DEVELOPMENT OF A THERMIONIC RF GUN FOR COHERENT THz SOURCE AT TOHOKU UNIVERSITY*

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Abstract

A test accelerator for the coherent terahertz source (t-ACTS) has been under development at Research Center for Electron Photon Science, Tohoku University. Intense coherent terahertz radiation will be generated by the very short electron bunch less than 100 fs using a thermionic RF gun. The RF gun has been already manufactured and the measurement of RF characteristics is now in progress. We present the results of low-power measurement and also discuss the effect of the cathode misalignment on the beam parameters such as transverse emittance and longitudinal phase space distribution.

INTRODUCTION

The t-ACTS consists of an injector linac, an isochronous ring as a broad-band coherent synchrotron radiation source, and an undulator (or a free-electron laser) as a narrow-band THz radiation source [1]. The injector linac employs the thermionic RF gun (independently tunable cells [ITC] RF gun), an alpha magnet, and an off-crest acceleration followed by a magnetic chicane for the short bunch production. ITC RF gun is designed to have two cells uncoupled with each other, so that it can be operated at various combinations of different RF power levels and phase difference so as to optimize the longitudinal phase space distribution of the electron beam for bunch compression [2]. The electron beam is extracted from a single crystal LaB_6 cathode with small diameter of 1.8 mm to obtain a very small initial emittance with sufficiently high current density larger than 50 A/cm^2 (see Fig. 1). The performance of the ITC RF gun would be especially important for the test accelerator, because the longitudinal emittance at the gun exit will limit the minimum bunch length compressed by the magnetic chicane. In order to keep the significant total charge in a bunch, it is also important to concentrate the high energy particles into the head part in the longitudinal phase space as high as possible by the RF gun.

IMPROVEMENTS OF CONTACT BETWEEN THE CATHODE ENDPLATE AND CAVITY WALL

At the high power test of the gun performed in the last year, we had a serious problem in the cathode cell. As shown in Fig. 1, the LaB_6 cathode is mounted on a ceramic base, and which is further mounted on a cathode plug to be inserted into a cathode endplate. The cathode endplate has a hole with 3 mm in diameter for the cathode to ensure the thermal insulation. No RF contact is employed for the cathode. Therefore the gap of about 0.6 mm exists between the cathode and the edge of the hole. The cathode endplate with the cathode plug is then inserted into the cavity block. Cross section of the gun is shown in Fig. 2. The electrical steady contact must be made at the corner of the cathode cell, while the vacuum seal is secured by the metal gasket. However it was found that the contact between the cathode endplate and the cavity wall was not sufficient, so that the Q-value was degraded so much (unloaded-Q ~ 3000) and also RF characteristics were unstable depending on the

Figure 1: Single crystal LaB_6 cathode mounted on a ceramic base, which is further mounted on a cathode plug.

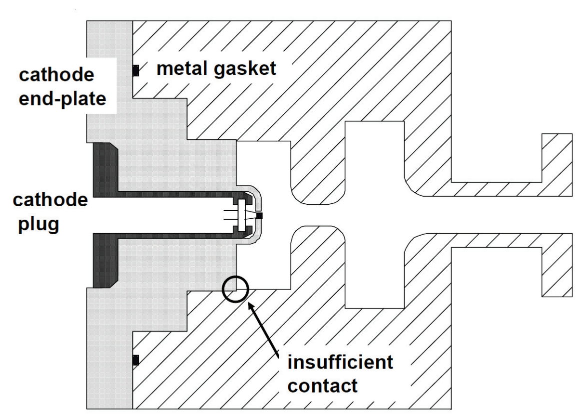

Figure 2: Cross section of the ITC RF gun.

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temperature condition of the cavity (see Fig. 2). The gap width at the corner of the cathode cell was deduced to be less than 0.1 mm by the precise measurement of dimensions of endplate and cavity block using a 3D coordinate measuring machine. It was also found that the cathode endplate do not have sufficient firmness to use the metal gasket (metal O-ring) sealing the vacuum. A significant distortion of the cathode endplate was measured for the bolting torque over the 130 kgf-cm, which could also cause the insufficient RF contact.

