COMMISSIONING OF SAGA LIGHT SOURCE

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Abstract

The SAGA Light Source (SAGA-LS) consists of a 250-MeV electron linac injector and a 1.4-GeV storage ring with eight double-bend (DB) cell and eight 2.93-m long straight sections. The DB cell structure with a distributed dispersion system was chosen to produce a compact and low cost ring of 75.6-m long circumference.

The machine installation began on September 29, 2003. The ring magnets of steel laminated structure, vacuum chambers made of aluminium alloy, pumping systems and temperature controlled cooling water systems for the linac accelerating tubes etc. were installed in March, 2004. The 250-MeV linac, a 499.8-MHz ring rf damped cavity, rf klystrons, a beam transport system for injection and their controlled systems were installed in July, 2004.

The commissioning began on August 25, 2004. The first 250-MeV beam was accelerated on September 29. The beam size is 1-mm in diameter and the energy spread is 0.9 % (FWHM). The first synchrotron light of stored beam was observed on November 12. Energy ramping process up to 1.4-GeV was performed in a minute.

INTRODUCTION

The SAGA-LS is the first synchrotron light source designed, constructed and operated by the local government, Saga Prefecture, for the promotion of scientific researches and industrial applications in Kyushu area. The layout of the Saga 1.4-GeV storage ring, the 250-MeV linac injector and the two-color IR-FEL facility is shown in Figure 1.

The building has been constructed in fall of 2002 in Tosu, Saga Prefecture. Tosu is 25 km north-east of Saga and 25 km south of Fukuoka. The machine installation began on September 29, 2003. The ring magnets of steel laminated structure, vacuum chambers made of aluminium alloy, pumping systems and temperature controlled cooling water systems for the linac accelerating tubes etc. were installed in March, 2004.

The DB cell structure with a distributed dispersion system was chosen to produce a compact and low cost ring of 75.6-m long circumference [1].

The linac injector consists of the 250-MeV linac, a beam transport system, a septum magnet and four kickers for injection and beam storage. The linac injector, a 499.8-MHz ring rf damped cavity [2], rf klystrons and their control systems were installed in the end of July. The commissioning of the linac injector began on August 25, 2004.

After adjustment of 2-μs flat rf pulse and rf ageing, the first 250-MeV, 1-μs macropulse beam was accelerated at 1pps on September 29, since rf filling time is 1-μs. Cherenkov light in a water bath induced by the linac beam was observed for easy adjustment of rf phase at each accelerating tube to get high electron energy. The beam size is 1-mm (2σ) in diameter and the energy spread is 0.9 ~1.0 % (FWHM). The first revolution of 250-MeV beam around the ring took place October 22. The first synchrotron light of stored beam was observed on November 12. Energy ramping process up to 1.4-GeV was performed in a minute.

250-MEV LINAC INJECTOR

The installation of the linac injector began on May 26, 2004. The linac injector consists of a 6-MeV buncher [3], six Electrotechnical Laboratory type accelerating tubes (AT1~AT6) and beam transport systems from the buncher to succeeding accelerating tubes and to a septum magnet. The accelerating tubes with a length of 2.93 m are of linearly narrowed iris type to prevent beam blow up effect [4]. These were manufactured, installed and adjusted by Mitsubishi Electric Corp., IDX Corp., ULVAC Corp. and SAGA-LS.

The buncher consists of a 120-keV thermionic triode gun, a 714-MHz prebuncher, a 2856-MHz standing-wave type buncher (SWB). The electron gun with a dispenser cathode (EIMAC Y646B) and the grid pulser emits 0.6-ns (FWHM) pulses of 2.3 A at 22.3125 MHZ or 89.25 MHz. The grid pulser was supplied by Kentech Instruments, Ltd., UK. The 714-MHz prebuncher is made of stainless

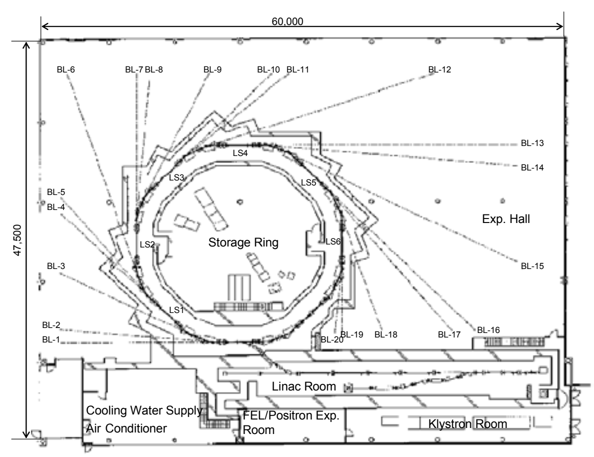

Figure 1: Layout of the 1.4-GeV Saga storage ring, the 250-MeV linac injector and the two-color IR-FEL facility.

