THE 250-MEV LINAC INJECTOR OF SAGA 1.4 GEV LIGHT SOURCE

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Abstract

The SAGA third-generation light source is the first light source which is constructed and operated before the end of 2004 in Tosu by Japanese local government, Saga Prefecture. The SAGA light source (SAGA-LS) consists of a 250-MeV linac injector and an eight-hold symmetry 1.4-GeV storage ring with eight double-bend (DB) cell and eight 2.93-m long straight sections. The 250-MeV linac beam is used for injection and a 40-MeV linac beam branched of from the first accelerator tube (AT-1) is proposed to be used for infrared (IR) free electron laser (FEL) generation. We report recent design study on the 250-MeV linac injector, beam position monitors and new radio-frequency (rf) systems for the linac and the 1.4-GeV storage ring to synchronize the IR-FEL macropulse with the SR macropulse for new pump-probe applications as much as possible.

1. INTRODUCTION

The Saga storage ring and the 250-MeV electron linac are constructed and operated before the end of 2004 in Tosu by a local Government, Saga Prefecture. The ring has eight double-bend (DB) cell and 2.93-m long straight sections. The DB cell structure with a distributed dispersion system was chosen to produce a compact design because the budget and space are limited. The circumference is 75.6 m and the emittance is 15 nm-rad at 1.4 GeV. Six insertion devices including a 7.5-T wiggler can be installed. The critical energy of synchrotron radiation (SR) from the bending magnet and the wiggler are 1.9 keV and 9.8 keV, respectively. Recently we have reported design study of SAGA-LS [1], lattice selection [2], control system [3] and a proposed two-color IR-FEL facility [4] elsewhere.

After one-year ring operation, we expect that the stored beam current and its lifetime of the ring will be 300-mA at 1.4 GeV and 5 hours and that the linac beam can be used for two-color IR-FEL generation during the interval of 5 hours between injections. Recently new pump-probe applications were proposed such as combination of the SR based X-ray spectromicroscopy of 500 nm spatial resolution and the molecular bond-selective excitation by the IR-FEL [5], and the rf frequencies of the ring cavity and the linac accelerating tube are selected to be 499.8-MHz and 2856-MHz, respectively, to synchronize the IR-FEL macropulse with the synchrotron radiation (SR) macropulse as much as possible.

In this paper, we report the Saga linac, beam parameters at injection and oscillation, beam position monitors, the rf frequency system and rf power level for new pump-probe applications, and recent design study on the two-color IR-FEL facility.

2. SAGA LINAC

The Saga linac consists of an FELI type 6-MeV injector [6] and six Electrotechnical Laboratory (ETL) type accelerating tubes [7]. The accelerating tubes with a length of 2.93 m are of linearly narrowed iris type to prevent beam blow up effect.

The schematic layout of the Saga linac and the two-color IR-FEL facility is shown in Fig.1. The new rf frequency system and power level for the linac accelerating tube and the ring cavity is also shown in Fig.1. The frequencies of 499.8-MHz and 2856-MHz(89.25-MHz × 32) are selected for the ring cavity and the linac accelerating tube, respectively, to synchronize the IR-FEL macropulse with the synchrotron radiation (SR) macropulse as much as possible for new applications. The 89.25-MHz signals for the linac accelerating tube are generated from a 499.8-MHz signal generator for the ring cavity by a synchronous system including a frequency divider.

The injector consists of a 120-keV thermionic triode gun, a 714-MHz prebuncher and a 2856-MHz standing wave type buncher. The gun with a dispenser cathode (EIMAC Y646B) usually emits 600-ps (FWHM) pulses of 2.3 A at 22.3125 MHz or 89.25 MHz. The grid pulser is supplied by Kentech Instruments, Ltd., U.K.. These pulses are compressed to 60A × 10ps by the prebuncher and the buncher. The rf source for the prebuncher is a 714-MHz semiconductor type 25-μs macropulse rf source, of which the latter phase stable part is available for beam bunching. A 2856-MHz klystron (Toshiba E3729, 36 MW) is used for the buncher and the first two accelerating tubes (AT1~AT2).

