STATUS AND DEVELOPMENT OF THE SAGA LIGHT SOURCE

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Abstract

The SAGA Light Source (SAGA-LS) is a 1.4 GeV synchrotron radiation facility that has been in operation since 2006. The annual failure rate during user time in the last two years has been of the order of 10^{-3}. Three insertion devices are currently installed in the storage ring: an APPLE-II type undulator, a planar undulator (Saga Univ.), and a hybrid three-pole 4-T superconducting wiggler (SCW). The SCW consists of a superconducting main pole and two normal-conducting side poles. The main pole of the SCW is cooled by a Gifford–McMahon cryocooler. The beam lifetime has been investigated and information was obtained regarding the contributions of various processes to the total lifetime. Laser Compton gamma-rays were generated by a CO_2 laser. They were used for measuring the machine parameters of the storage ring such as the beam energy and the momentum compaction factor. To permit full control of the undulator parameters during user time, a feed-forward correction system was developed that minimizes the effects of the undulators on the emittance coupling. In addition, an experimental study of the interaction between the electron beam and the crystal, improvement of the control system, and development of a multipole magnet are currently in progress.

INTRODUCTION

The SAGA Light Source (SAGA-LS) is a synchrotron radiation facility in Kyushu, Japan. Its accelerator complex consists of a 255-MeV injector linac and a 1.4-GeV storage ring with a circumference of 75.6 m. Since the facility was opened in 2006, the SAGA-LS has been stably providing synchrotron light over a wide spectral range from VUV to hard X-rays [1].

Figure 1 shows the present layout of the SAGA-LS facility and Table 1 lists the main parameters of the injector linac and storage ring. The SAGA-LS storage ring has eight 2.5-m long straight sections. Three of them have insertion devices: an APPLE-II type [2] variably polarizing undulator, a planar undulator (Saga Univ.), and a 4-T superconducting wiggler (SCW) [3].

OPERATIONAL STATUS

The SAGA-LS facility is routinely operated for users from Tuesday to Friday, while machine study is performed on Monday. The annual user time has been about 1500 hours over the last five years. Figure 2 shows the monthly and annual machine failure rates. The annual failure rate has gradually decreased; it has been reduced to the order of 10^{-3} for the last two years. Routine operation of the SCW commenced in November 2010. Since then, beam

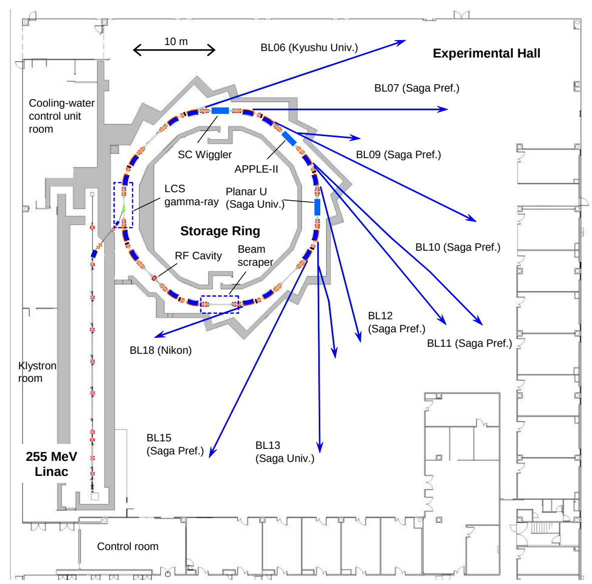

Figure 1: Layout of the SAGA-LS facility as of August 2011.

Table 1: Main Parameters of the Injector Linac and Storage Ring

Injector Linac	
Energy	255 MeV
Repetition rate	1 Hz
RF frequency	2856 MHz
Macropulse width	200 ns
Macropulse charge	12 nC
Storage Ring	
Maximum energy	1.4 GeV
Circumference	75.6 m
Natural emittance	25.1 nm·rad
RF frequency	499.8688 MHz
Harmonic number	126
Betatron tunes (H/V)	5.796/1.825
Energy spread	6.7×10^{-4}
Momentum compaction	0.013
Filling beam current	300 mA

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injection has been performed once a day with an initial current of 300 mA giving a user time of 10.5 hours.

