PRESENT STATUS OF THERMIONIC RF-GUN FOR TERAHERTZ SOURCE PROJECT AT TOHOKU UNIVERSITY*

F. Hinode#, H. Hama, N.Y. Huang, S. Kashiwagi, M. Kawai, X. Li†, T. Muto, I. Nagasawa, K. Nanbu, Y. Shibasaki, K. Takahashi, Tohoku University, Sendai, Japan.

Abstract

A thermionic RF gun for an accelerator-based terahertz source has been commissioned at Electron Light Science Centre, Tohoku University. Recently we constructed the measurement system to obtain the momentum distribution of the extracted beam from the RF gun. The system consists of the analyser magnet, tungsten beam slit followed by a Faraday cup and a Hall probe for the real-time magnetic field measurement. The momentum resolution of the spectrometer is estimated to be about 0.15 %, which will be sufficient to analyse the detailed distribution of highest energy part for the extracted electrons from the gun. The preliminary results of measured momentum spectrum and the current status of the terahertz source project are presented.

INTRODUCTION

Coherent radiation from a very short electron bunch can be considered as a candidate of the bright source in the terahertz frequency region. In Tohoku University, a test accelerator for the coherent terahertz source (t-ACTS) is now being constructed, in which a specially designed thermionic RF gun is equipped in the injector [1, 2]. The RF gun consisting of two independently-tunable cells (ITC RF-gun) can be operated so as to optimize the longitudinal phase space distribution of the extracted electrons for the further manipulation in an alpha magnet and a 3 m accelerating structure toward the short pulse generation. 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 in the accelerating structure [3].

In the early result of the gun commissioning with higher current density of about 50 A/cm^2, it was shown that the back-bombardment (B-B) effect seemed to be rather serious for the beam quality in spite of the operation with the short pulse length and slow repetition rate. The simulation study for the B-B effect with the 2D heat transfer model turned out that low energy electrons coming back in the cathode cell have the significant contribution for the additional cathode heating rather than the higher energy electrons. This is the reason why an attempt of simple dipole field on the cathode cannot avoid sufficiently hitting the cathode by back-streaming electrons [4]. At the moment, the other cathode with a little bit larger diameter is going to be employed for a new RF gun in order to mitigate the B-B effect. On the other hand, it is very important to investigate the actual property of the RF gun by measuring the beam quality. Especially a space charge effect will degrade the longitudinal beam distribution significantly, thus the measurement of the energy spectrum is one of the most essential issues for the RF gun in order to realize the very short electron bunch.

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hinode@lns.tohoku.ac.jp

† Present address: Tsinghua University, China

EXPERIMENTAL SETUP FOR MEASUREMENT OF MOMENTUM DISTRIBUTION

Measurement Setup

The energy spectrometer consists of a 45 degree analyzer magnet, tungsten beam slit followed by a Faraday cup (FC) as shown in Fig. 1. Furthermore, the same magnet as analyzer is connected in series, thus it can be anticipated to monitor the magnetic field precisely without vagueness such as instability of power supply and hysteresis. The beam current extracted from the gun is measured by a current transformer (CT) placed at the gun exit. Since the analyzer magnet was diverted from the other attempt, which was originally fabricated as the dipole magnet for the isochronous accumulator ring in t-ACTS, the pole edge has the tilting angle of 17.5 degree at each edge. This tilting angle may help to focus the beam in vertical direction. Since the extracted particles from the gun have different Twiss parameters depending on the RF phase and thus their energy, two quadrupole magnets placed at the gun exit can be used so as to focus the beam on the slit location.

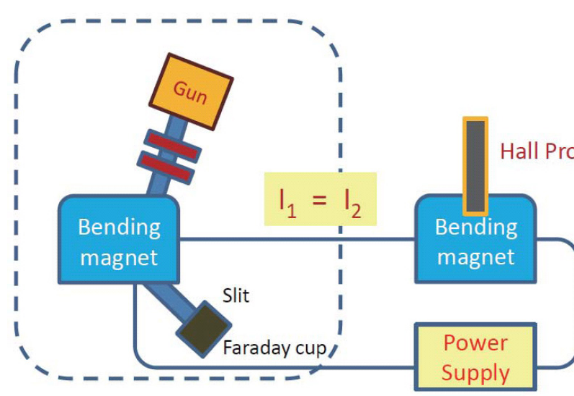

Figure 1: Measurement setup.

Estimation of Momentum Resolution

The momentum resolution for the beam passing through the beam slit is described as

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$$\delta_p = \frac{\sigma_p}{p} = \frac{1}{\eta}\sqrt{\left(\frac{W}{2\sqrt{3}}\right)^2 + (\sigma_\beta)^2}\,, \qquad (1)$$

where η is the dispersion function at the slit position, W the slit full width, $\sigma_\beta = \sqrt{\varepsilon\beta}$ the beam size due to the finite emittance ε, p and σ_p the central momentum and its standard deviation respectively. The dispersion function at the slit position is evaluated to be 0.302 m theoretically. The estimated momentum resolution as a function of the beam size for two cases of slit width is shown in Fig. 2. As expected by Eq. (1), the practical momentum resolution gets improved as decreasing the beam size. If we allow the beam size to be comparable to the slit width, the momentum resolution of about 0.15 % can be achieved for the slit width of 0.5 mm, in which the resolution is required to analyse the distribution of the highest energy electrons precisely.