The linac is operated in two modes; 1-μs macropulse 262-MeV electron beam operation for the storage ring injection and 9-μs macropulse 28~36-MeV electron beam operation for two-color FEL oscillation. At the injection mode, a 2856-MHz klystron (Toshiba E3712, 88 MW)

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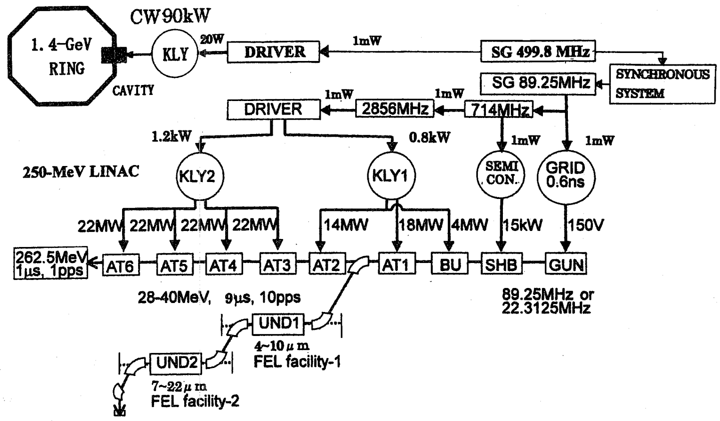

Fig.1 The schematic layout of the Saga-LS and rf systems for 1.4-GeV storage ring and 250-MeV linac.

is used for the following four accelerating tubes (AT3~AT6). At the FEL mode, the 9-μs macropulse electron beam is accelerated up to 40-MeV at the end of the AT-1. Table 1 shows design parameters of the Saga linac.

The electron beam consists of a train of several ps, 0.6-nC microbunch repeating at 22.3125 or 89.25-MHz like the former FELI linac [8]. The 1-μs macropulse operation mode at the 262-MeV is for electron injection and an electron charge of 12-nC (0.6-nC × 20 pulses) is injected to the storage ring per second. The beam energy can be ramped from 262-MeV to 1.4 GeV in a half minute after beam storage, because all storage ring magnets are made of laminations of 1mm or 0.5mm thick steel. The rf frequencies of the linac accelerator tube and the ring cavity are selected to be 2856 and 499.8-MHz, respectively, to synchronize the IR-FEL macropulse with the SR macropulse as much as possible for new pump-probe applications such as combination of the SR based X-ray spectro-microscopy of 500 nm spatial resolution and the molecular bond-selective excitation by the IR-FEL. Table 2 shows beam parameters of the Saga linac at injection and FEL application.

3. BEAM POSITION MONITORS

Screen monitors are installed at the inlet and outlet of every accelerating tube and quadrupole doublet. The interval of screen monitors is 3.81m from AT-2 to AT-6. Each screen monitor is an alumina plate and has a 2-mmφ aperture where the linac beam can pass through. The center of each 2-mmφ aperture is aligned with the fiducial line. The iris center of the accelerating tube is also aligned with this line. The almina plate is set at 45° to the line but the 2-mmφ aperture is bored in parallel to the line. A CCD camera with a zoom lens is set at horizontal side of the almina plate and the fluorescent light from the almina is observed with it. The merit of the 2-mmφ aperture is that the linac beam is focused to be less than 2-mmφ so as to pass through succeeding one or

Table 1. Design parameters of the Saga linac.

Gun	Thermoionic triode	(EIMAC 646B)
	Injection energy	120keV
	Trigger pulse	150V-0.6ns pulse (22.3125MHz or 89.25MHz)
Prebuncher		
	Frequency	714MHz
	Q-value	~2000
	Peak field	80kV
Buncher		
	Frequency	2856MHz
	Energy	~5MeV for 1MWrf

Table 2. Beam parameters of the Saga linac.