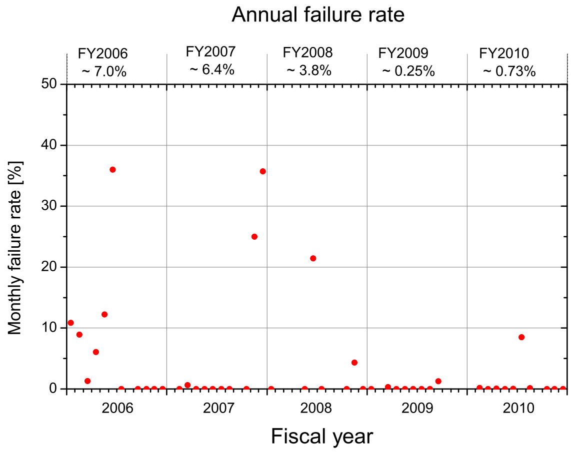

Figure 2: Operation statistics for the monthly and annual machine failure rates.

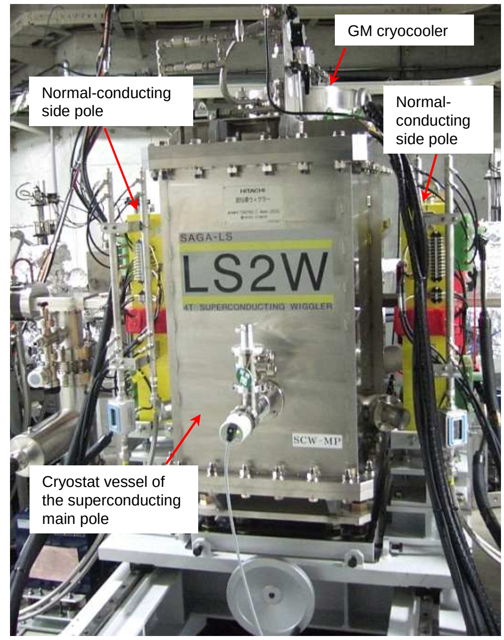

Figure 3: Photograph of the SCW installed in 2010.

RECENT DEVELOPMENTS

Superconducting Wiggler

To generate hard X-rays up to 40 keV, we developed a SCW that has a peak magnetic field of 4 T, which gives a critical energy of 5.2 keV [3]. The SCW was installed in the storage ring in March 2010 and it has been operated stably without any problems that have necessitated a beam abort during user time. The SCW is a hybrid three-pole wiggler; Fig. 3 shows a photograph of it. To reduce the heat load on the cryogenic system for the SCW, we employed a hybrid system consisting of a superconducting main pole and two normal-conducting side poles. The main pole of the SCW is cooled by a Gifford–McMahon cryocooler, which allows the SCW to be operated without liquid helium. The cryogen-free system ensures the long-term operational stability of the SCW.

In routine operation, the magnetic field of the SCW is excited to 4 T after beam injection and the energy is ramped from 255 MeV to 1.4 GeV. It takes about 15 minutes to excite the SCW to 4 T, after which multipole fields induced by the SCW are corrected for the dipole, normal and skew quadrupole, and sextupole components.

Beam Lifetime Study

An experimental investigation of the beam lifetime of the storage ring has been conducted using a beam scraper. The beam scraper consists of four movable rods that restrict the horizontal and vertical apertures and it is installed in the straight section LS6. We measured the beam lifetime as a function of rod position to investigate the contribution of the Touschek effect and residual gas scattering (elastic, inelastic, and bremsstrahlung) on the total lifetime. The dependence of the beam lifetime on the rod position provides information about the average pressure in the storage ring and the contributions of the different scattering processes to the total lifetime. Figure 4 shows the beam lifetime measured as a function of the horizontal rod position. The measured lifetime is analyzed by using cross sections for Touschek and residual gas scatterings [4] where the reduction in the momentum acceptance due to rod insertion is taken into account. The present method clearly reveals the contributions of the different processes to the lifetime. At present, the Touschek effect dominates the beam lifetime of the storage ring.

