COMMISSIONING OF ITC-RF GUN FOR t-ACTS PROJECT AT TOHOKU UNIVERSITY*

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Abstract

A project t-ACTS (test accelerator as the coherent terahertz source) is in progress at Tohoku University, in which an isochronous accumulator ring and a bunched free electron laser will provide the intense terahertz radiation by employing sub-picoseconds electron pulses. A thermionic RF gun with two independently-tunable cells (ITC), an alpha magnet and a 3 m accelerating structure are employed in the t-ACTS injector, where the velocity bunching scheme will be adopted for the short pulse generation. We already accomplished high power RF processing for the gun, and then started the beam commissioning. We report first results of beam commissioning of the ITC-RF gun and also present the current status of t-ACTS project.

INTRODUCTION

Coherent synchrotron radiation from the short electron pulses can be a bright radiation source with considerable power in the terahertz frequency region, which will be a very useful tool in many scientific fields [1]. In the t-ACTS project, the intense terahertz radiation will be generated from an isochronous accumulator ring and a bunched free electron laser based on the sub-picoseconds electron pulses [2]. The machine layout of t-ACTS, which will be constructed in a light source house occupying an area of 20×10 m, is shown in Fig. 1. A 50 MW S-band RF source altogether feeds the power into a 3 m accelerating structure and each cell of the ITC-RF gun. The maximum pulse duration of RF power is 3 μs. Figure 2 shows the injector part of t-ACTS, in which the entire orbit path-length from gun to accelerating structure is about 1.5 m. Using the alpha magnet, the distribution in the longitudinal phase space can be manipulated, and simultaneously the low energy tail is removed by a slit inside the magnet. The operating condition for the ITC-RF gun and the alpha magnet should be carefully settled so as to realize the optimum beam parameters. Tracking simulations show that very short electron pulse less than 100 fs with a bunch charge of about 20 pC can be obtained by means of the velocity bunching scheme in the accelerating structure [3]. Although the usable amount of charge in the extracted beam from the ITC-RF gun is quite small comparing with photo-injectors, there seem to be distinct features such as the better stability and the multi-bunch capability.

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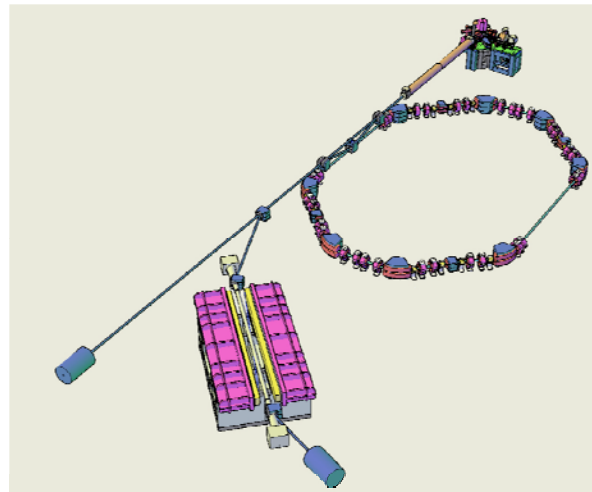

Figure 1: Layout of t-ACTS.

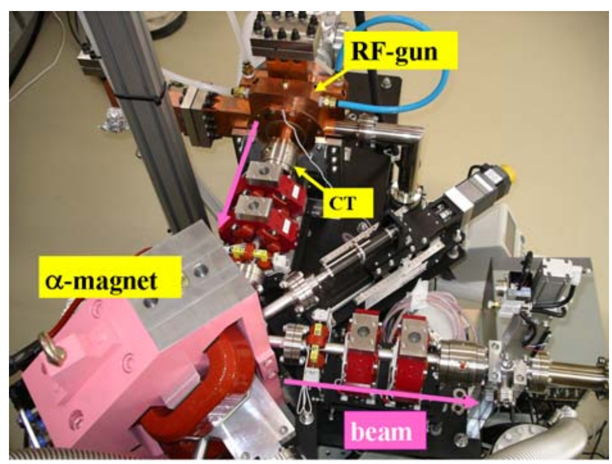

Figure 2: Injector part of t-ACTS. Extracted beam from the gun is measured by the current monitor (CT).

