REDUCING BACK-BOMBARDMENT EFFECT USING THERMIONIC CATHODE IN IAE RF GUN

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Abstract

We have studied the improvement in electron beam macropulse properties from a 4.5 cell thermionic RF gun. Energy spectrum, macropulse duration and emittance, were measured with a 2 mm diameter slim thermionic dispenser cathode. The effect of a transverse magnetic field reducing back-streaming electrons was studied experimentally. The effect of non-flat RF power to compensate decreasing beam energy during macropulse due to a back-streaming electrons has also been studied.

INTRODUCTION

Compact and simple FEL machines will be important for various applications such as material processing, medical, bio science, and so on. A thermionic RF gun seems to be a good choice for such compact machines, because it is compact, easy to operate, and can produce high brightness electron beams. However, back-bombardment problem is limiting the macropulse duration.

We evaluated the effect of back-streaming electrons quantitatively, using an IR thermometer and numerical simulations[1,2], and the effect of transverse magnetic field on cathode surface quantitatively[3],[4]. Furthermore, we have estimated the effect of a combination of slim cathode and transverse magnetic field[5], and concluded that the combination is effective to suppress a temperature rise during macro pulse.

In this study, the effect of slim cathode and transverse magnetic field is studied experimentally. Effect of a non-flat RF input to compensate for decreasing beam energy during macropulse due to a back-bombardment effect is studied.

EXPERIMENTAL SETUP

Fig. 1 shows the experimental setup. A dispenser cathode of disk like shape with 2 mm diameter is mounted in the first half cell of our 4.5 cell RF gun. Initially the surface temperature of the cathode is kept at around 1020 °C. To reduce back-streaming electrons, transverse magnetic field is applied by a dipole magnet, which is located just behind the RF gun. The amplitude of the magnetic field on the cathode surface is 29 gauss.

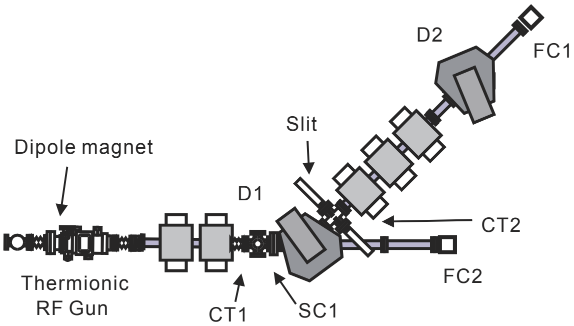

Fig. 1 Experimental setup

RF power fed to the RF gun is controlled by changing reactance in a pulse forming network (PFN) of modulator during operation by controlling remotely the reactors with stepping motors. By using the variable reactor system, we can modulate the RF amplitude up to about 20%.

The performance of the modulator is shown in table 1.

Table 1 Performance of the modulator NKLY-170-10u (manufactured by Nissin High Voltage)

Pulse voltage	170 kV
Pulse current	140 A
Pulse duration	10 μs
Maximum repetition	10 pps

Extracted beam properties are measured using current transformers (CT1 and CT2), Faraday cups (FC1 and FC2) and a fluorescent screen (SC1).

RESULTS

Beam properties

Effect of the slim cathode and the transverse magnetic field on the cathode surface was checked by measuring maximum electron macro pulse width after the bending magnet (D1). Results on a previous cathode with 6 mm diameter and on the slim cathode are shown in table 2.

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Table 2 Maximum macro pulse width

Condition	Pulse width
6 mmϕ without magnetic field $T_{cathode}$ = 1000 °C Pin=7.4 MW	<500 nsec
6 mmϕ with magnetic field $T_{cathode}$ = 1000 °C Pin=7.4 MW	500 nsec
2 mmϕ with magnetic field $T_{cathode}$ = 1020 °C Pin=5.0 MW	3.0 μsec

As shown in table 2, pulse width has been improved by using the slim cathode and the transverse magnetic field, but this is still not sufficient for the FEL experiment[6].

