SUPERCONDUCTING ELECTRON STORAGE RING FOR A SYNCHROTRON LIGHT SOURCE AURORA

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Abstract

A superconducting synchrotorn light source which has only 1-m orbital diameter was constructed at Sumitomo Tanashi Works. This light source is designed to provide 1-nm critical wavelength, which is suitable for an x-ray lithography. An uniform source size is expected throughout the circumference because of the weak-focussing single magnet. The irradiative power is 1.5 W/mrad at the stored current of 300 mA. The commissioning of AURORA is now undertaking.

Introduction

Compact SR rings are being intensively developed recently at several countries[1,2). for seeking an industrial use particularly for an x-ray lithography. These machines are designed so as to satisfy the lithographic requirements such as wavelength, beam size, and radiation power. A compactness of the machine and an easiness of operation are important from the economical point of view.

A solution for the simplest and smallest SR ring is a circularly symmetric storage ring composed of a single superconducting magnet, while most of the superconducting rings are the racetrack type[1,2)]. The existing accelerator technologies can be mostly applied to a separate sector type superconducting storage ring. The circularly symmetric machine, however, claim challenging new accelerator technology such as a high energy beam injection, small rf-cavity, and ultra high vacuum technologies.

Sumitomo Heavy Industries, Ltd. is developing a compact synchrotron light source named AURORA, which is composed of a single cylindrical superconducting weak-focussing magnet[3−6)], as shown in Fig.1. In order to accomplish this type of machine, we have introduced so called a half-integer resonance injection method, and developed unique components for the beam injection, acceleration, tuning, diagnostics, and ultra-high vacuum.

The main specifications are listed in Table 1. Concerning the lithographic requirements, the critical wavelength is set at 1.0 nm. The safety of the NbTi superconducting coil limits the maximum applicable magnetic field to less than 5 Tesla with the present technology, so the electron orbit diameter is set at 1.0 m in conjunction with the electron energy of 650 MeV. The injection energy is decided from the cost of the injection accelerator as well as from the performance of the storage ring. The Touscheck lifetime, which depends on the electron energy, must be sufficiently long to accumulate and keep the beam current as much as possible during the injection and acceleration, since the excitation speed of the magnet is limited by the stability of the superconducting coil. The radiation dumping time must be short enough to repeat the injection until the stored current becomes satisfactory. As a consequence the injection energy is set at 150 MeV. We have already succeeded in constructing an economical 150 MeV racetrack microtron as an injector[7,8)].

In order to demonstrate the feasibility of the industrial use of our machine and to study various applications, we have completed the construction of prototype system for our own

Table I. Parameters of the conpact superconducting storage ring "AURORA".

	At injection	At accumulation
Energy (MeV)	150	650
Critical wavelength (nm)	82.8	1.0
Radiation loss/turn (keV)	0.09	31.6
Current (A)		300
Bending field (Tesla)	1.0	4.3
Bending radius (m)		0.5
Field index	0.73	0.3
Revolution frequency (MHz)		95.43
RF frequency (MHz)		190.86
RF voltage (kV)	60	120
Radiation dumping time (msec)		
Radial	13.0	1.0
Vertical	35.1	0.43
Longitudinal	118.4	0.17
Radial emittance (mm·mrad)	0.17	4.9
Beam size σ (mm)		
Radial	0.9	1.3
Longitudinal	40.0	51.0
Touscheck lifetime	71 seconds	40 hours
Vacuum pressure (torr)		$1.0 \cdot 10^{-9}$

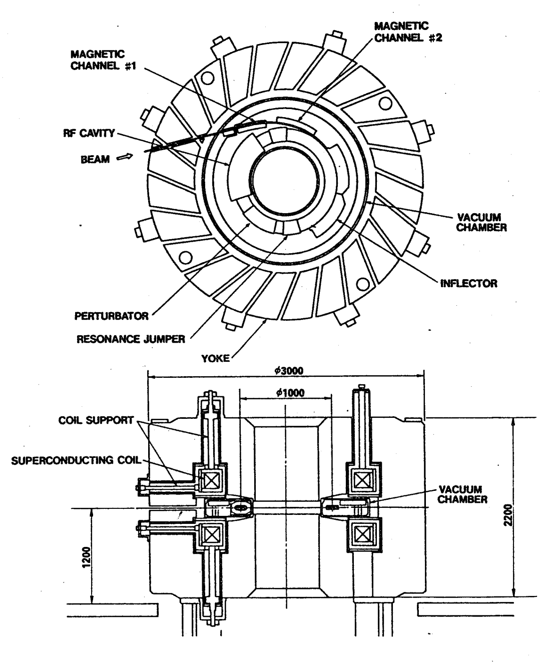

Fig. 1. Structure of the compact superconducting SR ring. Configurations of the main components are shown: (top) by the horizontal cross section at the median plane and (bottom) by a vertical cross section.

use at Tanashi Works in Tokyo. This paper describes briefly the features of our machine and reports the construction status.

