PULSED HV ELECTRON GUN WITH THERMIONIC CATHODE FOR THE SOFT X-RAY FEL PROJECT AT SPRING-8

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Abstract

A pulsed high-voltage electron gun with a thermionic cathode is under development 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, i.e., high resistance against contamination, uniform emission density and smooth surface [2]. Since we need to apply a -500 kV pulse to the cathode, all gun related high-voltage components; ceramic insulator, step-up transformer, dummy load etc. are immersed in insulating oil to avoid discharge problems. A same model of the C-band klystron modulator is used to provide -500 kV through a step-up transformer. We report on recent progress in the gun development.

ELECTRON INJECTOR CONCEPT

For the SCSS project, we chose a pulsed high-voltage electron gun with a thermionic cathode instead of a photocathode RF-gun. As is well known in SASE-FEL theory, the quality of the internal structure of the bunched beam dominates the FEL gain, that is, the sliced emittance of the beam should be very low to saturate SASE-FEL. Also from the FEL users point of view, the FEL light should be stable with low jitter over long time periods. Therefore, stability is essential for the electron gun. We believe that a cathode made from a single crystal of CeB_6 is suitable to produce such a low emittance, extremely stable beam, because its surface maintains fairly flat at the nano-meter scale due to material evaporation.

The CeB_6 cathode 3 mm in diameter will produce a 3 A beam with 2 μsec FWHM. The gun voltage of -500 kV was chosen as a compromise between HV breakdown technical problems versus the emittance growth due to space charge with lower voltages. Beam parameters at the gun exit are summarized in Table 1.

A beam chopper will be installed after the gun which will cut out the rising and falling parts of the pulse, and thus create a 2 nsec beam pulse. A 476 MHz pre-buncher modulates the beam energy to form a short bunch. The followed energy filter removes the energy tails (top and bottom). Finally an L-band accelerator captures the bunch, and accelerates it to 20 MeV. Fig. 1 shows the layout of the injector system of the SCSS project.

Beam Energy	500 keV
Peak Current	3 A
Pulse Width	2 μs FWHM
Repetition Rate	60 Hz
Normalized RMS Emittance	0.4 π.mm.mrad