Emittance with / without the transverse magnetic field were also measured using the fluorescent screen (SC1) and quadrupole magnet (Q1). Projected images on the screen are analyzed with tomographic method using algebraic reconstruction technique[7,8]. The measured geometric emittance are shown in table 3.

Table 3 Beam emittance

Condition	Emittance
2 mmϕ without magnetic field	1.96 πmm-mrad
2 mmϕ with magnetic field	1.79 πmm-mrad

As shown in tables 2 and 3, the transverse magnetic field can reduce back-streaming electrons without changing beam emittance.

Energy spectra were also measured with / without the magnetic field. As shown in fig. 2, the energy spectrum is not changed by the transverse magnetic field.

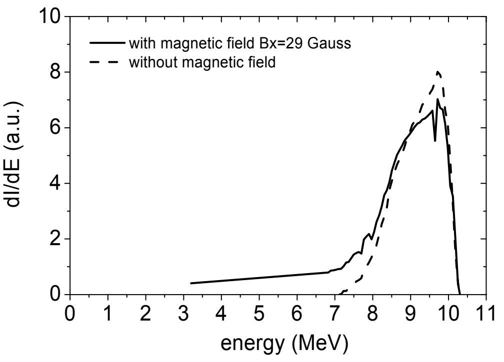

Fig. 2 Energy spectra

Energy compensation

For the FEL experiment, a macro pulse longer than 3 μsec will be required. For this purpose, we tried to compensate for the decrease of the beam energy during macro pulse by controlling input RF waveform.

When flat RF power was fed to the RF gun as shown in fig. 3 by open circles, peak energy decreases rapidly as shown in fig. 4 by dotted line. Thus, pulse width after the bending magnet (D1) is limited to about 3.0 μsec as shown in fig. 5 by open circles. To compensate the energy decrease, amplitude of the input RF power was modified as shown in fig. 3 by solid line. As shown in fig. 4, the peak energy was successfully kept constant up to 3.5 μsec. Pulse width is improved and peak current increases as shown in fig. 5 by solid line and total charge in a macropulse increases up to about twice that with the flat input. The effect of the amplitude modulation method is summarised in table 4.

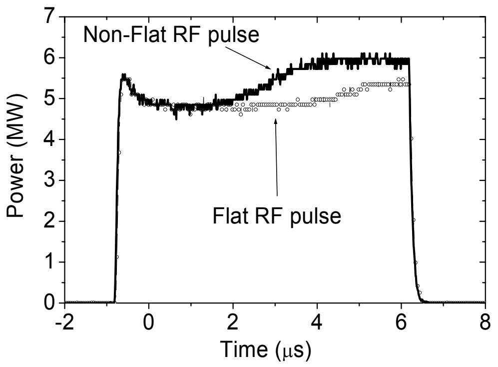

Fig. 3 Flat/non-flat RF power fed to the RF gun

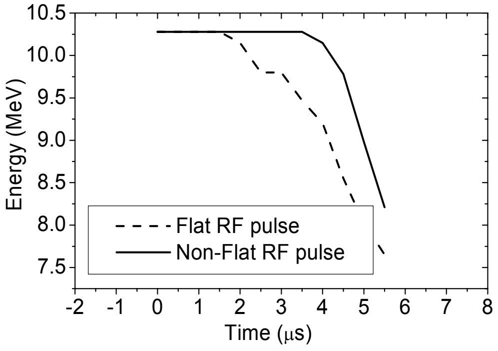

Fig.4 Time evolution of the peak energy during macro pulse

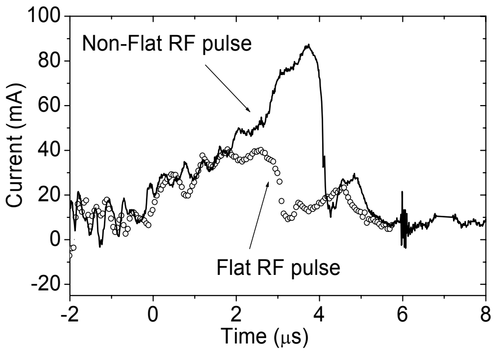

Fig. 5 Wave form of the beam current, measured using CT2

Table 4 Effect of non-flat RF input

	Flat RF pulse	Non-Flat RF pulse
Pulse width	3.0 μs	4.2 μs
Peak current	40 mA	90 mA
Total charge	97.7 nC	205.8 nC

