PRESENT STATUS OF ACCELERATORS IN AICHI SYNCHROTRON RADIATION CENTER

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Abstract

Aichi Synchrotron Radiation Center is a synchrotron radiation facility in operation since 2013. The electron energy of the storage ring is 1.2 GeV and the circumference is 72 m. In spite of the compact size of the storage ring, synchrotron radiation up to hard X-ray region (~20 keV) is available from the 5 T superconducting bending magnets. Presently (Apr. 2017), 8 beamlines (5 hard X-ray and 3 soft X-ray) are in operation. In the daily operation, 300 mA top-up mode has been performed to realize the beam current stability of better than 0.3%. In addition to the delivery of the synchrotron radiation to the beamlines, R&Ds for accelerator components have been continuously performed; fabrication of a model permanent bending magnet and turn-by-turn beam profile measurement at the beam injection by a pulse sextupole magnet.

INTRODUCTION

Aichi Synchrotron Radiation Center (Aichi-SR) [1] is the newest synchrotron radiation facility in Japan. The construction was started in 2010 and the facility was opened for public use on March 2013. Aichi-SR is the main facility of the project "Knowledge Hub Aichi" of Aichi prefecture, to establish a new research center for technological innovations in collaboration with universities, research institutes, local government and industries. Aichi-SR supplies the synchrotron radiation light of soft X-rays as well as hard X-rays to the beamlines with good accelerator operation stability; the rate of operation is more than 98.5% with the total users-operation time of more than 1700 hours. Because of full energy injector (booster synchrotron) the top-up operation is performed in routine users-operation; beam current of 300 mA is always kept with the fluctuation of better than 0.3%.

ACCELERATORS

Figure 1 shows the top view of the accelerators and the synchrotron radiation beamlines. To maximize the number of the available sections for the beamlines, the injector linac of 50 MeV and the full energy booster synchrotron are placed inside the storage ring. The accelerators are housed in a concrete shield hutch which is placed at the center of the experimental hall.

The main parameters of the accelerators in Aichi-SR are listed in Table 1 [2]. Due to the full energy booster synchrotron, the top-up operation has been performed from the beginning of the public use.

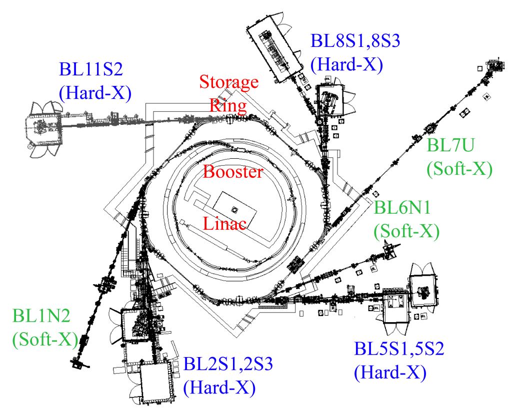

Figure 1: Top view of Aichi-SR accelerator complex.

From the conceptual design of Aichi-SR, hard X-ray beamlines as well as soft X-ray had been strongly demanded especially from industrial applications. On the other hand, a compact scale had been desired for the new synchrotron radiation facility. To settle these requirements, Aichi-SR had been adopted to use superconducting bending magnets (superbends) which can generate hard X-rays in spite of moderate electron beam energy. The storage ring consists of four triple-bend cells; two normal bending magnets and one superbend are placed in one cell. The operating coil current of the superbends is 100 A at 3.6 K. The refrigerators of the superbends are 4K-GM type cryocooler which is liquid-He and liquid-N_2 free. The cryocoolers are replaced at an annual maintenance period. At the replacement the coil temperature increases up to ~40 K; after the replacement the temperature becomes below 4 K again in about 15 hours. The superbends are running without any trouble since the public open of Aichi-SR and used for hard X-ray sources in the facility.

The storage ring has four straight sections; two sections are used for the beam injection septum and the RF cavity. One straight section is used for APPLE-II type undulator which generates the quasi-monochromatic VUV radiation. The undulator can switch polarization mode of photons; horizontal, vertical and helical modes. At present only horizontal

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Table 1: Main Parameters of Accelerators in Aichi-SR

Storage Ring	
Beam energy	1.2 GeV
Circumference	72 m
Beam current (in routine)	300 mA
Natural emittance	53 nm–rad
RF frequency	499.69 MHz
Harmonic number	120
Betatron tune (ν_x, ν_y)	(4.73, 3.18)
Energy spread	8.4×10^{-4}
Normal bending magnets	1.4 T, 39°
Critical photon energy of NBs	1.3 keV
Superconducting bending magnets	5 T, 12°
Critical photon energy of SBs	4.8 keV
Booster Synchrotron	
Beam energy	50 MeV~1.2 GeV
Circumference	48 m
Beam current	~ 1 mA
Repetition rate	1 Hz
Linac	
Beam energy	50 MeV
Charge per pulse	~1 nC
Pulse duration	~1 ns
RF frequency	2856 MHz
Repetition rate	1 Hz

mode is available; introduction of vertical and helical mode would need optimization of the electron beam condition such as lattice function and steering magnet system.