Table 1: Beam parameters at the gun exit

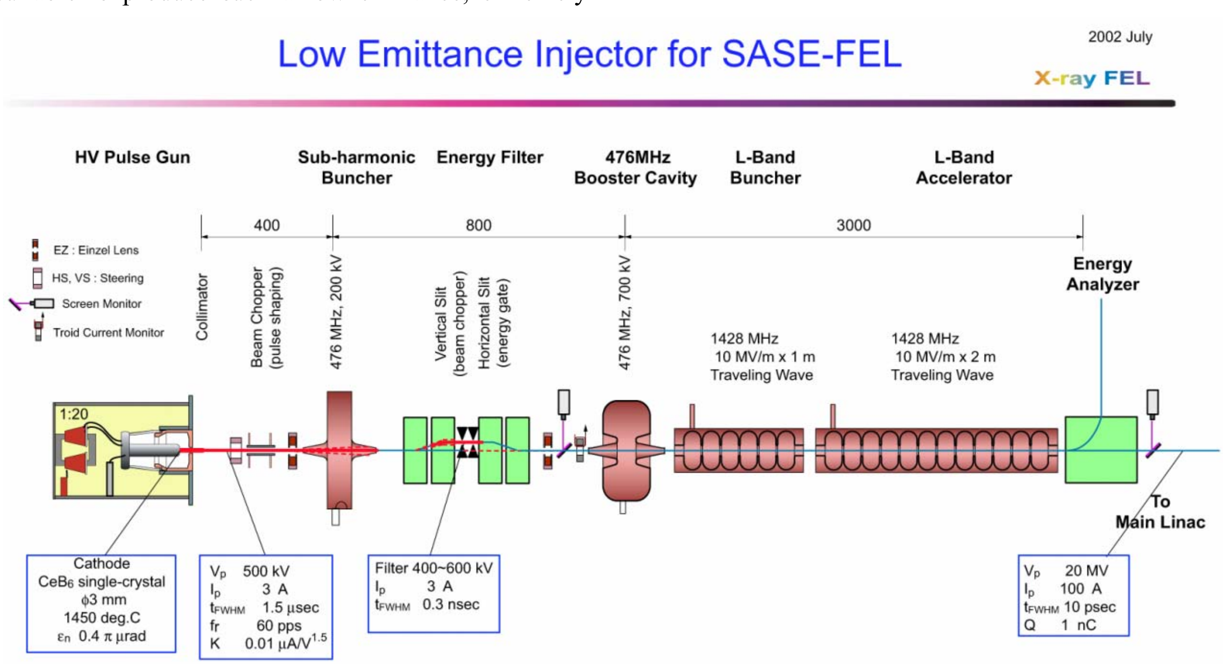

Figure 1: Injector system of SCSS project

CATHODE DEVELOPMENT

The normalized RMS emittance of an electron beam emitted from a hot cathode is described 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. It is obvious from the above relation that a small cathode is necessary to obtain a low emittance beam. The single crystal CeB_6 cathode with a 3 mm diameter will produce a 3 A peak current when heated to 1450 deg.-C. In this case, the beam emittance becomes as low as 0.4 π.mm.mrad, which is much lower than the requirement of 2 π.mm.mrad emittance for FEL operation at the undulator section.

Fig. 2 shows the cathode assembly. The CeB_6 crystal is mounted in a graphite sleeve. This produces a surface electric field uniform over the whole cathode area. This is quite important to eliminate halo beam emission from the cathode edge which can cause damage to the undulator magnets.

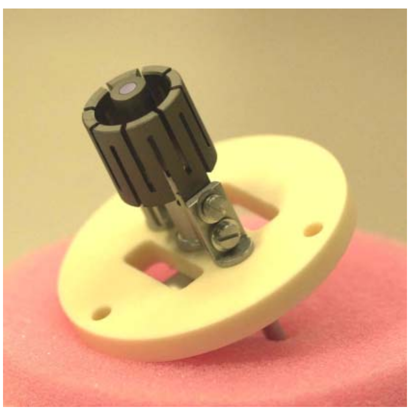

Figure 2: CeB_6 cathode assembly

We use a graphite heater rather than the conventional metallic filament made of tungsten or the like. Graphite is mechanically and chemically stable even at very high temperatures and does not evaporate like metal. Since its electric resistance does not change much as a function of temperature, it is easy to control the heater power. Fig. 3 shows the graphite heater in operation in the vacuum chamber. The cathode was heated up to more than 1450 deg.-C.

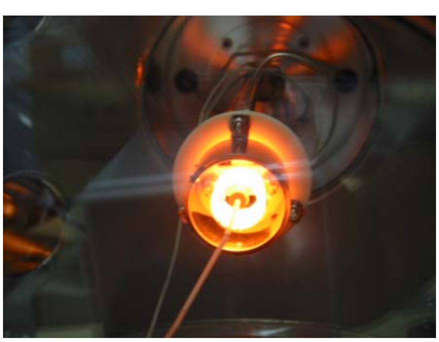

Figure 3: Heating test for the graphite heater

GUN GEOMETRY DESIGN

We chose a flat wehnelt rather than the common Pierce-type electrode. Our reasons are as follows. (1) The Pierce electrode has a strong focusing electric field which acts against the radial space charge force of the beam. If the cathode is not exactly centered on the axis of the gun, as may be caused by misalignment of cathode mount or movement of cathode position due to heating, the focusing field does not act on the beam symmetrically. This may cause emittance growth. The flat wehnelt do not have such an effect. (2) We plan to vary the beam current over a wide range in order to tune the accelerator system. The gun will be operated in a temperature limited region. The Pierce electrode is not suitable for such operation because a low intensity beam is over-focused at the electrode. The flat wehnelt never over-focuses the beam because there is no external focusing field.