Superconducting magnet

The magnet is shaped as cylindrical symmetry, and is comprised of iron poles, iron yoke, and a pair of superconducting coils[9]. This yoke for a return path of the magnetic flux plays an addition role. The magnetic force between the coils is reduced to less than 140 tons by this iron yoke. If the iron yoke is not introduced, the force between the coils might exceed one thousand tons. Since the force is reduced, the coils can be supported with carbon fiber reinforced plastic rods(CFRP). The use of CFRP resulted in small thermal penetration, and the upper and lower coils are now suspended at the top and the bottom of the yoke, respectively. This technique made possible the magnet to be separated at the median plane and the vacuum chamber to be installed in the magnet.

The use of the iron pole produces not only a sophisticated field distribution, but also provides the change of the field index. This change of the field index is brought from the saturation of the magnet, and its value is controlled by the pole shape. The field index of the magnet is set to be 0.73 at 1 Tesla for the half-integer resonance injection, and changed to 0.3 at 4.3 Tesla for the storage. This dynamical transition of the field index resulted in the longer longitudinal quantum lifetime.

Field measurements were performed with hall probes and a search coil assisted with an automated scanning table. The radial field distributions at several excitation currents were measured as shown in Fig.2. The first harmonic error fields were found to be less than 0.016% at the injection field and less than 0.05 % at the maximum field in the radial aperture R=450−550 mm. The computer simulation of the beam dynamics based on these field maps indicates the satisfactory behavior of the beam throughout the course of the injection.

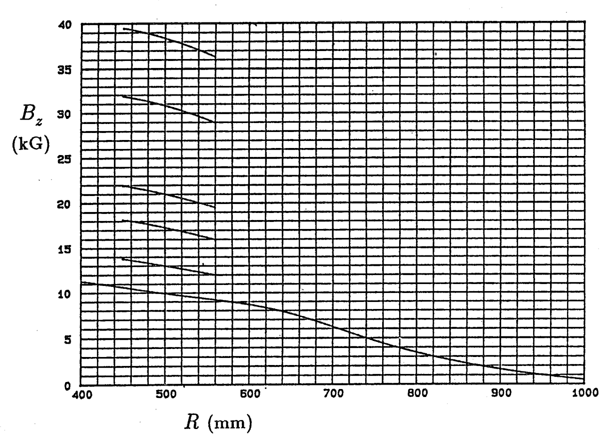

Fig. 2. Radial distribution of the measured magnetic field. Excitation currents of the superconducting coils are 60.9 (at the injection), 100, 200, 300, 600 and 850 (A) coresponding to the field strength.

Rf system

The main components of the rf system are rf cavity, a 30-kW circulator, a 40-kW rf power supply and rf controller. The rf cavity consists of two $\lambda/4$ coaxial resonators operated in the push-pull mode. In order to make the outlet for the synchrotron radiation, there are slits in the median plane of the cavity. The energy loss of the electron by the synchrotron radiation is 31.6 keV at the energy of 650 MeV. The total radiation power of the beam reaches 10 kW at the stored current of 300 mA. The rf power source must supply this power loss in addition to the 20 kW wall loss of the rf cavity, and was prepared with 10 kW margin which can be used for the control of the Robinson instability. At the beam injection, the rf cavity is operated at 60 kV which is the optimum for capture of the electrons. After the injection, the rf voltage is increased up to 120 kV so as to obtain a sufficient longitudinal quantum lifetime at the maximum energy.

When the full power is supplied to the rf cavity, the resonant frequency drifts too quickly by the thermal distortion to be reserved manually. The feedback was successfully carried out by the computer control system.