MACHINE OPERATION

Aichi-SR is operated about 170 days in one year for users-operation. Machine tuning, machine study and beamlile study are scheduled on every Monday. The users-time is scheduled from Tuesday to Friday; the machine stops in weekend. In the weekdays the machine starts to operate in the morning and stops at night. The users-shifts are 10:00 am to 2:00 pm and 2:30 pm to 6:30 pm.

The total time for the users-operation was 1779 hours in fiscal year of 2016. The scheduled users-time was 1452 hours which corresponded to 363 users-shifts. The loss time, which is defined by the time in which the synchrotron radiation was not delivered to the users in the scheduled users-time, was 17 hours; that corresponds to the operation rate of more than 98.5%. The loss time is caused by accidental beam damp; almost all of the beam damp are accompanied by the reflection power from the RF cavity, however, the direct cause of the beam damp has not been understood so far because the sudden beam damp cause increase of the RF reflection power.

In the routine operation, the linac injects ~0.7 nC electrons into the booster synchrotron, and the booster delivers 1.2 GeV electron beam to the storage ring with the efficiency of ~30%. The beam current in the storage ring increases ~0.2mA in one injection from the booster. The beam current of the storage ring is 300 mA; the fluctuation of the stored beam current is always kept less than 0.3% due to the top-up operation.

RESEARCH AND DEVELOPMENT

Development of Permanent Bending Magnet

Because the Aichi-SR has full energy booster synchrotron, in principle it is possible to replace the present normal bending electromagnets to permanent magnets. The key issue of the development of the permanent-type magnets is the magnetic field strength; as shown in Table 1, the magnetic field in the normal bending magnet is 1.4 T. It is not easy to realize such strong magnetic field with permanent magnet assembly with keeping good field region wide enough. The other important issue is temperature dependence on the magnetic field of the permanent magnet. From this point of view, Sm-Co magnet is suitable for accelerator magnets because of good temperature dependence on the magnetic field. However, 1.4 T magnetic field is difficult to achieve by Sm-Co magnetic assembly. Therefore, Nd-Fe-B magnet, which can produce stronger magnetic field than Sm-Co magnet, adopted for our design of the bending magnet. Figure 2 shows the permanent bending magnet design for Aichi-SR storage ring. The shape and the arrangement of the magnets as well as yokes have been optimized through trial and error. From the simulation, it is concluded that the field strength of above 1.406 T and horizontal good field region of ±35.2 mm which is wide enough for the bending magnets of Aichi-SR have been achieved.

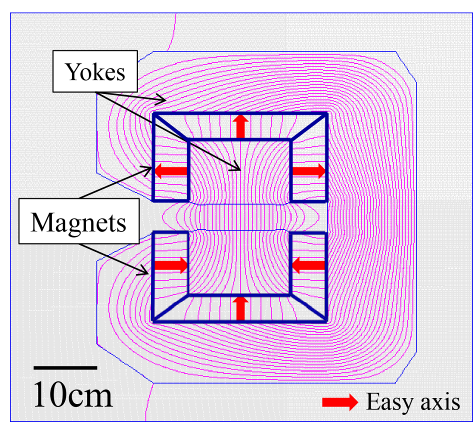

Figure 2: Cross section of permanent bending magnet design.

The demagnetization due to heating of the permanent magnet depends on the operating point on the B-H curve of the magnet. The minimum magnetization in the magnet is estimated to be 35.95 G. From the magnetic polarization at the minimum magnetization point, the remnant magnetic field and the coercivity of the magnet, it is estimated that the irreversible demagnetization occurs above 40°C in the designed permanent bending magnet.

From the calculation, a model magnet whose size is 1/5 scale has been fabricated with Nd-Fe-B permanent magnet. Figure 3 shows the photograph of the model magnet.

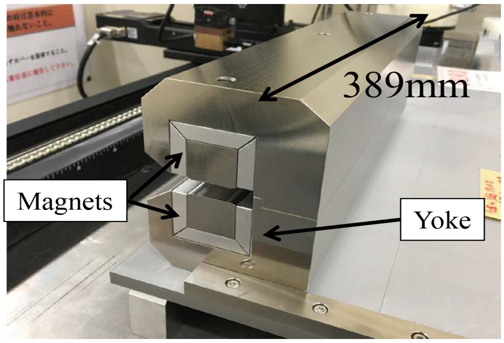

Figure 3: Photograph of 1/5 model magnet.

