INJECTOR SYSTEM OF TEST ACCELERATOR AS COHERENT TERAHERTZ SOURCE *

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Abstract

A test accelerator as coherent terahertz source (t-ACTS) project has been under development at Tohoku University, in which a generation of intense coherent terahertz (THz) radiation from sub-picosecond electron bunch will be demonstrated. We will supply wide-band coherent radiation from bending magnets in an isochronous accumulator ring and narrow-band coherent THz radiation using an undulator in a linac. Stable generation of very short electron bunch is one of the key issues in the t-ACTS project. The injector system is consists of a thermionic RF gun with two independent cavity cells, an alpha magnet and an accelerating structure. Velocity bunching in an accelerating structure is employed to produce the very short electron bunch. Most of components for the t-ACTS injector have already been installed, and we have started a high power RF processing of the gun cavities. Characteristics of electron bunch extracted from the RF gun are measured by varying phase and amplitude of input RF fields for the gun cavities.

INTRODUCTION

The t-ACTS project has been progressed at Electron Light Science Centre, Tohoku University. The t-ACTS consists of an injector linac, an isochronous ring and an undulator beam line. A wide band coherent THz radiation is emitted from circulated electron beam in the isochronous accumulator ring [1,2] and a narrow-band coherent THz radiation using the undulator has been considered [3,4].

To generate intense coherent THz radiation, we have studied a production of the very short electron bunch theoretically. In order to obtain sufficiently large bunch form factor, the bunch length of electron beam must be much shorter than the wavelength of radiation, since an intensity of a coherent radiation is proportional to the bunch form factor. In a case of THz region, the electron bunch should be compressed to the order of hundred femtosecond in bunch length. The electron beam generated by the thermionic RF gun is introduced into the bunch compression system consists of an alpha magnet and a travelling-wave accelerating structure. The alpha magnet is used for rotating the longitudinal phase space distribution of electrons and the bunch is compressed employing a velocity bunching in the accelerating structure.

The RF processing for the RF gun cavities have been started and a dark current measurement of the RF gun and a beam test have been performed.

INJECTOR SYSTEM OF t-ACTS

We have developed a thermionic RF gun consists of two independent cavities so as to manipulate the longitudinal phase space distribution of electron beam, named the Independently-Tuneable Cells (ITC) RF gun [5]. Distribution system of high power RF was constructed to meet the requirement of the ITC RF gun system. Figure 1 shows the present setup of the t-ACTS injector. The beam line is composed of the ITC RF gun, the alpha magnet with a movable slit, four quadrupole magnets and beam monitors.

High Power RF System

Figure 2 shows a schematic drawing of high power RF system. A klystron produced RF pulses with peak power of 50 MW and pulse duration of 2 μs, and the RF power is divided by a 9 dB hybrid into two RF waveguides connected to the ITC RF gun and an S-band accelerating structure. The accelerating structure is not yet installed; we have set up a dummy load in place. The waveguide system for the two cavities of the ITC RF gun includes a 6.5 dB hybrid power divider, two high power phase shifters and attenuators, two circulators and RF widows. The waveguides for RF gun are filled with pressurized SF_6. The amplitude and the phase of RF power supplied to the two RF gun cavities can be independently controlled using the high power attenuators and phase shifters, respectively.

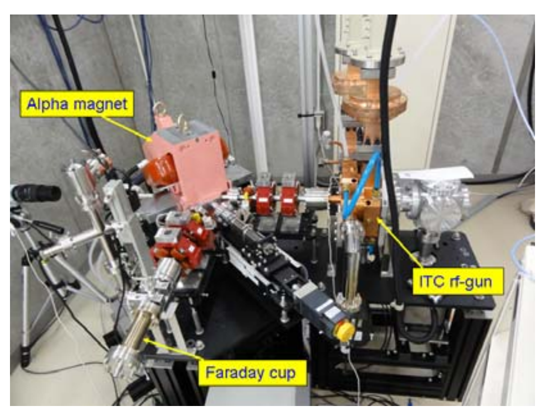

Figure 1: Present t-ACTS injector beam line.

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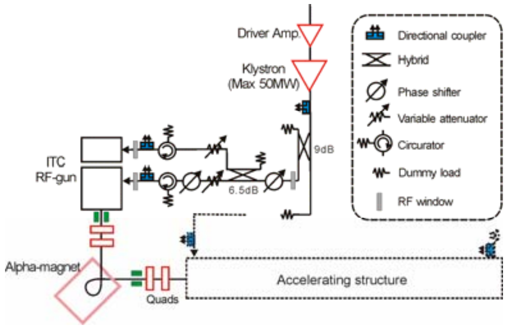

Figure 2: High power waveguide circuit for the t-ACTS injector.