In order to overcome this situation, we employed a specially designed copper gasket which can be used with much less torque than the metal O-ring in bolting flange to seal the vacuum [3]. Furthermore to ensure the steady RF contact at the corner of the cathode cell, we put a gold wire into the gap at the corner. The results of the low-power RF measurements are summarized in Table 1. Q-value of cathode cell has been regained to the designed level. The resonant frequencies measured in room temperature are listed in the Table 1 and which can be tuned to the design values by tuning knobs and temperature control. Note that although the unloaded-Q of the cathode cell is much high (Q_0 ~ 14500) for the ideal case, it drops to 9500 due to the existence of the cathode gap.

Table 1: results of low-power measurement

	design	measured
f_1 cathode cell [MHz]	2856	2857
f_2 acc. cell [MHz]	2856	2855
coupling β_1	~ 4	4.9
coupling β_2	~ 4	5.3
Q_0 cathode cell	9500	7900
Q_0 acc. cell	12500	13700

EFFECT OF LONGITUDINAL MISALIGNMENT OF THE CATHODE

In the present design, any adjustment knob is not prepared for the longitudinal positioning of the cathode because it is assumed that the cathode is precisely fabricated. According to the simulation study, however, the longitudinal misalignment of the cathode less than 0.1 mm, which corresponds to the nominal machining accuracy, might have a non-negligible effect on the performance of the extracted beam as described below.

So far we had been performed simulation study with an ideal field map inside the gun cavity, where the existence of the gap around the cathode had been neglected. Longitudinal field strength calculated by the SUPERFISH is shown in Fig. 3 for some cases of cathode position with offset [4]. The dashed line shows the ideal field strength with no cathode gap. Actually there is a gap around the cathode, so that the field strength near the cathode surface drops by more than 10 % comparing with the ideal case. The variations for cathode position with the longitudinal offsets of ±0.1 mm are also shown in Fig. 3.

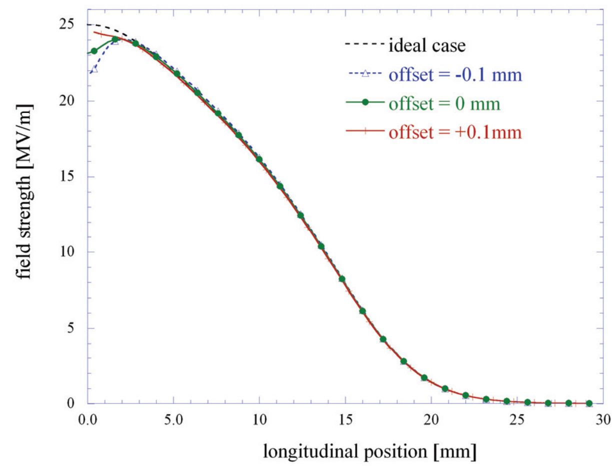

Figure 3: Longitudinal electric field of the cathode cell. The origin of longitudinal position is defined to the cathode surface with offset = 0 mm. Dashed line denotes the ideal case with no cathode gap and other lines with symbol denote the actual configuration considering the cathode gap with the longitudinal offset.

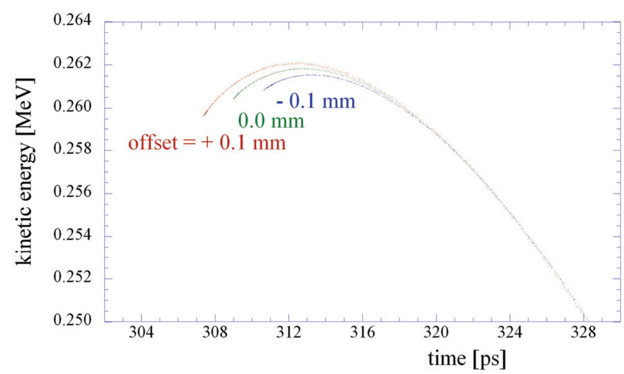

Figure 4: Longitudinal distribution at the entrance of accelerating cell without space charge effect, in the case where the cathode position has a 0.1mm offset.