ITC-RF GUN

The ITC-RF gun has two independent cells, and thus can be operated at various combinations of different RF power levels and phase difference so as to optimize the longitudinal phase space distribution for bunch compression [4]. At the moment, the nominal operating parameters are considered as follows; the peak field strength at the cathode is 25 MV/m, the peak field strength in the second cell is 70 MV/m and relative phase

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between cells is π+24 deg. In this gun, single crystal LaB_6 is employed as a thermionic cathode, which will provide the intense electron beam with current density more than 50 A/cm^2. The small cathode size with diameter of ϕ1.75 mm seems to be profitable for generation of lower emittance beam. Table 1 shows the design parameters of the ITC-RF gun. In order to make the filling time reasonably small, coupling of each cell has relatively higher value.

Table 1: Results of Low-power Measurement

	design	measured
f_1 1st cell [MHz]	2856	2855.8
f_2 2nd cell [MHz]	2856	2856.0
coupling β_1 1st cell	~ 4	4.6
coupling β_2 2nd cell	~ 4	4.1
Q_0 1st cell	9500	7500
Q_0 2nd cell	12500	10200

Frequency Shift due to Cathode Heater

In the earlier estimation, the operating temperature of cathode was considered to be ~1900 K to extract sufficient beam current (~50 A/cm^2). The cathode size is quite small, so that only ~20 W (heater current ~ 9 A) is enough to heat up the cathode to the target temperature. However, in spite of such small heater power, it was found that heated cathode affected to the frequency of the first cell. Figure 3 shows the frequency shift in the first cell due to the cathode heater power. It turned out that the resonant frequency of the first cell shifted to the lower frequency by about 150 kHz for the cathode heater current of 9 A. According to the estimation using SUPERFISH, this magnitude of 150 kHz can be explained by the displacement of 1.5 μm of the wehnelt plate position, which seems to be plausible.

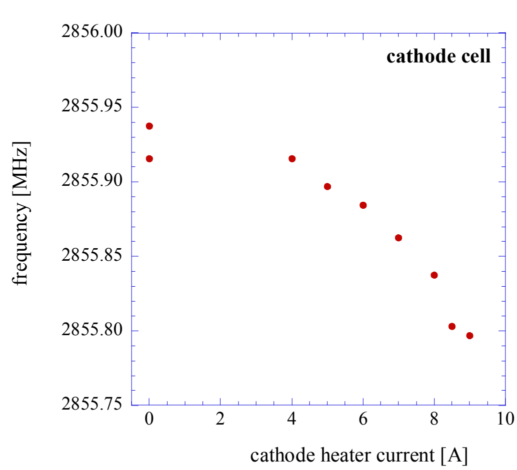

Figure 3: Frequency shift due to the cathode heater power.

Performing numerical simulations using SUPERFISH, it was also evaluated that the effect of the cathode displacement itself was quite small to make this frequency shift (~0.5 kHz/μm).

Furthermore, it was found that the coupling coefficient of the first cell was also changed from 5.5 to 4.6 corresponding to the heater current from 0 to 9 A. A likely reason of this shift in the first cell coupling is that some distortion of the cavity causes degradation of Q-value. These shifts must be taken into account for the actual operation. Measured values in the Table 1 were obtained under the realistic operating condition such as the heater current of 9 A, the cavity temperature of 40 deg., etc.

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Dark Current Measurement

High-power RF was fed into gun cavities, and thus the coupling of each cell was obtained by measuring the input and reflection RF power for each cell. An example of the measured RF power for the first cell is shown in Fig. 4. Taking into account the calibration about the diode response and attenuation in the signal cable, cavity couplings are estimated to be around 4.9 and 4.3 for the first and second cell, respectively, which seem to be consistent with the low-power measurement within the measurement error.

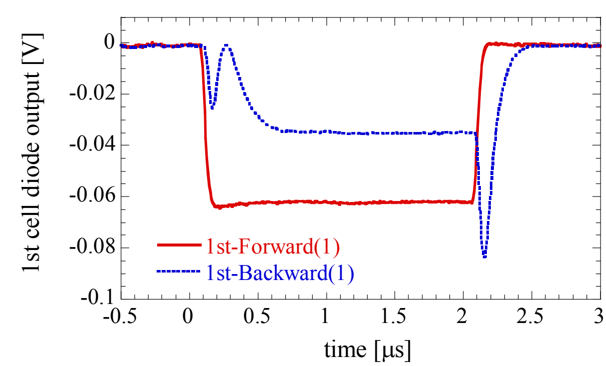

Figure 4: Measured waveform of input and reflection power for the first cell.