In order to check emittance growth of the beam from the flat wehnelt, we have performed a computer simulation using the EGUN code. The beam trajectory and the phase space plots in a temperature limited region are shown in Fig. 4 and Fig. 5, respectively. The beam does not diverge much and the slope of the phase space plot becomes straight. The estimated emittance for a rough mesh size is deemed to be non-physical and to be caused by a simulation error. The emittance converges to 0.1 π.mm.mrad at a mesh size of 0.05 mm. We conclude that emittance growth due to space charge in the gun region can be ignored.

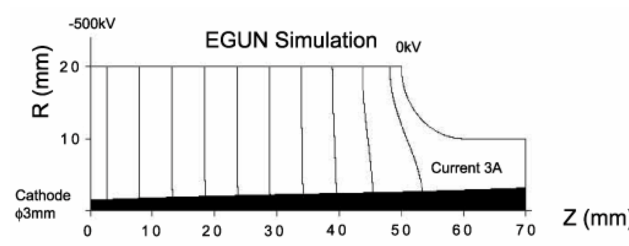

Figure 4: Beam trajectory simulated by the EGUN code

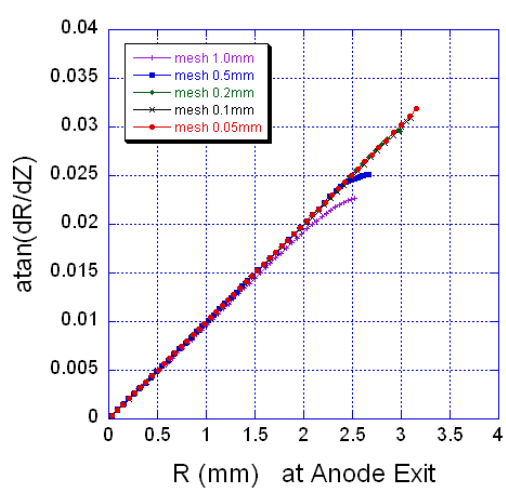

Figure 5: Phase space plot for various mesh sizes

500 KV GUN TEST STAND

We have constructed a 500 kV electron gun test stand and started performance tests. A side view of the test stand is shown in Fig. 6. It consists of the 500 kV electron gun and an emittance measurement system.

Since we need to apply a -500 kV pulse voltage to the cathode, all of the high-voltage components; ceramic insulator, pulse transformer, dummy load etc. are immersed in insulating oil to reduce discharge problems.

We use a same model of the C-band klystron modulator to feed -24 kV pulsed voltage to a pulse transformer, which steps-up the input voltage to -500 kV. In order to match the impedance of the gun to the modulator PFN circuit, a 1.9 kΩ dummy load is connected in parallel with the cathode.

We will measure the beam emittance by the so-called double slit method. Two sets of movable slits are installed in the beam line, one is for vertical emittance and the other for horizontal. The width and position of the slit gate can be controlled with an accuracy of 10 µm. Fig. 7 shows a photograph of the horizontal slit. The temporal profiles of beam currents are measured by means of core monitors. We also measure a time-resolved beam profile using a YAP:Ce fluorescent screen. We plan to measure emittance of a 500 keV beam from the CeB_6 cathode in this summer.

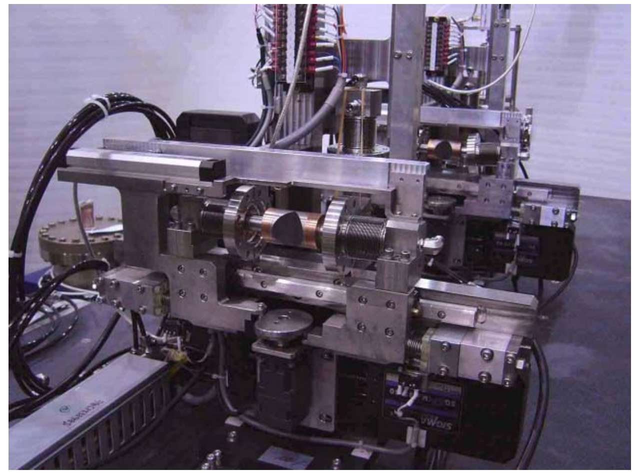

Figure 7: Photograph of the horizontal slit (the vacuum pipe has been removed)