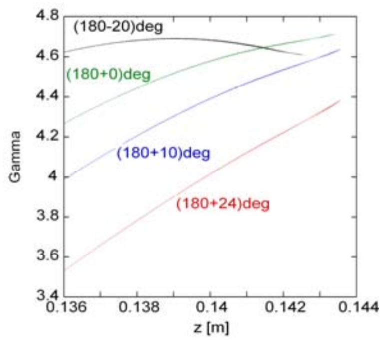

Figure 3: Longitudinal phase space distribution for different phases between two RF gun cavities operated at E_1 = 25 MV/m and E_2 = 70 MV/m. The cathode current density 50 A/cm^2 (calculated by GPT code).

ITC RF Gun

The two cavities of the ITC RF gun have no electrical coupling, therefore two RF cavities can be independently controlled. This makes it possible to control an optimal longitudinal phase space distribution for the bunch compression in the alpha magnet and the accelerating structure. Figure 3 shows the numerical simulation results of the longitudinal phase space distribution of the beam at the RF gun exit in case of varying the phase difference between the two cavities. From the studies so far, for produce ultra-short bunches, a linear chirp in the beam longitudinal phase space distribution at the exit of the RF gun is preferred [6]. The alpha magnet rotates the longitudinal phase space distribution of the bunch and the rotation is controlled varying the field gradient of alpha magnet. The higher energy part of the bunch is selected using a slit mounted in the alpha magnet and subsequently compressed by the velocity bunching in accelerating structure. Eventually, the electron bunch of 20pC charge will be compressed to less than 100 fs.

A LaB_6 single crystal cathode with a diameter of 1.75 mm has been chosen to obtain low emittance and high current density. In the case of RF gun using a thermionic cathode, sometimes the back-bombardment effect may prevent a stable beam generation. The ITC-gun is also no exception. From both experiments and simulations, we are conducting a research work on appropriate way to reduce the back-bombardment effect.

HIGH POWER TEST OF ITC-RF GUN

Performance of RF Gun Cavities

By measuring the forward and backward RF power using a directional coupler at the entrance of each RF gun cavity, the coupling factor between each gun cavity and the waveguide was derived. Figure 4 shows the forward and backward RF waveforms for the first cell of the RF gun. Figure 5 shows the coupling factor of each cell when the RF power supplied to the cavity is varied using the high power attenuator in the waveguide. From Fig. 5, the coupling of the 1st cell is changed periodically, meanwhile that of the 2nd cell was approximately constant at about 4.3. As one of possible reasons for which the coupling of the first cell is changed, contribution of the dark current emitted from the around cathode can be considered. By changing the field strength at the cathode surface, it was found the amount of dark current in the 1st cell was also changed and then the variation of the coupling between the cavity and the dark current may occur. In order to clarify the cause of this, further study will be performed using simulation code.

The dark current of the RF gun was measured using a fast current monitor that is installed downstream of the 160 mm from the RF gun exit. The input RF powers for two cavities have been adjusted so that the field gradient of the 1st and 2nd cavities may become to 25 MV/m (E_1) and 70 MV/m (E_2) with the 2 µs pulse duration. These field gradients are an operation condition of ITC RF gun to make short electron bunch. The average dark current

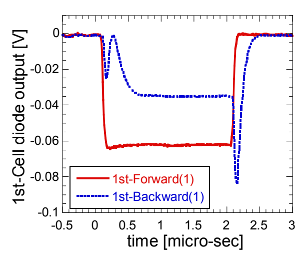

Figure 4: Waveforms of the RF power for 1st cell of the RF gun.

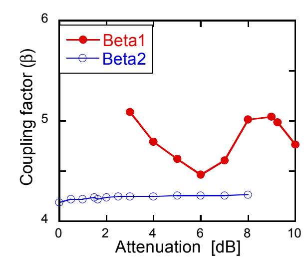

Figure 5: The coupling factors of 1st and 2nd cells plotted as a function of attenuation.