Since the required RF power is rather small for the nominal operation of the ITC-RF gun (~0.1 MW and ~2 MW for the first and second cell, respectively), the RF conditioning of the gun itself is not troublesome. After the RF conditioning with the nominal input power, we measured the dark current from the gun as shown in Fig. 5. The duration of RF macro pulse was set to 2 μs. Dark current was measured by the fast CT (bergoz, FCT-WB-10:1) placed at the gun exit. Since the amount of the dark current depends on the phase difference between cells, it was adjusted so as to maximize the dark current. For the input power higher than nominal operation, the dark current become increased drastically, however, it is still sufficiently small comparing with the beam current extracted from the cathode under the nominal operation.

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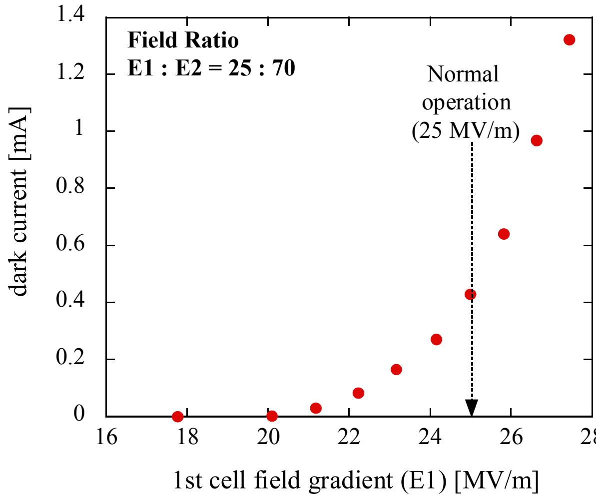

Figure 5: Measured dark current. The field gradient in the first cell was varied keeping the field ratio to 70/25 for the second cell.

Beam Commissioning

Recently we started the beam commissioning of the gun tentatively. Since the beam monitor system is not fully equipped at present, only the beam current has been measured for several conditions. In addition to the CT installed at the gun exit, we placed a same FCT in the cathode heater line, which can directly measure the emission current from the cathode. Figure 6 shows observed CT signal placed in the cathode heater line as changing the input power to the first cell. The minimum attenuation data corresponds to the case for 25 MV/m of the field strength at the cathode surface. The heater current was set to 9 A. Very noisy behavior was observed in the case of higher beam current for shot-by-shot, therefore waveforms were averaged over 16 times. Although this noisy feature is under investigation, it might be related to the back-bombardment (BB) effect. A thermionic RF gun is fated that back-streaming electrons hit their cathode, thus it is a very important subject to deal and suppress the BB effect [5].

In order to check the power dependence of emission current, the mean values of emission current were obtained for the several input power levels, where the each waveform from 0.4 to 1.9 μs was divided to three time slices, as shown in Fig. 7. The maximum input power level in Fig. 7 corresponds to the field strength of 25 MV/m. By Richardson's low, current density from the thermionic cathode is written as

$$J\,[\mathrm{A/cm}^2] = AT^2 \exp\left(-\frac{\phi_W - \phi_{qt}}{k_B T}\right), \tag{1}$$

where constant A and work function ϕ_W are 29 A/(cm^2-K^2) and 2.69 eV for LaB_6, respectively. The term ϕ_{qt} shows the contribution by Schottky effect, which is related to the field strength E_k as follows,

$$\phi_{qt}\,[\mathrm{eV}] = 0.012\sqrt{E_k\,[\mathrm{kV/cm}]} \;. \tag{2}$$

Significant excess is seen in the measured emission current with respect to the simple expectation by eq. (1) with Schottky effect, which can be quoted for the BB effect. In Fig. 7 the lager excess can be seen for the later time slice, which is reflected in the fact that the additional heat by the back-streaming electrons is piling up in the RF macro-pulse duration.

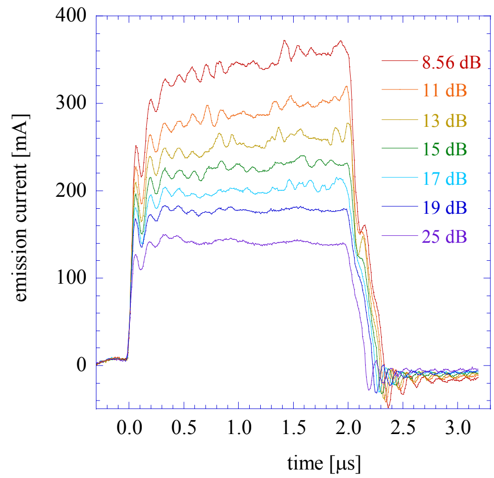

Figure 6: Observed CT signal placed in the heater line for the several input power levels. Heater current = 9 A. Each waveform is averaged over 16 times.