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steel to reduce wake-field effects induced by the 0.6-ns pulse of 2.3 A from the gun. The 714-MHz is chosen to meet a 10-cm long pulse beam accelerated by the 120-kV DC voltage and the 0.6-ns grid pulser. The rf source for the prebuncher is a 714-MHz semiconductor type 25-µs flat top pulse supplied by Nihon Koshuha Corp. of which phase stable part of the latter half is used for beam bunching.

The 2856-MHz SWB consists of nine cavities made of copper. The peak electric field is 14-MV/m for rf input of 2MW. In order to reduce space-charge effect in electron bunch, a drift space from the prebuncher to the SWB is designed to be around 40cm. The axial field distribution from the gun to the SWB has been designed so as to set a radius of the electron bunch to be constant from the prebuncher to the SWB. These pulses are compressed to 60 A ×10 ps by the prebuncher and buncher. The design concept is the same as that of the Free Electron Laser Research Institute (FELI) linac [4].

A 2856-MHz klystron (Toshiba E3729, 36 MW) is used for the buncher and the first two accelerating tubes (AT1 and AT2). At injection mode, a 2856-MHz klystron (Toshiba E3712, 88 MW) is used for the following four accelerating tubes (AT3, AT4, AT5, and AT6). The rf waveguides, rf phase shifters and rf drivers for klystrons were supplied and installed by Nihon Koshuha Corp. Cherenkov light in water induced by the linac beam was observed for easy adjustment of rf phase at each accelerating tube to get the highest electron energy.

The linac is operated in two modes; 1-µs macropulse 250-MeV electron beam operation for ring injection and 10-µs macropulse 28~38-MeV electron beam operation for two-color FEL project [5]. The stable and flat klystron pulse modulators were supplied by Nissin Electric Corp. [6].

The beam transport system for a 20º septum magnet consists of a 40º Bending magnet following a 5-m long QDQF-QFQD beam transport line, a 20º bending magnet following a 1.5-m long beam transport line including a QF singlet and steering magnets [7].

The five current monitors with amorphous core are set at the outlet of the 6-MeV buncher, at the outlet of the first accelerating tube, at the end of the 250-MeV linac, at the end of a 5-m long beam line following a 40º bending magnet and at the inlet of a 20º septum magnet. The electron beam spectra are measured with the 40º bending magnet and the current monitor at the end of the 5-m long beam line. The beam slit is 22mm φbeam duct. A typical injection beam spectrum is shown in Figure 2.

The electron beam consists of a train of several ps microbunch of 0.45-nC at the outlet of the 6-MeV buncher and a train of several ps microbunch of 0.1-nC at the inlet of the septum repeating at 22.3125 MHz or 89.25 MHz.

The 1-µs macropulse operation mode at the 250-MeV is for electron injection and an electron charge of 2-nC (0.1-nC × 20 pulses) is injected to the septum magnet per second. The RF frequencies of the linac accelerator tube and the ring cavity are selected to be 2856 and 499.8-MHz to achieve time overlap on the micropulse of the IR-FEL and the SR so as to do pump-probe experiments [5].

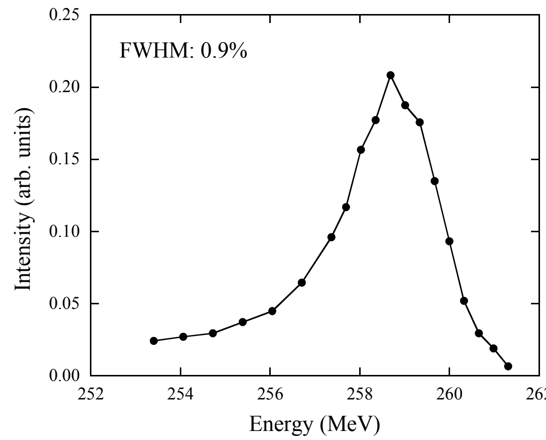

Figure 2: Typical injection beam spectrum.

SAGA 1.4-GEV STORAGE RING

The C-shaped dipoles, symmetric closed yoke type quadrupoles, sextupoles, and magnet supports with spherical rod end bearings for precise adjustment were supplied and installed by Budker Institute of Nuclear Physics and Kawasaki Heavy Industries Ltd. The symmetric closed yoke consists of an upper and a lower half bolted vertically with each other for setting their vacuum chambers. The C-shaped dipole cores are fabricated from A94068-100 steel laminations 1.0mm thick. The magnet cores of quadrupoles and sextupoles are from A94068-50 steel laminations 0.5mm thick. The laminations are compressed and glued with a packing factor no less than 97 %. The main coils are made of water-cooled hollow copper conductor insulated with fiberglass and vacuum impregnated with epoxy. Trim coils and power supplies for a 1~2% field adjustment are prepared for the dipoles and quadrupoles. Steering coils are built in sextupole magnets. The magnet control system is discussed elsewhere [8]. The 499.8-MHz rf damping cavity with SiC beam duct and the 90-kW rf power supply were supplied and installed by Toshiba Corp. The rf voltage is 500 kV for a 90-kW rf power [9].

