20.8MHZ ELECTRON GUN SYSTEM FOR AN ENERGY RECOVERY LINAC FEL AT JAERI

N. Nishimori*, R. Hajima, N. Kikuzawa, E.J. Minehara, R. Nagai, M. Sawamura,
JAERI, Ibaraki, Japan

Abstract

A high power Free-Electron Laser (FEL) driven by an energy recovery linac (ERL) has been developed in the Japan Atomic Energy Research Institute (JAERI) FEL facility. The repetition rate of the electron micropulses from the electron gun has been doubled from 10.4 MHz to 20.8 MHz for increase of the FEL power. The gun is based on a thermionic gridded cathode driven by a grid pulser and is operated at 230 kV. The doubling was realized by installing a new grid pulser developed at the Budker Institute for Nuclear Physics. The measured electron micropulse length is 0.6 ns at 0.54 nC. The peak current fluctuation is 1.2 % rms and the time jitter is 13 ps rms. The transversal emittance is 20 mm-mrad rms.

INTRODUCTION

In recent years, a Free-Electron Laser (FEL) oscillator has been developed as a high-power and wavelength-tunable coherent radiation source for processing materials and studying applied and basic science [1]. For these purposes, a high-power FEL at far infrared wavelengths of 20–30 μm driven by a superconducting linac has been developed in the Japan Atomic Energy Research Institute (JAERI) FEL facility. The FEL power averaged over a macropulse length of 500 μs exceeded kilowatt in 2000 [2]. For further increase of the FEL power, a one turn ring has been added to the accelerator system, and JAERI-FEL is now driven by an Energy Recovery Linac (ERL) [3]. The ERL does not only serve as a driver for a high power FEL but can also produce a ultra-high brilliance x-ray radiation as alternative to storage ring synchrotron light sources [4]. A design study for such future ERL machines has been also performed in JAERI-FEL [5, 6].

The first lasing in JAERI-FEL with the ERL mode was achieved in 2002 [7]. At that time, the distance between successive two electron micropulses was 28.8 m corresponding to 10.4 MHz repetition, while the distance between optical cavity mirrors is 7.2 m. The effective optical cavity loss is twice larger than the loss per round-trip, since the FEL micropulse interacts with an incident electron pulse every two round trips. For increasing the FEL power as well as reducing the effective optical cavity loss, we have doubled the repetition frequency of the electron micropulses from the gun. The beam performances such as peak current, micropulse length and stability between micropulses are improved or remains unchanged. In this paper, the electron gun system for 20.8 MHz operation is described, and the electron beam performance from the gun is presented.

* nisi@milford.tokai.jaeri.go.jp

GRID PULSER

The gun in JAERI-FEL is based on a thermionic gridded cathode driven by a grid pulser (GP). A dispenser cathode of 8 mm in diameter , Y646B (EIMAC), is used. The cathode-grid gap is 0.1 mm. The DC high voltage of 230 kV is applied to the cathode-anode gap of 42 mm during normal operation. The accelerator tube is contained in a tank filled with $\mathrm{SF_6}$ gas with an absolute pressure of 2.5 atm. The grid pulser for 20.8 MHz operation has been designed and made by Kuper and Ovchar in the Budker Institute for Nuclear Physics (BINP) [8], where the electron gun is operated in CW mode at 22.5 MHz for generation of a high power FEL at a far infrared wavelength [9].

Figure 1 shows a block diagram of the 20.8 MHz GP system. The input reference signal from a master oscillator is amplified by a pulse generator (HP8116A) and is fed into the tank filled with $\mathrm{SF_6}$ gas. The reference signal is fed into a high voltage terminal through an optical fiber and drives a pulse amplifier composed of a step recovery diode (SRD) with two pulse switches and an energy accumulation line. When the first switch is switched on, the SRD behaves as a capacitor and is charged. When the first switch is switched off and the second switch is switched on, the SRD is discharged and a magnetic energy is accumulated in the accumulation line. When a sharp restoration of the resistance of SRD occurs, the energy accumulated in the line is sent to a cathode as a fast current [8].

