EMITTANCE MEASUREMENT ON THE CeB_6 ELECTRON GUN FOR THE SPring-8 COMPACT SASE SOURCE FEL PROJECT

K. Togawa, T. Tanaka, K. Onoe, T. Inagaki, H. Baba, T. Shintake, SPring-8 / RIKEN Harima Institute, Hyogo 679-5148, Japan
T. Ohata, SPring-8 / JASRI, Hyogo 679-5148, Japan
H. Matsumoto, High Energy Accelerator Research Organization (KEK), Ibaraki 305-0801, Japan

Abstract

A 500 kV pulsed electron gun has been constructed for the injector system of the SASE-FEL project at SPring-8 (SCSS project [1]). A CeB_6 single crystal is chosen as a thermionic emitter, because of its excellent emission properties. We have succeeded in generating a 500 keV beam with 1 A peak current and 3 μsec FWHM. The beam emittance has been measured by means of double-slits method. The normalized rms emittance was 1.1πmmmrad. We report on the preliminary result on the emittance measurement of the CeB_6 electron gun.

INTRODUCTION

The SASE-FEL requires a low emittance, high peak current electron beam. The electron beam must be also stable with low jitter over long time periods in order to provide a stable FEL light to users.

For the SCSS project, we chose a pulsed high-voltage electron gun with a thermionic cathode instead of the photocathode RF-gun, because the pulsed power technology with a thermionic cathode are well established in high power vacuum tubes, such as klystron.

A cathode made from a single crystal of CeB_6 was chosen to produce a low emittance, extremely stable beam, because its surface maintains fairly flat at the nano-meter scale due to material evaporation. The gun voltage of -500 kV was chosen as a compromise between high-voltage breakdown technical problems versus the emittance growth due to space charge with lower voltages. Design beam parameters at the gun exit are summarized in Table 1.

Table 1: Design beam parameters at the gun exit.

Beam Energy	500 keV
Peak Current	3 A
Pulse Width (FWHM)	2 μsec
Repetition Rate	60 Hz
Normalized Emittance (rms)	0.4π mm mrad

THE CeB_6 CATHODE

The theoretical rms emittance of an electron beam emitted from a hot cathode is given by

$$\varepsilon_{n,rms} = \frac{r_c}{2}\sqrt{\frac{kT}{m_0 c^2}} ,$$

where r_c is the cathode radius and T is the cathode temperature. From the above relation, in order to obtain small emittance less than 1π mm mrad, the diameter of the cathode must be in the range of a few mm at the temperature of 1000~1500°C. To produce a several ampere peak current from the small surface, very high emission density (~50 A/cm^2) is required. The cathode that can generate such a high dense beam with long lifetime is the rare-earth hexaborides (LaB_6, CeB_6, etc.). We use a single crystal CeB_6 cathode, because it is widely used for electron microscope and the stability has been demonstrated.

The diameter of our CeB_6 cathode is 3 mm. 3A peak current will be produced when heated to 1450°C. The theoretical emittance is 0.4πmmmrad.

Fig. 1 shows the CeB_6 cathode assembly (left) and the cathode in heat run test (right). The CeB_6 crystal is mounted in a graphite sleeve. This is quite important to eliminate halo beam emission from the cathode edge which can cause damage to the undulator magnets [2]. We use a graphite heater rather than the conventional metallic filament such as tungsten, because it is stable at very high temperature.

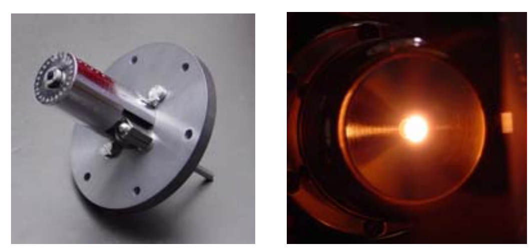

Figure 1: CeB_6 cathode assembly.

