BURST PULSE SUPERIMPOSED ELECTRON BEAM ACCELERATION IN LEBRA FEL LINAC*

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Abstract

The extraction and acceleration of an intensity modulated electron beam was carried out with a conventional DC gun by applying a high-speed grid pulse train superimposed on a long square-wave grid pulse to the grid electrode. A grid pulse coupler was developed for this purpose. Short beam peaks on the normal long macropulse beam, which were observed at immediately downstream of the gun, had a pulse width of 0.6 ns (FWHM) and a peak current of greater than 3 A. Although the beam waveform portions corresponding to the macropulse beam were considerably modulated due to fluctuation in the bottom voltage of the high-speed grid pulse train, acceleration of the burst beam superimposed on the macropulse beam was helpful in the adjustment of the linac operating condition on making the shift to lasing of the free electron laser by the burst mode beam only. With the long grid pulse turned off, acceleration of only a single electron bunch at each burst beam was achieved by adjusting the grid bias voltage and the timing of the high-speed grid pulse relative to the accelerating microwave.

INTRODUCTION

In the free electron laser (FEL) system of the Laboratory for Electron Beam Research and Application (LEBRA) at Nihon University, an electron beam with a maximum 50 μs of pulse width was extracted from a conventional DC electron gun. Then, the electron bunch was accelerated in each period of the 2856 MHz accelerating RF field in the 125 MeV linac. Over the RF pulse duration of 20 μs, every electron bunch contributed to lasing of the near-infrared FEL, generating FEL optical pulses with an interval of 350 ps [1]. On the other hand, the optical resonator length in the LEBRA FEL system was designed to be 64 times the free space wavelength of the RF, so that a burst mode electron beam would readily be applicable to future requirements for generation of long-interval FEL optical pulses.

As a part of the upgrade of the electron gun high voltage terminal in 2010, a Kentech high-speed grid pulser was installed in the terminal in addition to the conventional long-pulse grid pulser [2]. The high-speed grid pulser was aimed at extraction of the burst mode beam directly from the gun with a pulse width less than 1 ns (FWHM) and a peak current of higher than 1 A at a repetition rate of 1/64 or 1/128 the accelerating RF frequency. A similar system is in operation at SAGA Light Source [3, 4]. With the upgraded electron gun terminal system, as discussed in the following sections, the intensity modulated beam acceleration mode ("superimposed mode") has been made available by superimposing the high-speed grid pulse train on the long square grid pulse, in addition to the full macropulse beam and the burst beam modes.

THE GRID PULSE COUPLER

Due to low average electron beam current, the intensity of the undulator spontaneous emission of radiation in the burst beam acceleration mode was expected to be at least an order of magnitude lower than that in the full beam acceleration mode, which suggested that the electron beam handling for the FEL lasing could be difficult considering that the beam diagnostic devices and the optical detectors in the LEBRA FEL system were assumed to be used at the full beam mode only. Hence, a methodology was developed to extract the full mode and the burst mode beams simultaneously by superimposing the high-speed grid pulse train on the long square grid pulse. Once the FEL lasing is optimized at the full beam mode, then the high-speed grid pulser is turned on and the output burst pulse is superimposed on the long grid pulse. Due to small change in the beam loading in the linac, difference in the beam condition between the full mode and the superimposed mode is also expected to be small. A little adjustment on the linac is enough to regain the lasing. By gradually lowering the long grid pulse voltage without losing the FEL lasing, eventually the FEL optical pulses with a long interval are obtained by a complete shift to the burst mode beam only.

In order to superimpose the burst pulse on the long grid pulse, a pulse coupling module was developed. We now refer to this module as the grid pulse coupler. The photograph of the grid pulse coupler is shown in Fig. 1. The coaxial cable line for the burst pulse from the high-speed grid pulser is first converted to the stripline before the pulse is superimposed on the long grid pulse, then again converted to the coaxial line just before the plug for the cathode assembly and terminated with a 50 Ω coaxial

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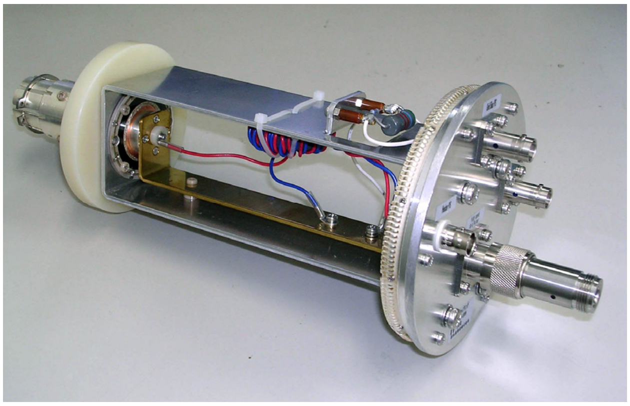

Figure 1: Photograph of the grid pulse coupler.

load. The grid pulse coupler is combined with the cathode heater power and the grid bias feeds for a coaxial-type EIMAC Y646B cathode assembly. A heat-resistant disk made of cross-linked polyethylene is used to guide the plug head to the cathode assembly.