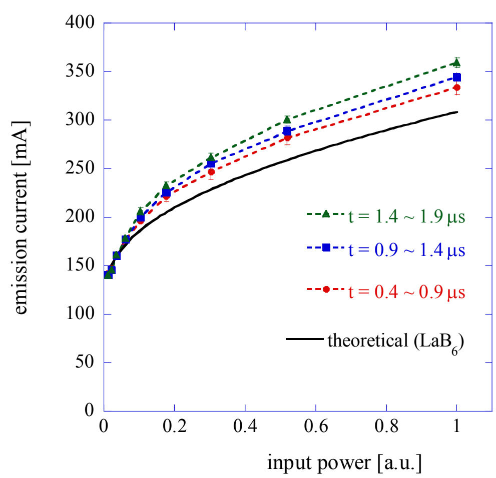

Figure 7: Power dependence of emission current. Solid line shows the expectation given by eq. (1).

Note that there is no emission from the cathode in the half period in one RF cycle, so that it is deduced the peak current extracted from the cathode is almost twice as measured emission current, which leads the current density of ~30 A/cm^2, if we neglect the contribution of the back-streaming electrons that hit the cathode. The enhancement of current density by the Schottky effect is evaluated to be about factor 3 at the maximum field strength, but actually the field strength on the cathode surface is dynamically changing with the RF phase. As the result, the current density should be treated with a time-dependent form. Since the estimation shown in Fig.

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7 does not include this dynamical effect, therefore the actual excess in the emission current due to the BB effect is deduced to be somewhat lager.

In Fig. 8, heater current dependence of the emission current is shown. The beam current extracted from the gun is also shown in Fig. 8. The measured currents represent the mean values over the last 1 μs of the RF pulse duration of 2 μs. The result shows that the ratio of extracted beam current to emission current, which is corresponding to the efficiency of the beam extraction, is almost constant over the variation of heater current. Thus this means that the extraction efficiency is almost independent on the cathode temperature, including the effect of additional heat by the BB effect. However, it is expected that the stronger space-charge force should cause the emittance growth for the higher beam current. Therefore, the preparation of measurement system, such as the emittance and energy distribution, etc., is in progress to investigate the performance of the ITC-RF gun in detail. We have been also carrying out the R&D work for new monitor system based on the velocity dependence of opening angle of Cherenkov radiation [6]. It will serve the very useful information about the longitudinal phase space distribution for the extracted beam from the gun.

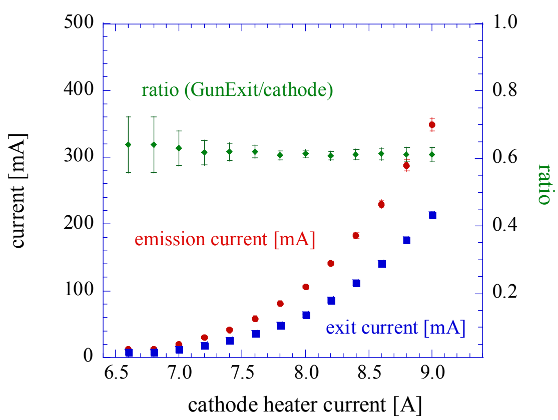

Figure 8: Heater current dependence of emission current.

SUMMARY AND t-ACTS STATUS

The t-ACTS project aiming at the demonstration to generate the coherent terahertz radiation by very short electron pulses is in progress at Tohoku University. We started the beam commissioning of the ITC-RF gun employed in t-ACTS injector. In the low-power measurement, it was confirmed which design parameters were almost fulfilled. Although the measured emission current seems to be less than the target value, the operation with higher heater current (~9.6 A) will recover the emission current density to the target value. Since the actual operating temperature will be determined by considering the several conditions such as finally available beam charge after the energy slit, etc, the preparation of monitor system is in progress to investigate the performance of the ITC-RF gun in detail.

On the day of March 11, 2011, we suffered a terrible disaster; 9.0-magnitude earthquake. Fortunately there was no fatal damage. Thus we had re-started the construction of t-ACTS. Concrete blocks for radiation shield were partially prepared. Radiation safety system is now under construction. Concerning the isochronous accumulator ring, the optics design was mostly fixed, and then the fabrication of magnets for half of the ring is in progress. For the terahertz undulator, their fabrication and tuning work of magnetic field was completed. We have been also preparing additional field measurement using the vibrating wire, which seems to be suitable for an undulator with long period length [7]. We have been preparing the machine components, and then we will start the construction of the isochronous accumulator ring in FY2012. Finally the generation of terahertz radiation will be demonstrated by the end of FY2012.

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