Applying these field maps, a simulation study was performed using General Particle Tracer [5]. The nominal operating parameters are as follows; the peak field strength at the cathode is 25MV/m, the peak field strength in the accelerating cell is 70MV/m and relative phase between cells is π+24deg. In this simulation, the whole field strength of the cathode cell is normalized by the power dissipation in the cathode cell. First we started the study without the space charge effect and found that the difference of the field strength near the cathode made the difference of 1 ~ 2 ps in the arrival time to the accelerating cell as shown in Fig. 4. As the result, the energy gain in the accelerating cell was changed and thus the difference between them occurred in the energy distribution at the gun exit. This difference is prominent only for the head part of the bunch, since the difference of the field strength is localized near the cathode surface and which effect becomes larger for the leading particles where the particle velocity is still very small comparing with the trailer particles. The offset of the cathode position can also affect the energy gain in the cathode cell because of the difference of the effective length of the accelerating field. This effect, however, partially cancels out the deviation of the field strength, so that the overall difference of the energy gain becomes small at the exit of the cathode cell.

Then we performed tracking simulation employing the Spacecharge3D model for the space charge effect, where the 30-k particles were generated for the each offset. The obtained distribution in longitudinal phase space is shown in Fig. 5. The peak kinetic energy shifts ±1.2 % by the offset of ±0.1 mm of the cathode position, which is come from the difference of the arrival time to the accelerating cell as mentioned before, while the detailed shape of the head part such as the nonlinearity reflects the space charge effect. Generally this kind of shift may be adjusted by the input power to the gun, but it would bring the unwanted change into the particle distribution. In the case of the ITC RF gun, however, the phase space distribution can be manipulated with the great flexibility, so that it might be not serious to compensate this energy shift.

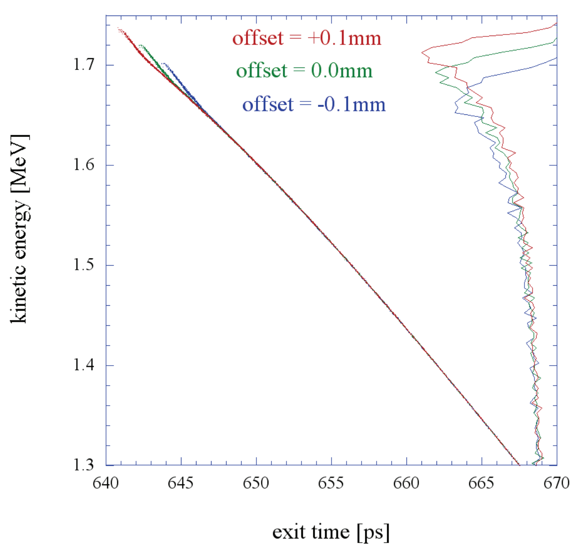

Figure 5: Simulated distribution in longitudinal phase space at the gun exit for each offset. The histogram of energy distribution corresponding to the each offset is also shown.

The existence of the cathode gap also changes the transverse component of the electric field near the cathode. The transverse field has purely diverging component near the cathode in the ideal case without the gap, on the other hand, it has converging one in the case of cathode gap. In addition, the offset of the cathode position change the transverse field too, so that the beam parameters in the transverse direction are also affected. The comparison was made for the transverse distributions of the high energy particles within the 5 % of top energy in the bunch head for each case of the longitudinal offset. The result shows the almost same normalized emittance of 1 mm-mrad for each case, but there is a difference of about 20 ~ 30 % in the Twiss parameters, which seems to be non-negligible in the actual beam handling. At this time, it is not clear that how much significance should be accounted by the misalignment to the contribution to the existing difference, since usually there exist a wide variety of the characteristics of the extracted beam from the gun depending on the space charge model in the simulation. Further progress in both theoretical and experimental approach is important for the well understanding of the beam dynamics in the RF gun [6].

SUMMARY

Development of a test accelerator for the coherent terahertz source is underway, where the specially designed thermionic RF gun is employed in the injector. Although the gun had a serious problem in the contact between the cathode endplate and the cavity block, it was resolved by putting the gold wire into the gap. Cathode heat-run and the high power test of the gun will be restarted soon.

The effect of cathode misalignment was also studied by the tracking simulation applying the field map with longitudinal offset of the cathode position. It was found that the longitudinal misalignment caused a shift of the highest beam energy due to the difference of the arrival time to the accelerating cell of the gun. In the case of the ITC RF gun, this energy shift will be compensated without any problem because of the great flexibility to manipulate the phase space distribution of the extracted beam from the gun. However, the detailed shape of the distribution strongly depends on the space charge effect in both transverse and longitudinal phase space, so that further study for well understanding of the space charge effect is required to extract fully the performance of the RF gun, and such experimental study can be performed using this novel tool; ITC RF gun.

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