The result of the magnetic field measurement is shown in Fig. 4. As seen in the figure, the magnetic field above 1.4 T can be achieved in horizontal region of wider than required value of ±6 mm.

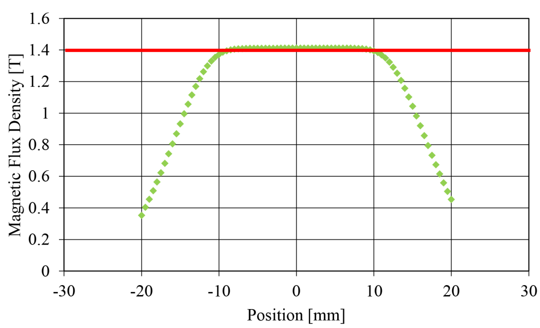

Figure 4: Measured magnetic field of 1/5 model magnet.

Nd-Fe-B magnet has larger temperature dependence on the magnetic field than Sm-Co magnet; to compensate the dependence a hybrid type bending magnet is under investigation. According to the calculation, applying a small coil around the return yoke can easily compensate the temperature dependence with small coil current. Measurement of the temperature dependence on the magnetic field and the test of the hybrid-type magnet are next subjects.

Turn-by-turn Beam Measurement under Pulse Sextupole Magnet System

Aichi-SR has introduced a pulse sextupole magnet (PSM) for the beam injection system [2]. The beam injection by the PSM was successfully achieved with the injection efficiency about 30%. However, not only the injection beam but also the stored beam is affected by the PSM. To investigate this, turn-by-turn transverse beam profile measurement has been performed by using a fast-gated CCD camera system. In the measurement, the gated CCD camera system was settled in the beam diagnostic beamline (BL9N1) which can extract visible synchrotron radiation. By synchronizing the gate camera operation with the injection trigger signal, a single-turn beam profile can be observed in enough image contrast. In the measurement successive 5 bunches were stored and PSM was operated only; the beam was not injected.

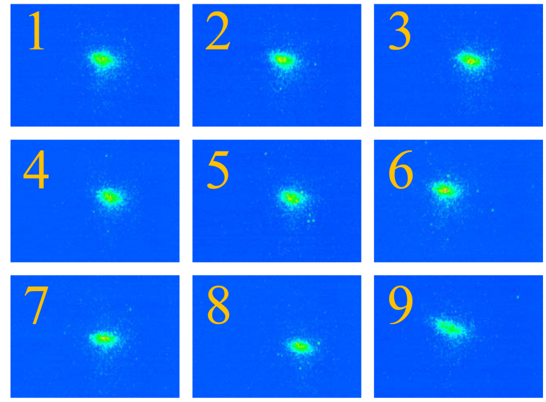

Figure 5: Turn-by-turn beam profile after PSM was on. The numbers correspond to the turn number after the PSM on.

Figure 5 shows turn-by-turn beam profile after PSM was on. The pulse duration of the PSM was ∼3 revolutions time of the beam. As seen in the figures, not only the beam position but also the beam profile changes due to the PSM kick. The change in the r.m.s. horizontal beam size on the turn number after PSM kick is shown in Fig. 6. As seen in the figure, the beam size tends to increase after the PSM kick. A tentative simulation shows that the effect by the PSM for the stored beam can be treated by single dipole kick and the saturation of the beam size seen in Fig. 6 is caused by non-linear field due to the sextupole magnets. Detailed simulation and introduction of a feedback system to suppress the beam oscillation are next subject.

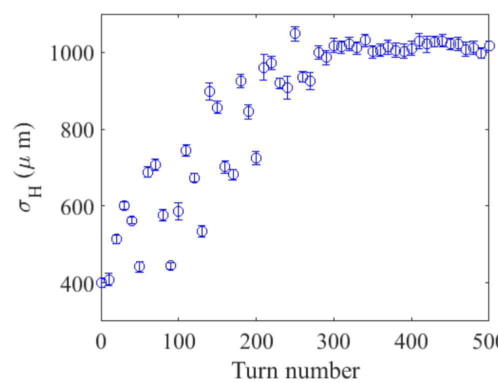

Figure 6: Change in horizontal beam size after PSM kick

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[1] Aichi Synchrotron Radiation Center, http://www.astf-kha.jp/synchrotron/en/

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