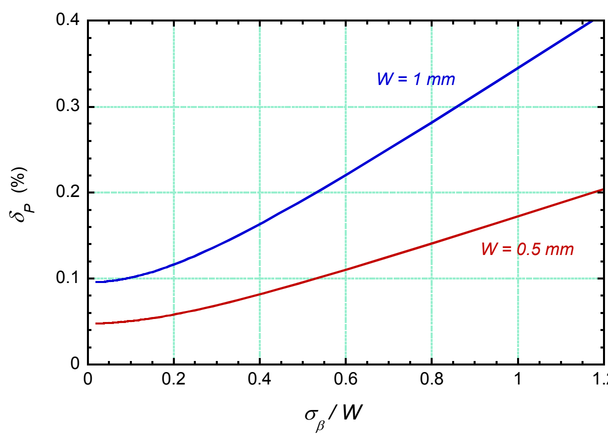

Figure 2: Estimated momentum resolution.

PRELIMINARY MEASUREMENT RESULTS

Spectrum Measurement

In prior to the measurement of the momentum spectrum, the phase difference between cells was set to π-mode. Field strengths of both cells were also set to the nominal values of 25 and 70 MV/m for the 1st and 2nd cell respectively. The emission current density of ~50 A/cm^2 was achieved by the cathode heater current of 9.95 A. The RF macropulse has the pulse length of 2 μs. Result of the 2D momentum spectrum is shown in Fig. 3. Measured beam intensity is obtained by averaging over five shots of beam signal. Note that the leading edge of RF pulse is positioned to 1 μs. Because of the finite filling time of the gun cavities of about 0.2 μs, there is a transient feature in the earlier time region of the RF macropulse. Due to the B-B effect, increase in the emission current is occurred in the later time region, which will cause a heavier beam loading and thus decrease the beam energy. As can be seen in Fig.3, however, such beam loading might be still small for this level of beam current, and thus the energy decrease might be not serious so much within the shorter pulse length of about 2 μs.

The time sliced momentum spectrum is also shown in Fig. 4. The sliced time is determined to 2.25 μs taking into account of the transient state by the RF filling time. The data plots show the average of 5 shots of beam pulses. Measured spectrum shows good resolution as expected. Although some small fraction can be seen in the higher momentum region than the peak, it may be considered as a contamination from scattered electrons.

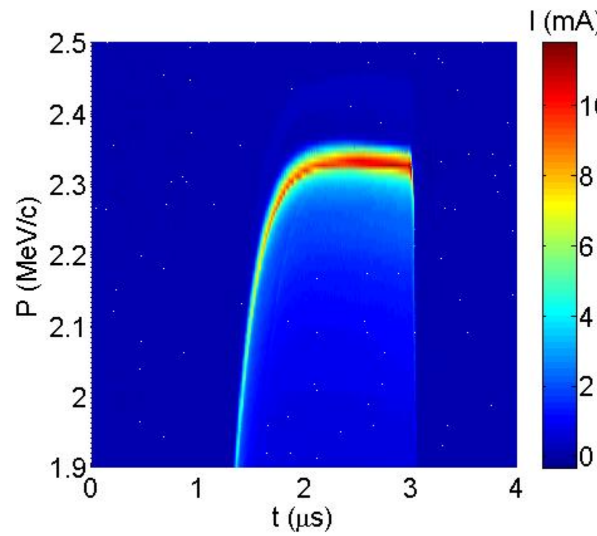

Figure 3: Measured 2D momentum spectrum. The leading edge of RF pulse corresponds to t = 1 μs.

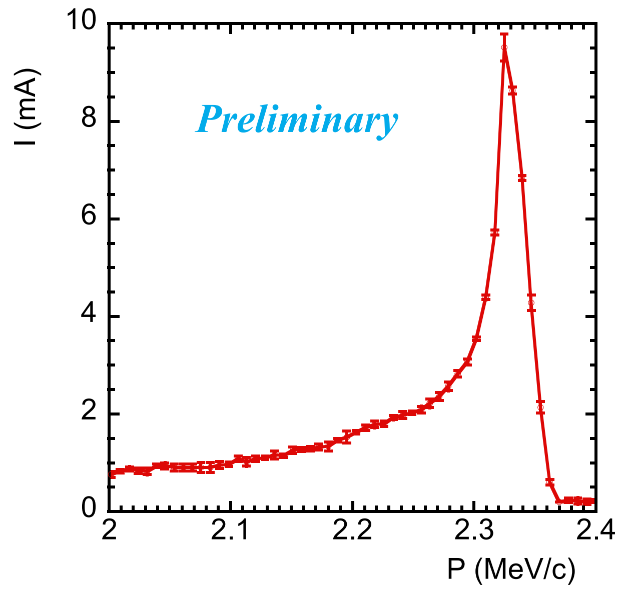

Figure 4: Measured momentum spectrum. The sliced time was set to 2.25 μs.