After 600 hours heat run test, the cathode was installed in the gun chamber. The pressure became as low as 1×10^{-6} Pa when the cathode was heated to 1500°C. The reference temperature was measured at the graphite sleeve by a radiation monitor. Up to now, this cathode has been heated for 2000 hours at 1500°C without failures.

500 KV ELECTRON GUN

We have constructed a 500 kV electron gun and an emittance monitor system (Fig. 2) [2]. All of the high-voltage components are immersed in insulating oil to reduce a risk of high-voltage breakdown failure. We use the same model of the C-band klystron modulator [3] to feed -24 kV pulsed voltage to the pulse transformer, which steps-up the voltage to -500 kV.

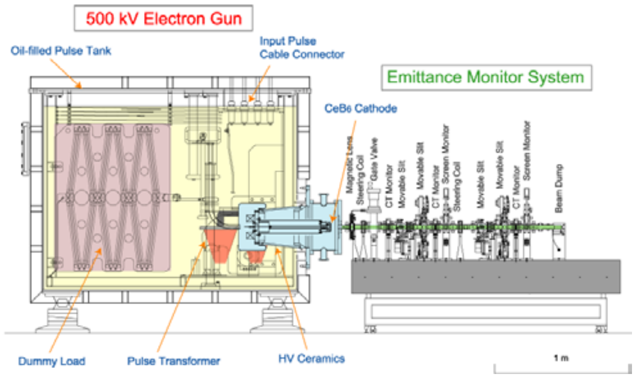

Figure 2: Schematic of the 500 kV electron gun and the emittance monitor system.

Fig. 3 shows the waveform of the gun voltage and the beam current. The beam current was measured by a current transformer (CT) located in the beam line right after the gun. The steep rising portion (0.4 μsec) at low voltage is a space charge limited current. The following portion (1.3 μsec) is rising slowly due to the Schottky effect in a temperature limited region. The flattop portion is 0.8μsec. It is slightly tilted due to droop of the CT monitor (~3%/μsec). The 1 nsec part in the flattop will be used for the SCSS accelerator.

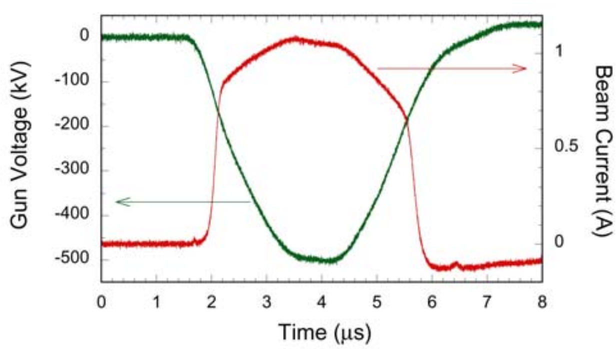

Figure 3: Waveform of beam current at 500 kV gun voltage.

EMITTANCE MEASUREMENT

We measured the beam emittance by the so-called double-slits method (Fig. 4). The upstream slit cut out a sheet shaped beamlet from the round beam, which spreads after passing through the drift space due to transverse thermal motion and space charge. The downstream slit measures the beamlet profile. By scanning the both slits throughout the whole beam area, the intensity profile in the phase space can be obtained.

We prepared four slits, two for horizontal (x-direction) scan and two for vertical (y-direction) scan. The upstream x-slit are located at 50 cm downstream from the cathode, followed by a 60 cm drift space and the downstream slit. The opening width must be narrow enough to ignore the beamlet broadening due to space charge. Fig. 5 shows the beamlet intensity profiles for several upstream slit width (25, 50, 100, 200 μm). The original beam energy and current was 400 keV and 0.9 A, respectively. The downstream slit width was set to 25 μm. Accuracy of the width and position is better than 10 μm. The profile became Gaussian for the narrow width less than 100 μm, as expected from the thermal spread. The beamlet broadening due to space charge is ~15% of the thermal spread at 50 μm width in the experimental condition.