The pulser DC bias and filament voltages are controlled by fiber optically coupled control links. The bias voltage can be adjusted from 0 to +100V. The filament voltage is 6.4 V during normal operation.

BEAM PERFORMANCE

The peak current and length of the electron micropulse are measured with a current transformer positioned 1m downstream from the gun cathode. The time resolution of the transformer is calibrated to be 0.53 ns. Figure 2 shows a typical shape of the micropulse analyzed with a digital oscilloscope (Tektronix TDS684). The measured peak current as a function of the micropulse length is plotted as an open circle in Fig. 3. These data were obtained by varying the pulser DC bias voltage. Open squares are data obtained in a similar measurement when the previous GP was used

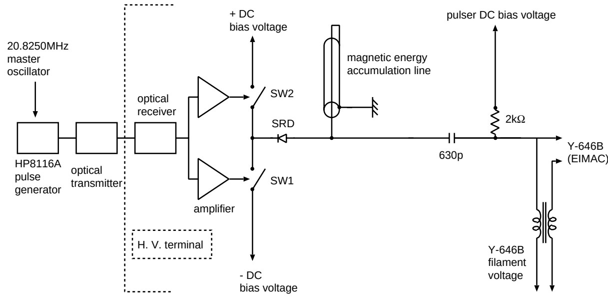

Figure 1: A block diagram of the 20.8 MHz grid pulser system

[10]. The previous pulser is similar to designed by Koontz [11]. The peak current is twice higher than before for the same micropulse length.

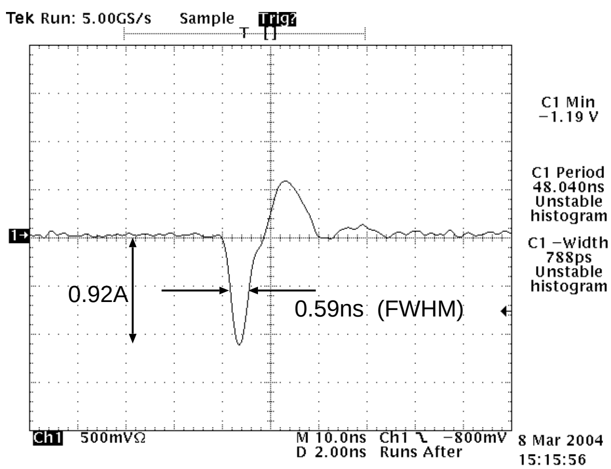

Figure 2: A typical shape of an electron micropulse measured with a current transformer. The length of 0.59 ns is obtained after correction of the time resolution of the transformer of 0.53 ns.

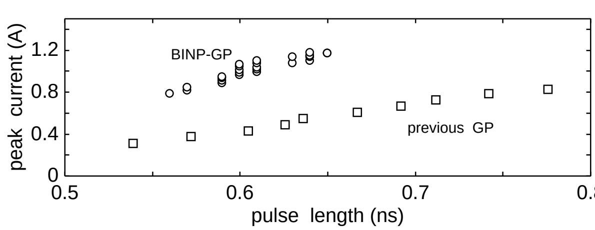

Figure 3: The peak current as a function of the micropulse length. Open circles are data with the present gun driven by BINP GP. Open squares are data obtained with the gun driven by the previous GP [10].

The stability of electron micropulses such as the peak current fluctuation and time jitter is also measured with the same current transformer as used for the measurement of the pulse length. The time interval between two successive micropulses $T_1 - T_2$ measured over a duration of 10 minutes is shown in Fig. 4, where T_1 and T_2 are arrival times of the two successive pulses. The standard deviation of the measured interval is $\sqrt{\langle (T_1 - T_2)^2\rangle - \langle T_1 - T_2\rangle^2} = 18$ ps. The standard deviation of the jitter between each micropulse and reference signal is given by $\sqrt{\langle (T_{1,2} - R)^2\rangle} = 13$ ps, since $\sqrt{\langle (T_1 - T_2)^2\rangle - \langle T_1 - T_2\rangle^2} = \sqrt{2\langle (T_{1,2} - R)^2\rangle}$ [10]. Here R represents reference time of 20.8250 MHz. The peak current fluctuation is 1.2 % rms, as shown in Fig. 5.