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Since the absolute value of the momentum is deduced by the measured field strength with an effective length obtained by the 3D field calculation, the energy calibration based on the measured effective length should be required to ensure the actual momentum accurately. Furthermore, although the data seems to be also well consistent with the tracking simulation, further study is being performed to investigate the beam property in detail [5].

Measurement of Stability

The Faraday cup signal placed after the beam slit is shown in Fig.5, which was measured at almost the peak energy. The CT signal placed at the gun exit is also shown in the figure, in which the increasing signal can be clearly seen. The increasing beam current due to the cathode heating by the B-B effect is reaching to 360 mA at the end of the macropulse.

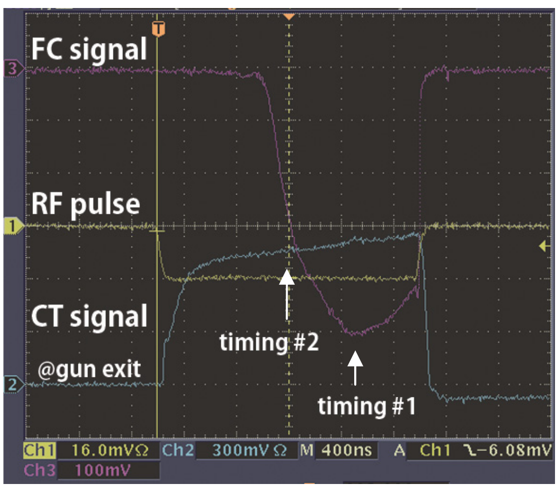

Figure 5: Observed beam signal. Ch.1: input RF pulse for cathode cell, Ch.2: CT signal and Ch.3: FC signal, respectively. Two different timings were assigned to measure the beam stability.

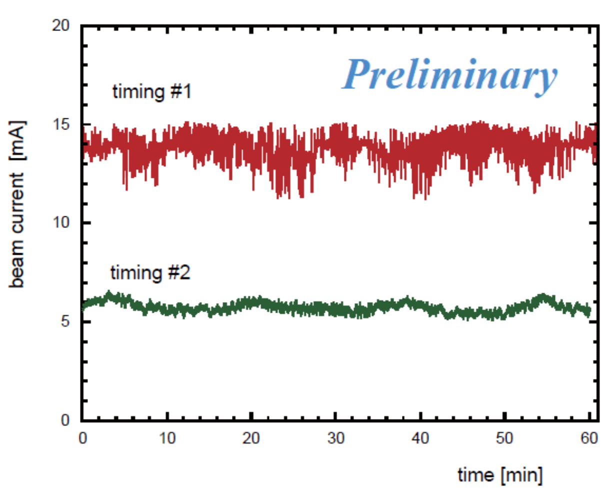

Figure 6: Preliminary result of measured beam stability.

Using the Faraday cup signal, the beam stability was observed as shown in Fig. 6. Two trends in Fig. 6 correspond to the different timings as depicted in Fig. 5, in which nearby 5 data points were averaged for each timing position to eliminate the noise contribution. The trend #1 has a rather large shot-by-shot fluctuation, in which overall deviation was estimated to be 4 % in rms. Although it may be considered that this large fluctuation is caused by the B-B effect at the moment, more information should be required to understand and overcome this feature. On the other hand, the trend #2 shows smaller shot-by-shot fluctuation but some cyclic structure. Note that these two trends were not observed simultaneously. Since the temperature of the gun cavities is well controlled within the stability of 0.1 degree, this cyclic structure might be considered to be caused by an insufficient stability of the other cooling water system. Anyhow, further investigation will be done to realize the more stable beam.

SUMMARY AND T-ACTS STATUS

Beam commissioning of ITC-RF gun has been performed for the t-ACTS project. Measured energy spectrum shows good momentum resolution as estimated and also looks well consistent with simulation. Since the preliminary results show unstable behaviour in the extracted beam, further study is continued to investigate the source of the instability. According to the simulation study with the 2D heat transfer model, increased emission current due to B-B effect might cause a problem, and thus fabrication of new RF gun is on going, which employs a little bit larger cathode diameter to mitigate the B-B effect.

Regarding the t-ACTS construction, injector linac has been almost constructed in the dedicated light source house. Dipole magnets were already fabricated for the half of isochronous accumulator ring. Towards the commissioning start in the next year, further efforts such as a study of beam dynamics, preparation of vacuum chamber and beam monitors, control system, etc. are also being done.

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