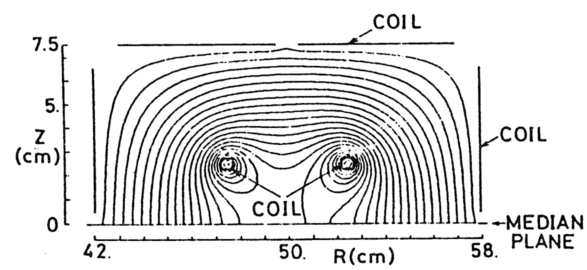

Fig. 3. Cross-section of the perturbator and magnetic flux line distribution. Assymmetry of flux lines arises due to the curved perturbator.

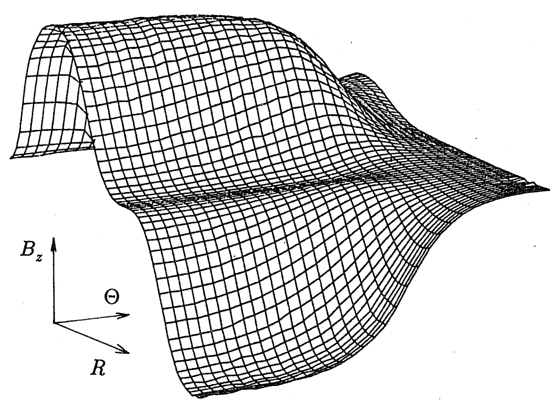

Fig. 4. Measured magnetic field distribution of the perturbator on the half of the median plane. The maximum magnetic field strength is 300 (G). The full span angle of perturbator is 25 degree.

Injection system

It is not easy to apply the ordinary injection method to our storage ring, since the perturbator must be made of an air-core to be placed in the strong magnetic field, and the pulse becomes too short and strong in order to manage the short revolution time and the high energy electrons. The half-integer resonance injection method was studied and adopted[10]. Our perturbator generates a modified octapole magnetic field instead of an ordinary dipole field. Fig.3 shows the configuration of the coil and the magnetic flux lines of the perturbator. The maximum field strength of 300 G is obtained over 25 degree along the orbit. The pulse is shaped as a half sine wave with 2μsec half period. A typical example of measured field distribution is shown in Fig. 4. The computer simulation using the measured perturbator and main fields demonstrates a good efficiency for the capture of electrons to the stable orbit.

The electrons are guided to the perturbator by two magnetic channels and an electrostatic inflector under the fringing field of the main magnet. The magnetic channels are coaxial-type air-core magnet. These magnets produce a static field of -2.0 kG and a field gradient of 40 G/mm.

Vacuum system

The lifetime of the beam is limited by the gas pressure due to the scattering with molecules in the vacuum chamber. The vacuum pressure below the 1×10^{-9} torr is required to keep the lifetime longer than 24 hours. On the other hand, gas load caused by the irradiation of the chamber wall is too large to keep the pressure by a conventional vacuum pump. This gas load is estimated to be 4.5×10^{-5} torr·l/s. Therefore, we developed a extremely powerful cryosorption pump and built in the vacuum chamber[11]. The chamber is separated into multi rooms as shown in Fig. 5. The effect of the gas load is greatly reduced in the beam duct by this multi-room structure. This evacuation system is now successfully operated at pumping speed of more than 40,000 l/s. We have recorded 1.0×10^{-9} torr after 24 hours of operation from the atmosphere.

Control system and operation of machine

The computer control system named CHAOS(Computer Hosted Accelerator Operation System), which has three layered hierarchical architecture, has already been constructed and tested[12]. The test operation of the whole light source in remote mode was successfully completed from the central console. The CHAOS provides an interactive man-machine console as well as an automatic operation sequences written in a BASIC like language which was specially developed. The beam monitoring system has also been completed as described in ref.13), and linked to the central console. A fully automatic operation is enabled by this link of the operation system and the beam monitoring system. We will achieve a fully automated operation after some experiences. We are now commissioning AURORA.

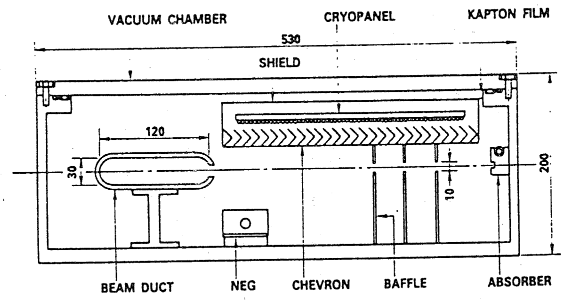

Fig. 5. Cross section of the vacuum chamber. Configurations of main components are shown.

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