A THERMIONIC ELECTRON GUN SYSTEM FOR THE JAERI SUPERCONDUCTING FEL

N. Nishimori, R. Nagai, R. Hajima, T. Shizuma, E.J. Minehara, JAERI, Ibaraki, Japan

Abstract

A highly stable and bright electron beam source was developed at the JAERI Free Electron Laser (FEL) facility. Though the electron beam source is a traditional thermionic electron gun, improvement of the gun greatly contributed to recent high brightness electron beam production at the JAERI FEL. The high voltage of the gun is set to 230 kV to reduce space charge effects in the low energy region. The initial pulse width from the gun is 0.81 ns at 0.51 nC/pulse. The amplitude fluctuation in peak to peak is less than 1 %. The root mean square (rms) timing jitter is 23 ps.

1 INTRODUCTION

The JAERI FEL electron gun was originally designed and developed to produce a bright electron beam of 4 ns width and 100 mA peak current with a low transversal emittance about 10 mm-mrad from a very small cathode of 1-2 mm radius [1]. Realization of the original design was, however, found to be impossible and a rather lower brightness electron beam of the same width and peak current but from a larger cathode of 4 mm radius had been used for daily operation. With such a low brightness of the initial electron beam, the first lasing was successfully achieved at the JAERI FEL [2].

Although the FEL lasing was obtained, we still had a serious problem to be solved, which was large amount of beam loss during the transport. The average current of 6 mA should have been transported into the undulator from the view of totally available RF power, but the only 2 mA was transported even after the first lasing [3].

The beam loss was caused by insufficient performance of the gun: large fluctuation in pulse amplitude, timing jitter and broad pulse width. The circuit of grid pulser (GP) was, therefore, modified to shorten the pulse width and reduce the amplitude fluctuation and timing jitter. We have also paid attention to the spatial configuration of GP and a stainless steel cylinder in which the GP is mounted, because the timing jitter was found to be sensitive to floating capacitance between the GP housing and the cylinder.

In this report, improvement of GP circuit and a method to reduce the timing jitter caused by floating capacitance are described.

2 GRID PULSER

A unique feature of our electron gun is the high voltage (230 kV) of the accelerator tube. The high voltage gun is very useful to prevent the influence of space charge effects in the low energy region and also to produce the electron beam with low longitudinal and transversal emittances. In spite of the above advantage, the high voltage gun has a restriction that the accelerator tube must be installed in a chamber filled with the highly pressured SF_6 gas to avoid the discharge. The absolute SF_6 gas pressure is 2.5 atm at our case.

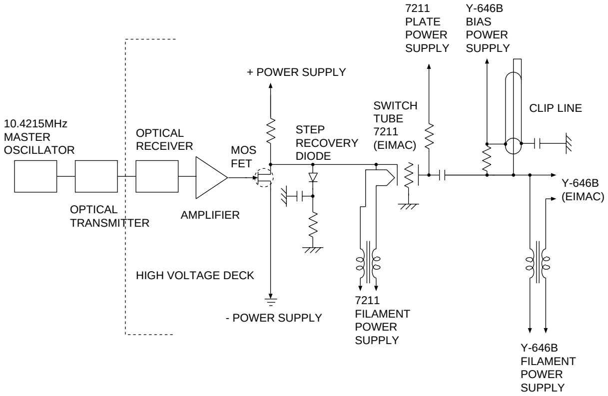

Figure 1: A block diagram of our grid pulser. The original model comes from ref. [4].

Fig. 1 shows the circuit diagram of our grid pulser which is similar to that of ref. [4] by R.F. Koontz. The input reference signal from the master oscillator is converted to the optical signal and fed to the high voltage deck through the optical fiber. If the gun is operated in the air, the optical fiber can be directly linked to the high voltage deck. In our case, though, the optical signal is attenuated too much at the optical connector attached to the SF_6 gas chamber, and the input signal for the GP circuit becomes very small. Therefore our GP circuit is very sensitive to the floating capacitance or other electrical error sources and we must assemble the GP circuit and mount it inside the accelerator tube very carefully.

Most essential components of the shorter pulse production are a step recovery diode (SRD) and a switch tube in our GP case. Then we made some trials and adopted optimum bias and plate voltages for the SRD and the tube, respectively.

One of main sources of the timing jitter was optical transmitter and receiver used to transmit the master oscillator signal to the high voltage deck from the ground level. They were replaced to ones designed for high speed applications, that is HFBR-1424 and HFBR-2426 (Hewllet Packard). After the replacement, the jitter due to optical fibers was successfully reduced to 0.1 ns from 1 ns. Even after the above modification, however, another jitter was observed. The whole timing of macro-pulses had slowly changed by about 0.3 ns against a reference signal in a long time range such as several seconds. After the careful investigation, it was found that the jitter had been induced from the fluctuation of the source voltage of the MOS FET. We could reduce the jitter in macro-pulses below 0.1 ns by inserting large electric field capacitor between the source of the FET and the ground level.