ANALYSIS

To establish the energy compensation method using amplitude modulation, we have estimated the effect of this method with a particle simulation code PARMELA (version 3.30)[9]. As a first step, current density during macro pulse on the cathode surface was evaluated. Time evolution of the current density on the cathode is shown in fig. 6

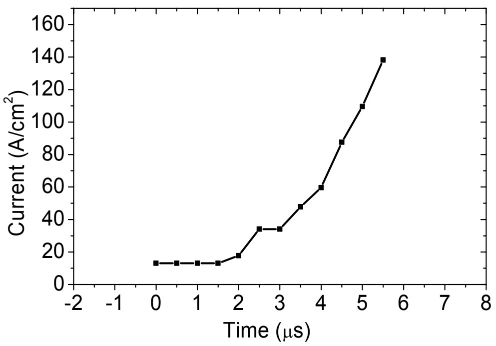

Fig. 6 Time evolution of current density during macropulse

Next, we evaluated the RF power required to accelerate up to the same energy as that for the initial current density. The required power is shown in table 5. Thus, the ideal RF wave form is derived as shown in fig. 7.

Table 5 Required RF power to keep beam energy constant

Current density [A/cm^2]	Required power [MW]
15.9	8.88
31.8	8.99
47.8	9.13
63.7	9.24
79.6	9.42
95.5	9.60
111.4	9.81
127.3	9.90
143.2	10.03

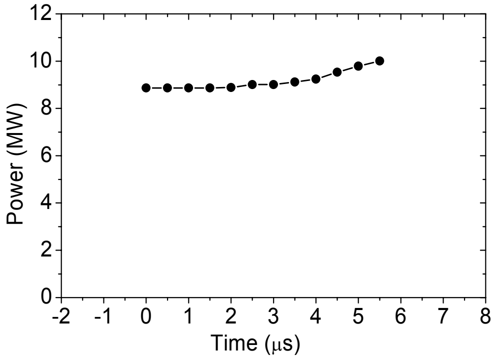

Fig. 7 Ideal RF wave form to extract electron beams with constant energy.

According to the results, in case for the maximum modulation of 19% of our power modulator, more than 1000% change of the current density is acceptable to keep the peak energy constant. In this case, estimated width of the macro pulse is longer than 5.5 μsec, but it is not consistent with the experimental results.

The reason of the inconsistency may be due to a transient phenomenon of the RF cavity and difference between matched loading and real beam loading.

SUMMARY

To improve electron beam properties, a slim cathode and transverse magnetic field are used. We could produce longer macro pulse, but it was not enough for FEL experiment, because beam energy is decreasing in the macro pulse due to the back-streaming electrons.

Thus, we fed non-flat RF to the 4.5 cell thermionic RF gun to compensate for the decrease of the beam energy by adjusting the reactance of the PFN. As a result, we succeeded in producing high-brightness electron beam with 4 μsec macropulse duration.

The effect of the energy compensation using this technique was numerically studied also. In the case of our 4.5cell thermionic RF gun, it was found that the amplitude modulation of 19% could keep the peak energy constant even when the current on the cathode surface changed by more than 1000%. To understand the discrepancy, transient analysis in the RF gun seems to be necessary.

For the future application of the FEL experiment, phase stability of electron micro bunches and beam emittance are also very important. These parameter will be measured and checked to see whether the extracted beam is acceptable for the FEL experiment.

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