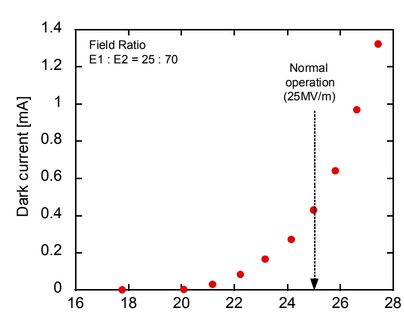

Figure 6: Amount of the dark current plotted as a function of the field strength in the 1st cell. The relation of the field strength of two cavities was set to E_1/ E_2 = 25/70.

was about 0.4 mA for the duration of RF pulse, this value corresponds to 0.8 nC of charge. The dark current may slightly vary by the phase relation between two cavities, and we have set the phase that the amount of dark current becomes a maximum in the measurement. Figure 6 shows the amount of dark current as function of the field strength of the 1st cell. The dark current has exponentially grown as the field gradient increases. However, the dark current is about three orders of magnitude smaller than the beam current in the nominal operation condition, because a beam current is more than 300 mA at the RF gun exit.

Beam Test of ITC RF Gun

We performed the beam test of the RF gun by turning on the cathode heater. Figure 7 shows the beam macro-pulse measured by a fast current monitor. As increasing the emission current from the cathode, the slope of the temporal profile of the beam is getting steep, which is caused by additional cathode heating due to the back-bombardment effect. When the beam current higher than 50 mA, the average current increase caused by the back bombardment is conspicuous as shown in Fig. 8.

Further we performed the beam current measurement by changing the RF phase of the 2nd cell. Keeping the cathode heater current at 9.6 A, the phase of 2nd cell was changed by every 15º steps. Figure 9 shows both the results of the measurement and the calculation. In the simulation, an emission current density from the cathode

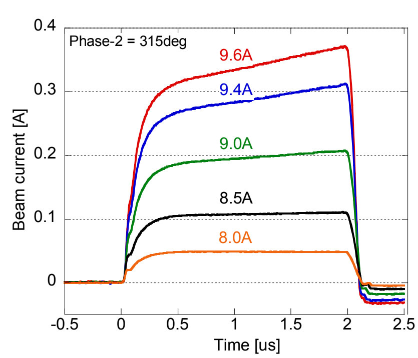

Figure 7: Temporal profile of the measured beam current.

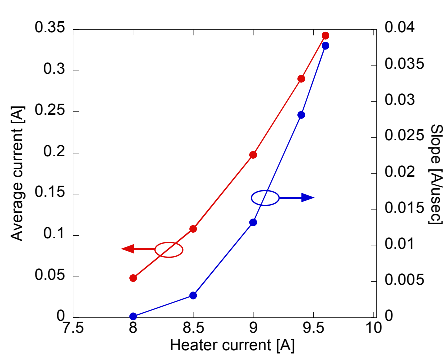

Figure 8: Average beam current and the slope of the beam current increase plotted as a function of cathode heater current.

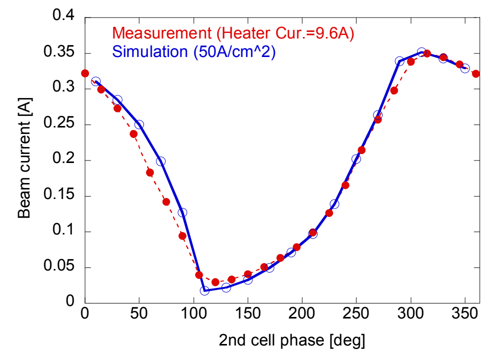

Figure 9: Extracted beam current from the RF gun at phase scan of the 2nd cell. Solid and open circles denote the measurement and the calculation by GPT code, respectively.

assumed to be 50 A/cm^2 and the RF fields of two cavities set to the nominal operation condition. They are in good agreement in entire phase as shown in Fig. 9, though there is a slight difference at 50º of the 2nd cell phase. This small deviation would have come from which the simulation does not include the back-bombardment effect on the emission current. In our scheme, the beam current at the gun exit is required approximately 330 mA to obtain the very short electron bunch with average current of about 57 mA after velocity bunching.

SUMMARY

We have started the RF conditioning of the ITC RF gun, and the dark current was measured at the RF gun exit. The dark current was measured to be about 0.4 mA in the nominal operation condition, which was sufficiently lower than the beam current. The beam test of the ITC RF gun has been performed and the extracted beam from the RF gun was measured with different setting of the cathode heater. Considerable increase of beam current in a macro-pulse due to the back-bombardment effect was observed. We continue to investigate the back-bombardment effect and will conduct demonstration of the extreme short bunch generation employing velocity bunching.

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