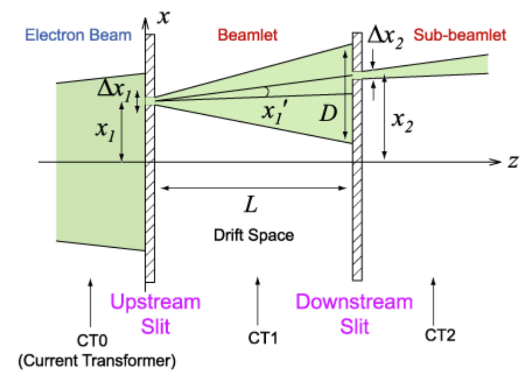

Figure 4: Principle of emittance measurement.

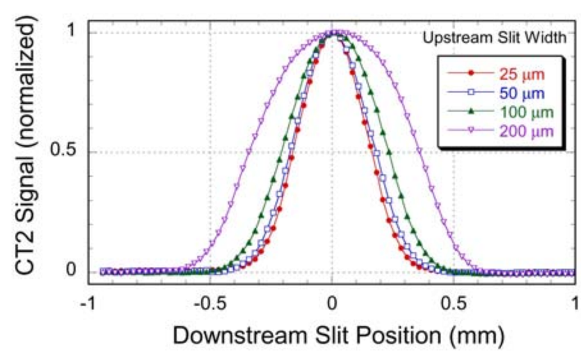

Figure 5: Beamlet profiles for different upstream slit width.

We found that the combination of a slit and a CT monitor with a digital scope is a very powerful tool to analyse the beam dynamics in time domain. The sub-beamlet current waveform provides the information about the time evolution of the phase space intensity at a certain point. From about 1500 waveforms stored by the slit scan, the time evolution of the phase space profile can be reconstructed. Fig. 6 shows an example of the animation screens of the phase space profile evolution.

Using a pair of vertical and horizontal slits, a time-resolved beam profile can be also measured by the same method.

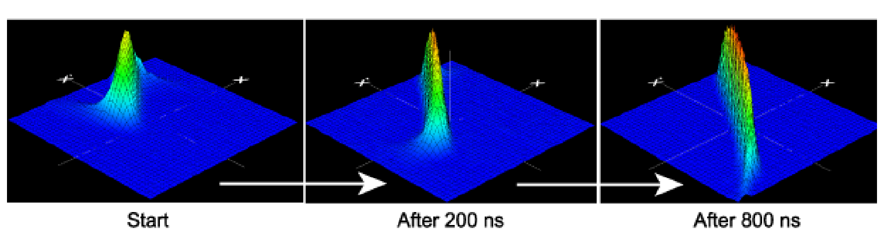

Figure 6: Time evolution of the phase space profile.

EXPERIMENTAL RESULT

We have measured the current density profile for the 500 keV beam with 1.0 A peak current. Fig. 7 shows the 3-demensional plot of the current density profile. The width for both the x- and y-slits was set to 0.5 mm × 0.5 mm and the scan step was 0.5 mm. It shows fairly flattop shape as we expected from the cathode geometry.

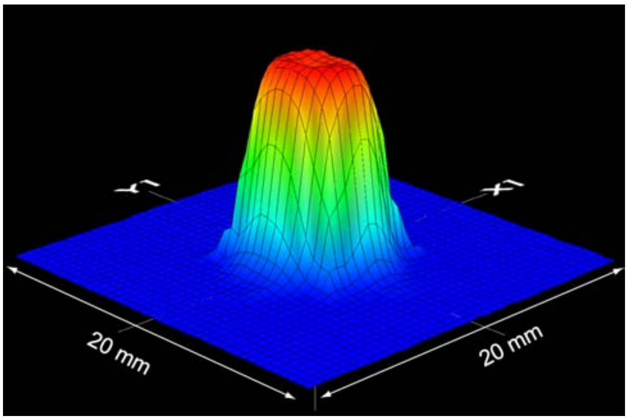

Figure 7: Current density profile of the 500 keV, 1.0 A beam.