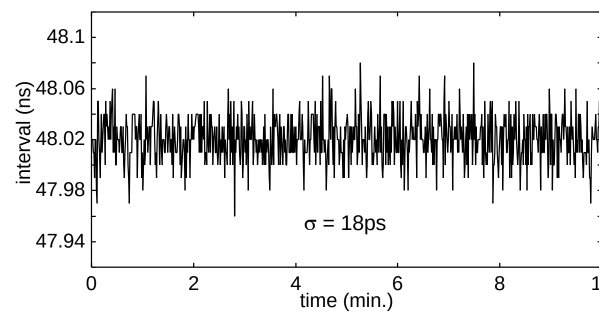

Figure 4: Time interval between two successive pulses measured over a duration of 10 minutes. The average interval is 49.020 ± 0.018 ns.

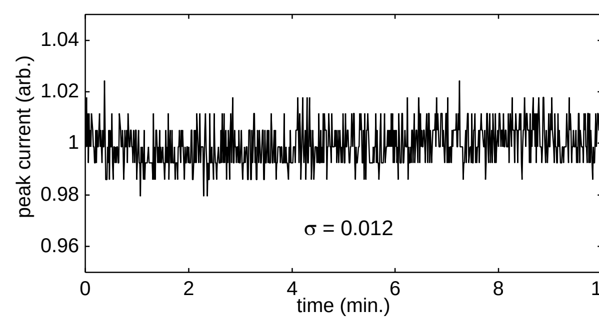

Figure 5: Peak current of the electron beam measured over a duration of 10 minutes. The peak current is normalized by the average value. The peak current fluctuation is 1.2 % rms.

We measured the transversal beam size at 640 mm downstream from the anode, varying the field of a solenoid placed at 270 mm from the anode. The anode size is 10 mm in diameter and the beam size at the anode is estimated to be 8 mm in diameter from E-gun computer simulation [12]. The effective length of the solenoid is 186 mm. The FWHM beam size is plotted as a solid circle in Fig. 6. The solid line shows a result calculated by TRACE3D [13] for normalized emittance of 20 mm-mrad. The calculation agrees well with the experiment. The open square shows the beam size when the previous GP was used. At that time, the normalized emittance was estimated to be 13 mm-mrad [10]. The emittance growth can be attributed to the increase of the peak current from the cathode, since the anode-cathode geometry optimized for the previous peak current has been used. We will try to optimize the geometry for the higher peak current produced from the present gun in the near future.

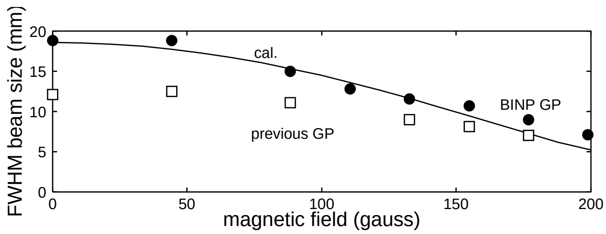

Figure 6: The FWHM beam size at 640 mm downstream from the anode as a function of the magnetic field of a solenoid, which is placed 270 mm downstream from the anode. The effective length of the solenoid is 186 mm. Solid circles are measured data for the present gun system. Open squares are data obtained for the previous gun system [10]. The solid line shows a result calculated by TRACE3D for normalized emittance of 20 mm-mrad.

The electron beam performance from the gun is listed in Table 1.