EXTRACTION OF SUPERIMPOSED BEAM AND FEL LASING

The waveforms of the burst pulses from the high-speed grid pulser are shown in Fig. 2 for the peak output voltage settings from 100 to 160 V in every 10 V step. The voltage is remote controlled from the operating room. The master trigger of the burst pulse is the output from the divide-by-32 frequency divider for 2856 MHz RF. The trigger pulse is divided by 2 or 4 in the pulser. The burst pulse interval is 44.8 ns at the final divide-by-128 output. There are bumps at approximately 4, 6 and 11 ns after the main pulse, which significantly change the peak voltages in phase or out of phase with the main pulse.

The waveform of the extracted electron beam was measured at immediate downstream the electron gun with a current transformer (CT1). Dependence of the beam waveform on the long grid pulse voltage is shown in Fig. 3, when the grid bias voltage and the high-speed grid pulse voltage are set at 53 V and 160 V, respectively. At 60 V of the long grid pulse the full beam of 0.2 mA peak is available for normal operation. In this measurement, attenuation of the short pulse signal in the coaxial cable

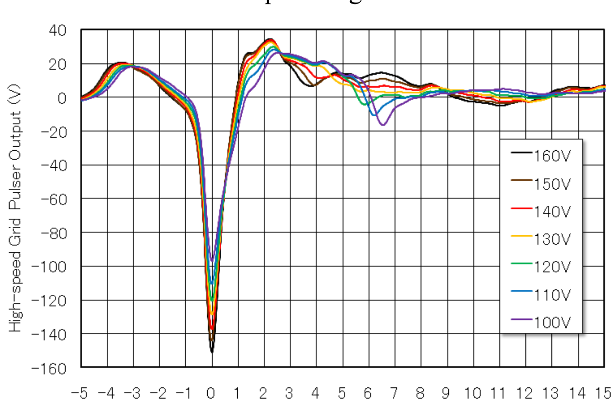

Figure 2: The high-speed grid pulser output waveforms for the peak voltages from 100 to 160 V in 10 V step.

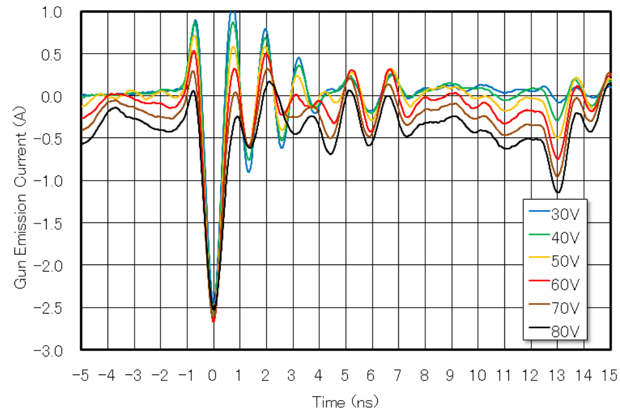

Figure 3: The beam emission waveform dependence on the long grid pulse voltage in the superimposed mode. The burst pulse voltage and the grid bias voltage are 160 V and 53 V, respectively.

on the way from CT1 to the oscilloscope was estimated at approximately 3 dB. The narrow peaks corresponding to the burst pulse have an approximate pulse width of 0.5-0.7 ns FWHM which is consistent with the spec of the pulser. The peak current is saturated at around 2.6 A which is estimated at 3.6 A taking the attenuation in the cable into account. The effect of the bumps observed in the high-speed grid pulser output is not clear. However, another small peak at 13ns after the main peak is significantly observed.

Thus, the electron beam extraction by the burst pulse train superimposed on the long grid pulse has strongly reflected the fluctuation of the bottom voltage between the burst pulses. As shown in Fig. 3 the resultant beam fluctuation is periodic in synchronism with the peak by the burst pulse, which means the fluctuation is also in synchronism with the accelerating RF phase. The fluctuation did not cause any difficulty in the FEL lasing experiment at the superimposed beam acceleration mode. Figure 4 shows the FEL macropulse waveform in the superimposed mode together with the electron beam waveform obtained at the end of the FEL beam line. Due to high bunch charge in the burst pulse region, the FEL power growth was clearly more rapid than that in the full beam mode.

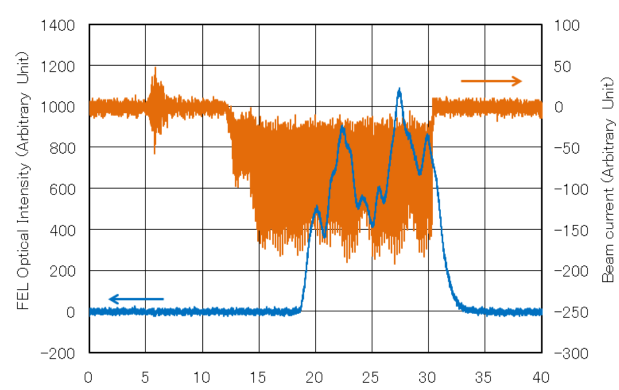

Figure 4: FEL macropulse waveform at a wavelength of 1.6 μm by the superimposed mode beam.