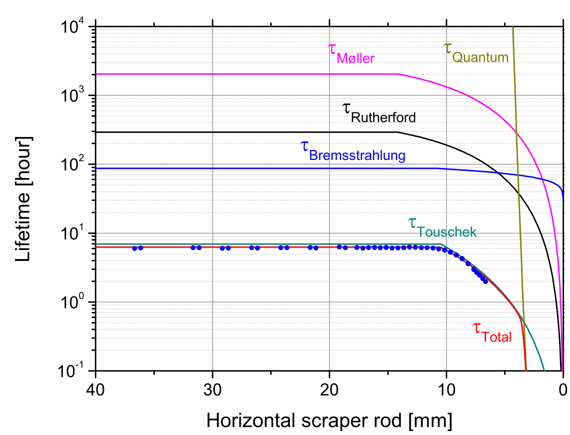

Figure 4: Beam lifetime measured as a function of the horizontal rod position and fitted lifetime curves. The beam current was about 300 mA during the measurement. Lifetime curves for Touschek and residual gas scatterings are obtained by assuming an N_2 equivalent pressure.

Laser Compton Scattering

A laser Compton scattering (LCS) experiment to generate high-flux gamma-rays with a maximum energy of 3.5 MeV is currently being conducted [5]. Since the energy acceptance of the storage ring far exceeds the LCS gamma-ray energy, the LCS experiment can be performed without reducing the beam lifetime. LCS gamma-rays are produced by a head-on collision between the 1.4 GeV beam and a CO_2 laser beam with a wavelength of 10.6 μm. The interaction region between the electron and laser beams is the straight section LS8 used for beam injection (see Fig. 1). The gamma-ray flux at the detector position was designed to be 3×10^7 photons/s without a collimator when the beam current is 300 mA and the laser power is 10 W.

Figure 5 shows a typical LCS gamma-ray spectrum measured by a BGO scintillation detector. We confirmed LCS gamma-ray generation without reducing the beam lifetime. Following the test experiments at a low beam current, gamma-rays were generated at a beam current of 300 mA and a laser power of 10 W. The gamma-ray flux was evaluated to be 6×10^6 photons/s, which is about 20% of the designed value [5]. In addition, LCS gamma-rays were used to measure the beam energy. The beam energy was determined with a relative uncertainty of 0.3% by analyzing the maximum energy edge of the gamma-ray spectrum [6, 7].

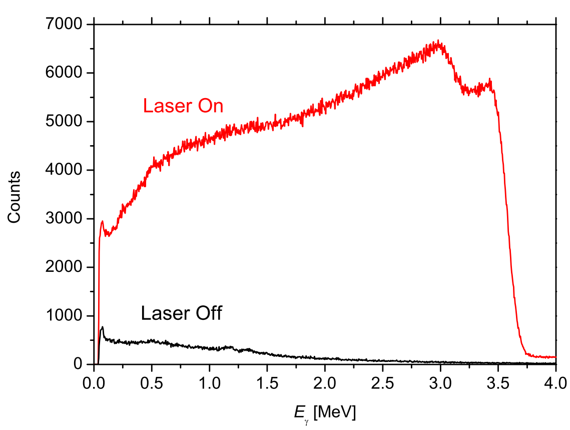

Figure 5: Gamma-ray spectra measured by a BGO scintillation detector (beam current: 2 mA; laser power: 1 W).

Improvements to the Control System

A simple PC-LabView based system that uses the EPICS channel access as a communication protocol is used to control the SAGA-LS accelerators. The SAGA-LS control system has been continuously developed and improved since the early stages of machine commissioning [8]. Except for the timing system, all the accelerator components are presently controlled by PCs. Recently, a multipurpose client program and a communication interface between the accelerator control system and the radiation interlock system have been developed [9]. The newly developed system reduces the operation procedures for machine control, which simplifies the daily operation of the accelerators.

Other Developments

We developed a feed-forward correction system to suppress the emittance coupling variation [10] induced by operation of the undulators. Utilizing the correction system, ID parameters such as the gap and phase of magnet arrays are fully controlled by beamline users during user time. The interaction between the electron beam and the crystal has been investigated by using the injector linac [11]. Generation of parametric X-rays and electron channeling were successfully performed in September 2010 and February 2011, respectively. We have commenced developing a multipole magnet for precise correction of the multipole fields of the SCW. This magnet consists of 12 poles and was manufactured in FY2010. Magnetic field measurements will be performed on a test stand.

SUMMARY

The SAGA-LS facility has been stably providing synchrotron light with an annual failure rate of the order of 10^{-3} over the last two years. The 4-T SCW installed in 2010 has been routinely operated for user time. The beam lifetime has been investigated and LCS gamma-rays have been generated. The control system has been improved to simplify machine operation. A feed-forward correction system has been developed to permit full control of the ID parameters during user time. In addition, an experimental study of the interaction between the beam and the crystal and development of a multipole magnet are currently in progress.

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