Electron energy at injection	262.5 MeV
Energy spread (FWHM)	0.5 %
Peak current	130 A
Beam radius	0.5 mm
Normalized emittance	25 $\pi 10^{-6}$ m-rad
Micropulse charge	0.6 nC
Micropulse duration	4 ps
Micropulse separation	44.8 ns
Macropulse	~1 μs
Macropulse repetition rate	1 Hz
Electron energy at FEL application	~40 MeV
Energy spread (FWHM)	~1 %
Peak current	60 A
Beam radius	0.5 mm
Normalized emittance	25 $\pi 10^{-6}$ m-rad
Micropulse charge	0.6 nC
Micropulse duration	6 ps
Micropulse separation	11.2 ns
Macropulse	~9 μs
Macropulse repetition rate	10 Hz

two screen monitors, since the normalized emittance of the Saga linac beam is estimated to be 25πmm-mrad. Further, four screen monitors are installed in S-type BT line (9) for electron energy spectrum measurement. The beam size and position are adjusted to pass through a narrow slit of a septum magnet. The first bending magnet of each S-type BT line and the water absorber are used as an energy spectrometer.

Two Al-foil optical transition radiation (OTR) beam profile monitors [10] will be installed in each narrow vacuum chamber of the two-color IR-FEL facility. Each Al foil has a 1-mmφ aperture. The S-type BT line can focus about 80-90% of the electron beam to pass through the aperture. The two-profile monitor emittance measurement method with the OTR beam profile monitor is useful for its simplicity and short time for data acquisition along the linac beam line.

4. TWO-COLOR IR-FEL FACILITY

The Saga two-color IR-FEL facility consists of two sets of undulators and optical cavity in series along a 40-MeV beam line. The configuration is similar to the two-color IR-FEL facility at the FELI [11]. However, as available electron macropulse length is reduced from 12μs to 9μs because of the limited budget for SAGA-LS project, the rise time of IR-FEL macropulse should be shortened. Therefore, the first optical cavity length is designed to be a half of the FELI FEL-1 (6.72 m long) and the period number of the second undulator is designed to be more than 45 comparing to 30 periods of the FELI FEL-4 [12].

The Saga two IR-FEL facilities independently cover most useful wave length ranges of 4~10μm and 7~22μm for biomedical applications and semiconductor applications, respectively [4]. The Saga two IR-FELs independently oscillate in each electron macropulse and are delivered to two different user groups for the application experiment synchronising with SR X-rays. For this purpose, the new rf frequency system has been designed to increase the number of SR X-ray macro-pulse synchronising with the IR-FEL macropulse as much as possible. Although the design parameters of the two-color IR-FEL undulators and optical cavities were discussed for the 12-μs electron macropulse in the previous paper [5], revised parameters for the 9-μs macropulse are given in Table 3. The cavity lengths of the first and the second facilities are 3.36 m and 6.72 m, respectively. The period number of the second undu-lator is increased to be more than 45 comparing to 30 periods of the FELI FEL-4 [12] to get higher net gain. The first facility covers 4~ 10-μm and the second facility can cover a broader range of 7~22-μm. Each optical cavity is a Fabry-Perot cavity which consists of two mirror vacuum chambers [10]. The spontaneous radiation and the IR-FEL beam are delivered with Au-coated mirrors through an evacuated optical pipe from the optical cavity to a diagnostic station on the same floor in the experimental hall of the SAGA-LS. Their macropulse shape, power and spectrum are simultaneously observed at the diagnostic station and the linac room.

Table 3. Main parameters of the two-color IR-FELoscillators.

	(4~10μm)	(7~22μm)
Electron energy	36~28MeV	
Undulator type	Halbach	Halbach
Undulator period (mm)	32	48
Period number	40	45
Gap length (mm)	15-24	24-36
K value	1.4-0.58	1.93-0.87
Permanent magnet	Nd-Fe-B	Nd-Fe-B
Cavity type	Fabry-Perot	Fabry-Perot
Cavity length (m)	3.36	6.72
Mirror curvature (m)	2.0	3.555
Material of mirror	Au/Cu	Au/Cu
Extraction	Hole	Hole
Aperture dia. (mm)	1.5	2.5
Window for FEL guide	ZnSe	KRS-5

5.SUMMARY

The Saga linac for the 1.4-GeV storage ring is designed and operated in the end of 2004. The new rf frequency system has been designed to increase the number of SR X-ray macropulse synchronising with the proposed IR-FEL macropulse as much as possible for new pump-probe applications. Beam position monitors for the Saga linac and the beam transport lines and recent design study on the two-color IR-FEL facility are reported.

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