Figure. 8 shows the 2-demensional plot of the phase space profile (x-direction) measured for the same beam parameters. The width for both the upstream and downstream slits was set to 50 μm and the scan step was 0.25 mm for the upstream slit and 0.1 mm for the downstream slit. From the phase space profile, we analysed the normalized rms emittance, defined as

$$\varepsilon_{n,rms} = \beta\gamma\sqrt{<x^2><x'^2> - <xx'>^2} \ ,$$

where $<x^2>$, $<x'^2>$ and $<xx'^2>$ denote mean square values weighted by current. The result was 1.1π mm mrad.

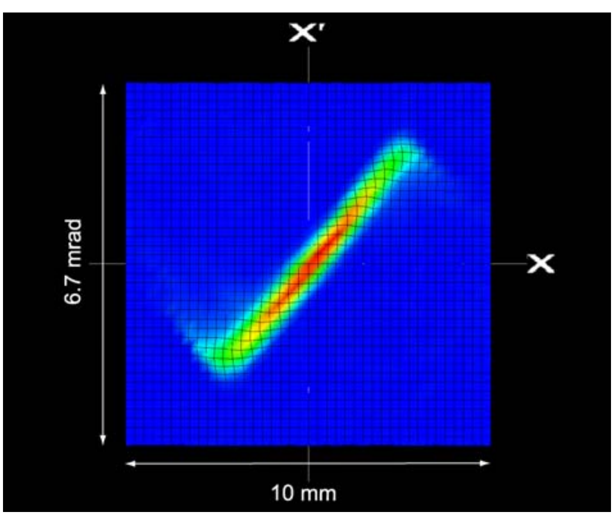

Figure 8: Phase space profile of the 500 keV, 1.0 A beam.

We achieved such a very small emittance, but it was somewhat larger than the theoretical value. The small tail at the profile edge should be a source of the emittance increase. In order to investigate the emittance growth, we have measured the emittance for the beam energies from 250 keV to 500 keV and the currents from 0.1 A to 1.0 A. Fig. 9 shows the emittance map as a function of beam energy and current. As clearly seen in the map, the emittance growth becomes more sever at lower energy and higher current. These data suggest that space charge is a cause of the emittance growth. We confirmed that the gun voltage as high as 500 kV is appropriate to generate a 1πmmmrad emittance beam.

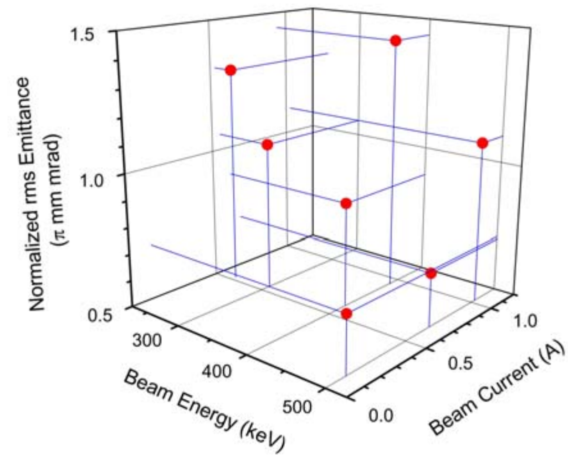

Figure 9: Emittance map as a function of beam energy and current.

The measurement of the rms emittance was very sensitive to the background noise. The noise signal of the CT monitor became a source of false emittance increase. The noise level (3σ) was ~1% of the peak intensity. To reduce the noise influence, we analysed the emittance using the signal which was larger than that of the noise level, then corrected it to the expected value without noise. In order to overcome this ambiguity, we will improve the noise reduction and study the method of emittance analysis.

Finally, the electron beam generated from the CeB_6 gun is very stable with low jitter. In 2004, we will develop a 238 MHz buncher system and measure the bunched beam emittance.

ACKNOWLEDGEMENT

We would like to thank the member of Sumitomo Heavy Industries for constructing the 500 keV electron gun and the emittance monitor. We also thank to the SPring-8 beamline group members for preparing the control system of the emittance monitor.

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