PROPERTY OF BURST MODE BEAM

A complete burst mode beam is obtained at the long grid pulse voltage sufficiently lower than the threshold of the beam emission. The period of the accelerating RF is approximately the half of the burst pulse FWHM width.

Therefore, acceleration of more than a single electron bunch in each burst beam is possible, depending on the grid bias voltage, the burst pulse peak voltage and its shape and the timing of the burst pulse relative to the accelerating RF phase. Though difficult to measure the correct waveforms of bunches, the behaviour of the burst beam acceleration was experimentally investigated by the beam current waveforms measured with the current transformer (CT5) at the linac exit as follows.

Figure 5 shows the beam current waveforms for the grid bias voltages of 90, 60 and 30 V, respectively, measured with CT5. Attenuation of the short pulses in the cable on the way from CT5 to the oscilloscope has been estimated roughly at 6 dB. The waveform of the burst pulse from the high-speed grid pulser with a peak voltage of 160 V is also shown in coincidence with the peak at 60 V. At 30 V the peaks indicated with the blue arrows are considered to be those of the satellite bunches that became prominent due to the low grid bias. There are no such noticeable peaks in the other waveforms, which suggests that a single bunch burst beam is possible at higher grid biases than 60 V.

The behaviour of the beam waveform in terms of the timing between the accelerating RF and the burst pulse is shown in Fig. 6. In this measurement the burst pulse peak and the grid bias voltages were 160 V and 60 V, respectively. The burst pulse timing was shifted using a

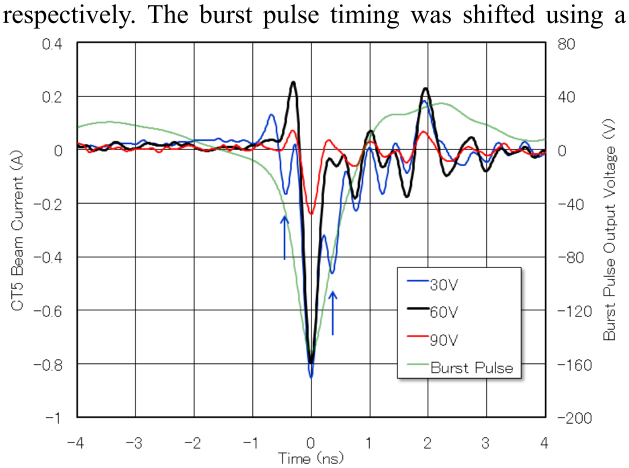

Figure 5: Dependence of the beam waveform on the grid bias voltage, measured at the exit of the linac. The high-speed grid pulser output burst pulse (160 V peak) is also shown with the green curve.

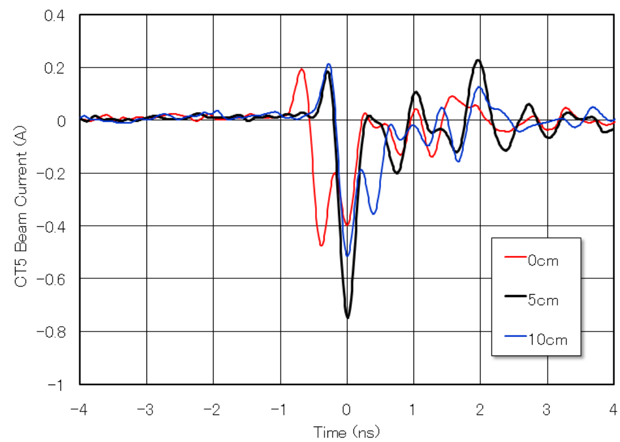

Figure 6: Dependence of the beam waveform on the timing of the burst pulse relative to the accelerating RF phase. The timing shift is described with the length of the coaxial tube in cm.

variable length coaxial tube for the input RF of the divide-by-32 frequency divider. The tube length shift from 0 to 10 cm approximately corresponds to 350 ps of the burst pulse timing shift, which is the same as the RF period. In Fig. 6 the horizontal position of each waveform has been normalized to a fixed 2856 MHz RF phase. Therefore, the effect of the burst pulse shift from left to right in 175 ps step is shown. The result suggests that only a single bunch was accelerated at the tube length shift of 5 cm, while two bunches were accelerated in the other cases.

SUMMARY

Acceleration of the electron beam extracted from the DC gun by applying the burst pulse superimposed on the normal long grid pulse has been successful, which was proved to be quite helpful for the FEL lasing at the burst mode operation of the linac at LEBRA. The single bunch burst beam acceleration has been verified by the dependence of the accelerated beam waveform on the grid bias voltage and the timing of the burst pulse.

REFERENCES

[1] K. Hayakawa et al., Proc. of the 29th International Free Electron Laser Conference, (Aug. 26-31, 2007, Budker INP, Novosibirsk, Russia) p.114.
[2] http://www.kentech.co.uk.
[3] http://www.saga-ls.jp.
[4] Y. Takabayashi et al., Proc. of the 5th Annual Meeting of Particle Accelerator Society of Japan (2008) p.966 (in Japanese).