Table 1: Performance of the thermionic electron gun for JAERI ERL

Parameter	Measured
High Voltage	230 kV
Cathode	Y646B (EIMAC)
Cathode size	8 mm in diameter
Micropulse repetition	20.8250 MHz, 10.4125 MHz
Macropulse length	up to 1 ms
Macropulse repetition	10 Hz
Peak current	0.92 A
Micropulse length (FWHM)	0.59 ns
Bunch charge	0.54 nC
Time jitter (rms)	13 ps
Peak current fluctuation (rms)	1.2%
Normalized emittance (rms)	20 mm-mrad

PROSPECT FOR OPERATION AT HIGHER FREQUENCY

We have a plan to produce the electron micropulses from the gun at repetition rates of 41.6 MHz and 83.3 MHz in order to increase FEL power [6]. The BINP GP is a promising candidate for 41.6 MHz operation, but it will not be suited for operation at 83.3 MHz. This is because it generally takes more than 20 ns for charging and discharging such SRD as used in a grid pulser. At present, there are two candidates as a grid pulser for 83.3 MHz operation. One is a pulser used in Stanford university [14], which is composed of two SRD switches and can produce high voltage pulses with short micropulse durations at 100 MHz repetition rates in principle. The other is a pulser in which 1 GHz bandwidth RF amplifier with output power of 200 watt is used [15].

SUMMARY

We have successfully doubled the repetition rate of electron micropulses from the electron gun to 20.8 MHz by installing the grid pulser developed in BINP. The FWHM pulse length of each micropulse is 0.6 ns at 0.54 nC, and the longitudinal brightness is twice higher than before. On the other hand, the transversal emittance is 1.5 times larger than before. For suppression of the emittance growth, optimization of the cathode-anode geometry will be required. The timing jitter between each micropulse and the reference time of a master oscillator is 13 ps rms, and the peak current fluctuation is 1.2 % rms.

REFERENCES

[1] G.R. Neil et al., Phys. Rev. Lett. **84**, 662 (2000); http://www.jlab.org/FEL/

[2] N. Nishimori et al., Nucl. Instr. Meth., **A475**, 266 (2001); R. Hajima et al., *ibid* **475**, 270 (2001).

[3] R. Hajima et al., Nucl. Instr. and Meth. **A445**, 384 (2000); T. Shizuma et al., in Proc. EPAC-2000, 1074–1076; T. Shizuma et al., Nucl. Instr. and Meth. **A475**, 569 (2001); R. Hajima et al., “Development of an energy-recovery linac for a high-power FEL at JAERI”, in Proc. APAC-2004.

[4] http://erl.chess.cornell.edu/

[5] R. Nagai et al., in Proc. PAC-2003, 3443–3445; M. Sawamura et al., in Proc. PAC-2003, 3449–3451; R. Hajima, E.J. Minehara and R. Nagai., in Proc. FEL-2003, Tsukuba (2003).

[6] M. Sawamura et al., in Proc. PAC-2003, 3446–3448.

[7] R. Hajima, et al., Nucl. Instr. and Meth. **A507**, 115 (2003).

[8] E.A. Kuper and V.K. Ovchar, in Proceedings of the Third Symposium on APR (JAERI-Conf 2002-008), 165 (2002).

[9] B.A. Baklakov et al., Nucl. Instr. Meth., **A470**, 60 (2001).

[10] N. Nishimori et al., in Proc. EPAC-2000, 1672–1674; N. Nishimori et al., Nucl. Instr. Meth., **A445**, 432 (2000).

[11] R.F. Koontz, IEEE Trans. Nuclear Scien. **26**, 4129 (1979).

[12] W.B. Herrmannsfeldt, SLAC-Report-226, (1979).

[13] K.R. Krandall and D.P. Rusthoi, LA-UR-97-886, (1997).

[14] S. Talmadge et al., Nucl. Instr. Meth., **A285** 333 (1989).

[15] E. Minehara and K. Whitham, EPAC-98 1474–1476.