Fig. 2 shows the typical output signal of the GP, which should be adopted to the cathode, measured by an oscilloscope with a 400 MHz probe. The peak voltage should be higher than the observed value because of the limited bandwidth of the probe. However, it is a good measure to check the quality of the GP circuit such as pulse width, timing jitter and amplitude fluctuation before mounting it in the gun.

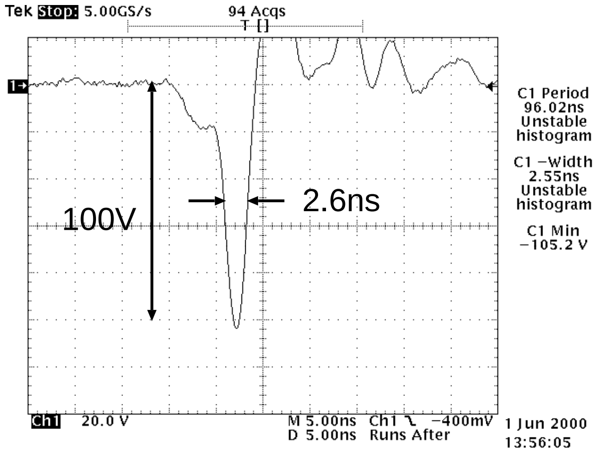

Figure 2: A output signal of our grid pulser measured by an oscilloscope. It is adopted to the cathode at a frequency of 10.4125 MHz for a macropulse duration up to 1 ms at 10 Hz.

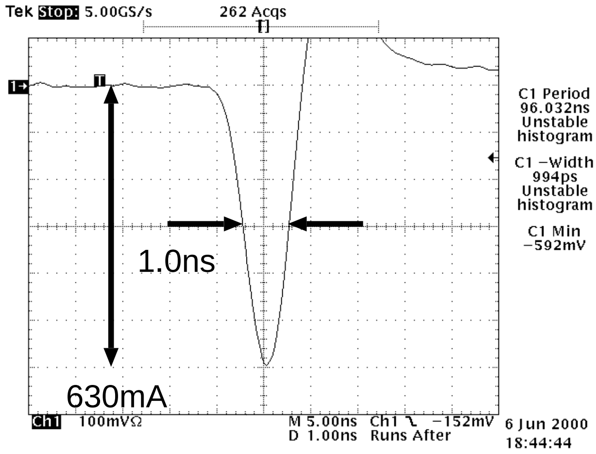

Figure 3: A current transformer signal just after the electron gun. The measured FWHM is 1.0 ns which includes 0.58 ns time resolution of the current transformer.

After the whole improvement of the GP, the electron beam signal shown in Fig. 3 was obtained by a current transformer just downstream the electron gun. As the measured FWHM pulse width (1.0 ns) includes time resolution of the current transformer (0.58 ns), the actual beam width is estimated to be 0.81 ns and the peak current about 630 mA. Accordingly, the bunch width was 5 times shortened compared with the original design value by improving the GP only.

The amplitude fluctuation and time jitter were also checked by monitoring the current transformer signal, but the stable beam with satisfied quality was not always obtained in this case. Therefore it was implied that another instability appeared after mounting the GP inside the gun.

3 TIME JITTER

The time jitter of the electron gun causes fluctuations of the micropulse arrival times in the undulator. The 10 fs difference in the undulator is equivalent to 3 μm difference of the optical cavity length. The FEL efficiency increases rapidly near the perfect synchronism of the optical cavity as seen in a theoretical study by N. Piovella et al [5]. In our case the 0.5 μm difference of the detuning length may bring severe decrease of the efficiency. Hence the time jitter must be reduced as small as possible.

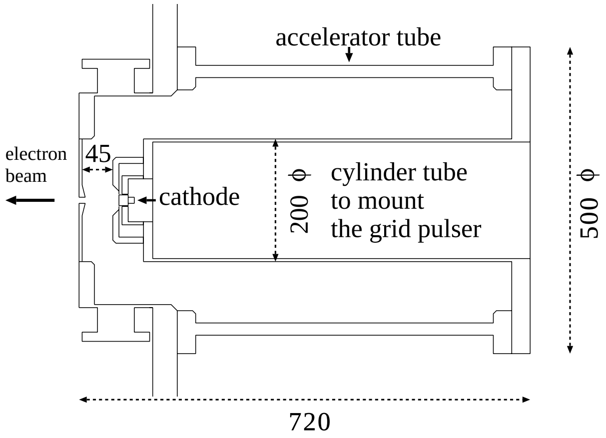

Figure 4: A block diagram of the accelerator tube.

