted SASE pulse [4, 5]. The advantage of transmission type self-seeding is the small delay required for the electron beam. The transmission type self-seeded XFEL was also tested at SACLA in 2014 [6]. Although the monochromatized seed was successfully amplified, spectral purity and brightness were less than expected and a broad pedestal was consistently observed in the spectrum due to the transmitted SASE pulse. To improve spectral brightness, a reflection type self-seeded XFEL was developed at SACLA [7]. In this scheme, conventional Bragg reflection is used to generate a monochromatized seed pulse from the upstream SASE pulse, so there is no transmission of the SASE pulse downstream. Figure 4 shows a schematic configuration for the reflection type self-seeded XFEL. The SASE pulse of the upstream undulators is reflected twice and monochromatized by a Si channel-cut crystal. To reduce the electron beam delay, the gap of the channel-cut crystal is set to about 100 µm. Figure 5 shows the measured averaged spectra. A clear single spectral peak was obtained and the spectral brightness was increased by a factor of six compared with normal SASE operation. The reflection type self-seeded XFEL has been used in several pilot experiments and will be open to users in FY2019.

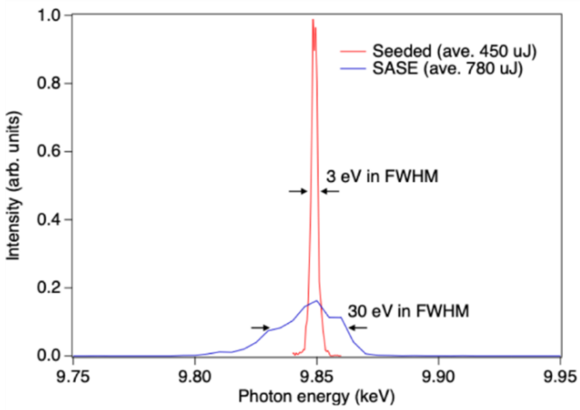


Fig. 5. Averaged spectra obtained during self-seeded and SASE operations.

3-2. Design of BL1 nonlinear correction using sextupoles

Currently, a soft X-ray FEL pulse energy of ~100 µJ with a pulse width of ≤100 fs is obtained at a photon energy of 100 eV. However, users have requested a higher peak power and a shorter pulse width. Since the injector of the BL1 accelerator is not equipped with an energy chirp linearizer to correct the longitudinal phase space curve, the electron bunch is easily over-bunched and the FEL pulse properties are limited to the current values. In order to meet the users' request, we have proposed nonlinear correction using sextupole magnets at the first bunch compressor (BC1) chicane, as shown in Fig. 6. Since the head and tail energies of the bunch are lower than that of the linear component due to RF nonlinearity, these parts travel a long distance in the chicane and are delayed at the BC1 exit. As a result, the bunch is over-compressed. To correct it, the sextupole magnets are introduced in the dispersive section. By kicking the head and tail parts to the same direction, they travel short cut courses and the bunch can be linearized by properly tuning the magnet strengths. This year, we completed parameter optimization of the sextupole magnets and the BC1 layout [8]. We completed design for the components and have started manufacturing them. The reconfiguration of BC1 is scheduled during the winter shutdown period of FY2019.

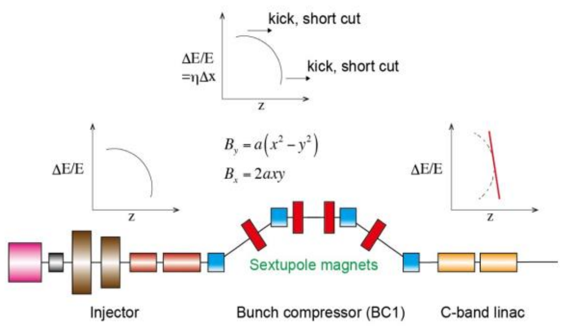


Fig. 6. Schematic for the nonlinear energy chirp correction using sextupole magnets at the SACLA soft X-ray beamline (BL1).

3-3. Beam injection into the SPring-8 storage ring

The SPring-8-II upgrade project expects to use SACLA as a low-emittance injector. In addition, if SACLA provides the 8 GeV electron beam for SPring-8, we can eliminate the operation and maintenance costs for the existing 1 GeV linear accelerator and 8 GeV synchrotron. Beginning in October 2018, the electron beam injection was tested using the existing SPring-8 storage ring. The injection tests will continue in FY2019 until SACLA replaces the existing injector in FY2020.

Takahiro Watanabe[*1], Shiro Takano[*1],
Kazuaki Togawa[*2] and Toru Hara[*2]
[*1] Light Source Division, JASRI
[*2] RIKEN SPring-8 Center

References:

[1] H. Maesaka et al., *proceedings of IPAC2019*, Melbourne, 2427 (2019).
[2] T. Watanabe et al., *Phys. Rev. Accel. Beams* **20**, 072401 (2017).
[3] S. Owada et al., *J. Synchrotron Rad.* **25**, 282 (2018).
[4] G. Geloni, V. Kocharyan and E. Saldin, *J. Mod. Opt.* **58**, 1391 (2011).
[5] J. Amann et al., *Nat. Photon.* **6**, 693 (2012).
[6] T. Inagaki et al., *proceedings of FEL2014*, Basel, 603 (2014).
[7] I. Inoue et al., *Nat. Photon.* **13**, 319 (2019).
[8] K. Togawa et al., *proceedings of IPAC2019*, Melbourne, 1782 (2019).