The vacuum chambers except for long straight section made of aluminium alloy and pumping systems were supplied and installed by IHI Corp. and ULVAC Corp. At the present, total pumping speeds of sputter ion pumps and titanium getter pumps are 8800-l/s and 48000-l/s, respectively. Vacuum pressures were measured with twenty four cold cathode gauges mounted at the sixteen bending magnet chambers and eight long straight sections. Average residual pressure at the bending magnets is 1.9×10^{-8} Pa. Vacuum chambers for eight long straight sections were tentatively made of stainless steel and therefore average residual pressure is of the order of 9×10^{-8} Pa. After beam storage, energy ramping process was easily performed up to 1.4-GeV in a minute, since all magnets are made of laminations of 1mm or 0.5mm thick silicon steel. At the first energy ramping process, the pressure rose with the stored beam current (1.0×10-6 Pa/mA at 1.4 GeV). The rf damped cavity with SiC beam-duct is used for stable storage of high-current beam.

The lattice has been designed by relaxing the constraint of zero-dispersion in the long straight section as MAX-II. For various dispersions, the rms electron beam sizes are calculated from the electron beam emittance ε_x, the horizontal and vertical beta functions, (β_x and β_y) and the relative momentum spread $\Delta p/p$, assuming 1 % coupling ratio in the vertical direction. The horizontal beam size is minimized for a dispersion $\eta_x = (\varepsilon_x\beta_x)^{1/2}/(\Delta p/p)$. The minimum value is close to $2^{1/2}\ \eta_x\ (\Delta p/p)$. The beam emittance is also minimized by distributing dispersion. However, detuned optics with a larger emittance is used for commissioning. For instance, measured tune values are $\nu_x = 5.233$ and $\nu_y = 2.825$. Table 1 shows main parameters of the Saga ring magnets and stored beam.

Eight 2.93-m long straight sections are used for six insertion devices (IDs), a septum magnet, four kickers, various type beam monitors and an RF cavity. The available lengths for IDs are 2.4 m × 5 and 1.6 m × 1. In total, twenty beam ports are constructed and more than twenty beam lines can be installed. All vacuum chambers are made of aluminium alloy except for eight long straight sections. Inner size of the chamber at the quadrupoles and sextupoles is 100 mm wide and 40 mm high because

Table 1: Main parameters of the Saga storage ring magnets and stored beam.

Electron beam energy	0.2~1.4 GeV	
Beam current & life	300 mA & 5 hs at 1.4 GeV	
Circumference	75.6 m	
Lattice	DB(A) × 8 (eight fold symmetry)	
Straight sections	2.93 m × 8	
Emittance (nm-rad)	15	[35 (7.5-T wiggler)]
Tunes (ν_x,ν_y)	6.796, 1.825	[6.796, 1.825]
Momentum compaction	0.008074	
Energy sprea	0.000672	[0.00079]
Radiation loss (keV)	106	[123]
RF frequency (MHz)	499.8	
RF power & field	90 kW & 500 kV	
Harmonic number	126	
Bunch length σ(mm)	8.8	[10.35]
Beam sizes at straight section (coupling = 0.01) at η=0.62		
σ_x (μm)	580	[680]
σ_y (μm)	34	[52]
Injection energy (MeV)	262	
Dipoles & number	11.25^o edge focusing & 16	
Radius & field	3.2 m & 1.459 T	
Number of quadrupoles	40 (16QF1, 16QD1, 8QF2)	
Length (m)	0.2(QF1), 0.2(QD1), 0.3(QF2)	
Max. gradient(T/m)	27(QF1), 27(QD1), 25(Qf2)	
Number of sextupoles	32 (16SF, 16SD)	
Length (m)	0.10(SF), 0.14(SD)	
Max. gradient(T/m^2)	150	

the damping time is of the order of 1 second due to the 250-MeV injection. The calculated dynamic aperture [10] for a stored beam is the same as the physical aperture of the vacuum chamber.

We are planning to install a superconducting wiggler [11], two permanent magnet undulators, and five beam lines for soft X-ray scanning and X-ray imaging microscopes, for XAFS and crystallography.

The wiggler is to shift synchrotron radiation spectrum to hard X-ray region (ε_c = 9.8 keV at 7.5T) and a permanent magnet undulator (λ_u = 5 cm, K=1.2, N=49 photon energy 200 eV) provides high intensity photons of 4.8×10^{15} [photons/s·(0.1mrad)$^{-2}$·(1%bw)$^{-1}$] [12], since the rms irradiation angle of the undulator photons is 0.052 mrad.

The wiggler is a three-pole planar type like the 7-T wiggler of the Louisiana State University, Center of for Advanced Micro-structure and Devices [13]. The insertion effect of a 7.5T wiggler for the beam parameters effect is shown in Table 1 as key parenthesis.

SUMMARY

The commissioning of the SAGA-LS began on August 25, 2004. The first 250-MeV beam was accelerated on September 29, 2004. The beam size is 1-mm in diameter and the energy spread is 0.9~1.0 % (FWHM). The first revolution of 250-MeV beam around the ring took place October 22. The first synchrotron light of stored beam was observed on November 12. Energy ramping process up to 1.4-GeV was performed in a minute.

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