REFERENCES

[1] http://www-xfel.spring8.or.jp/
[2] http://www.feibeamtech.com/

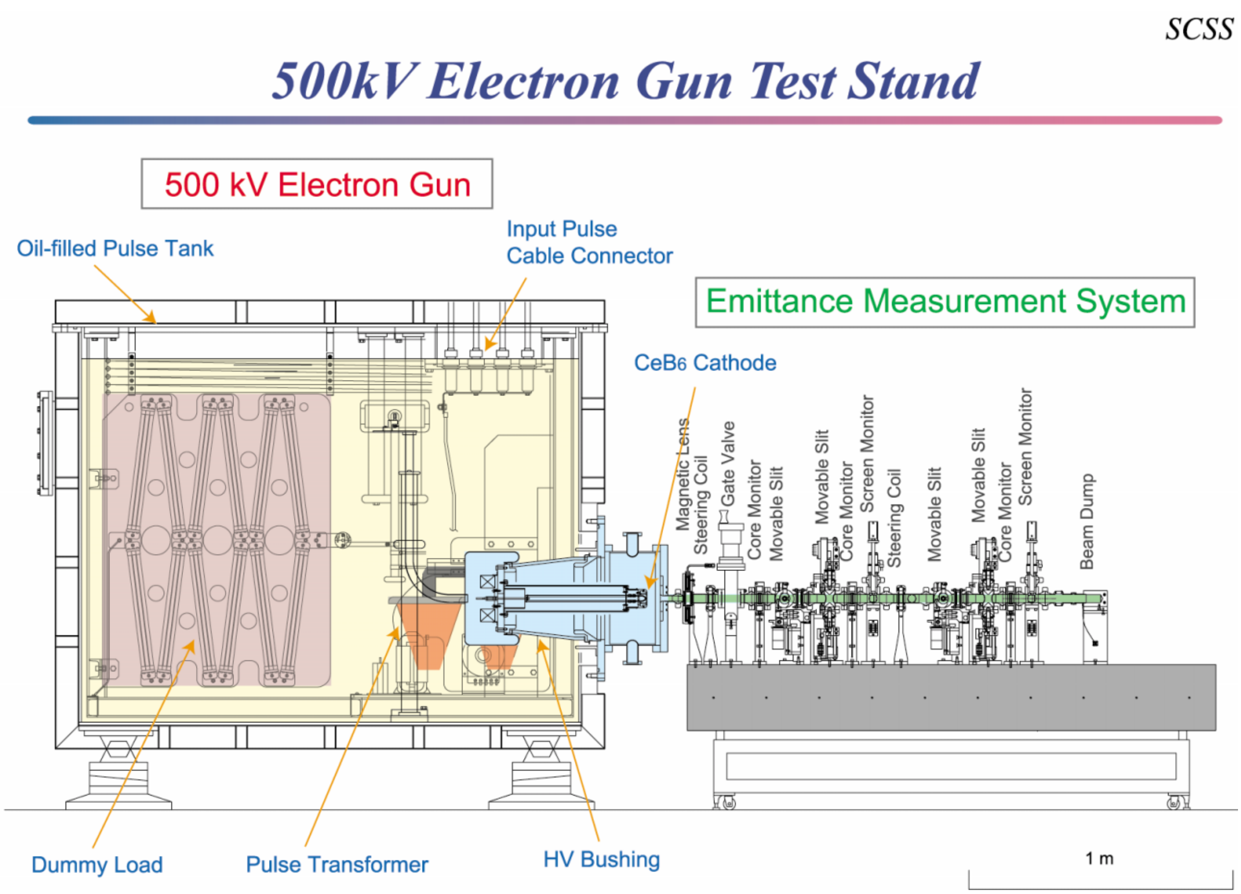

Figure 6: 500 kV Electron Gun Test Stand