While the time jitter in the GP circuit was almost completely reduced by methods described in Sec. 2, the another time jitter was observed after mounting the GP inside the cylinder tube in the accelerator tube. The structure of the accelerator tube is shown in Fig. 4. Probably the time jitter had been produced by the floating capacitance between the GP and the cylinder tube.

To reduce the time jitter, we repeated the beam test by operating the electron gun at 70 kV in the air. The time jitter seemed to be controlled by the capacitance between the cylinder tube and the back flange of the GP. Eventually, smaller time jitter was obtained by inserting a rubber sheet with thickness of 6 mm under the back flange of the GP and electronically connecting the top of the flange and the cylinder tube by an aluminum tape. Reproducibility of the jitter reduction by the above method is quite good in our case.

For a quantitative measurement of the time jitter, a simple method has been used in our laboratory. A recently available digital oscilloscope, for example Tektronix TDS684 (1GHz), has a function to measure the interval between micropulses and can easily send data to a personal computer via GPIB connector. Totally 500 data can be recorded for a 5 minutes measurement. The typical distribution of micropulse interval is shown in Fig. 5. Data are distributed around 96.04 ns which is ideal interval between successive micropulses. The rms of the distribution is 32 ps.

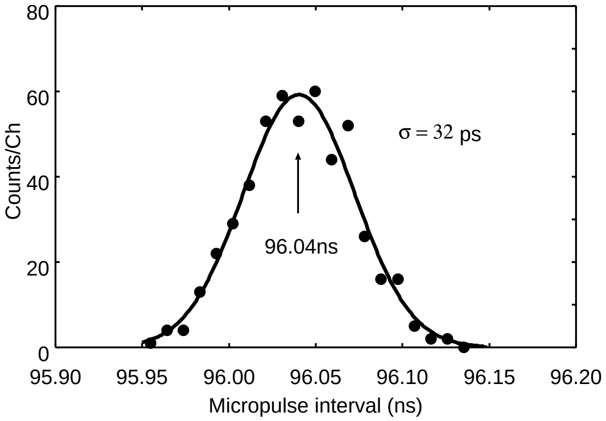

Figure 5: The distribution of time intervals between two successive micropulses. The data were obtained by a digital oscilloscope and recorded by a PC.

The timing jitter of electron pulses is usually defined as the jitter between each pulse and the reference signal, and can be obtained from the above measurement as follows. We define $T_{1,2}$ as arrival times of two successive electron beam pulses on the current transformer and $\Delta_{1,2}$ as differences of $T_{1,2}$ against the reference signal (R). Here R equals to 96.04 ns equivalent to the ideal interval between two successive pulses. The relation between the measured rms time jitter $\sqrt{\langle (T_1 - T_2)^2 \rangle}$ and the rms time jitter to the reference signal $\sqrt{\langle \Delta_1^2 \rangle}$ is obtained by following equations. Here we assume $\langle \Delta_1 \Delta_2 \rangle \simeq 0$ and $\langle {\Delta_1}^2 \rangle \simeq \langle {\Delta_2}^2 \rangle$.

$$\begin{aligned} \Delta_{1,2} &= T_{1,2} - R \\ \langle (T_1 - T_2)^2 \rangle &= \langle (\Delta_1 - \Delta_2)^2 \rangle \\ &\simeq 2\langle {\Delta_1}^2 \rangle \end{aligned}$$

The measured rms time jitter $\sqrt{\langle (T_1 - T_2)^2 \rangle}$ is $\sqrt{2}$ times larger than the time jitter against reference time $\sqrt{\langle \Delta_1^2 \rangle}$. Then the time jitter of electron gun is estimated to be 23 ps. Since at the JAERI FEL, the electron bunch in the undulator is more than 100 times compressed compared to the initial width, it is expected that the jitter is also small enough to get the satisfactory FEL performance.

Table 1: Performance of the thermionic electron gun for the JAERI superconducting linac driven FEL

Parameter	Measured
High Voltage	230 kV
Cathode	Y646B (EIMAC)
Cathode size	4 mm radius
Micropulse repetition	10.4125 MHz
Macropulse length	up to 1 ms
Macropulse repetition	10 Hz
Peak current	630 mA
Pulse width (FWHM)	0.81 ns
Bunch charge	0.51 nC
Time jitter (rms)	23 ps
Amplitude fluctuation	$< 1\%$
Normalized emittance	13 mm-mrad

4 SUMMARY

The JAERI FEL thermionic electron gun was improved to produce 230 keV electron beam with peak current of 630 mA and pulse width of 0.81 ns. The amplitude fluctuation and rms timing jitter were reduced less than 1 % and 23 ps, respectively. Especially the small timing jitter significantly contributed to recent achievement of the high extraction FEL efficiency near perfect synchronism of the optical cavity in our laboratory.

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