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DEVELOPMENT OF A PRE-INJECTOR TEST BENCH FOR FUTURE SLRI LIGHT SOURCE

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Abstract

A pre-injector test bench at the Synchrotron Light Research Institute (SLRI) is under development as one of the preparations for the future SLRI light source and of choices for the possible upgrade of the current injector. The pre-injector test bench includes a pulsed thermionic gun, a fast pulse deflector, a buncher and a pre-buncher. The thermionic electron gun with a cathode made of a single crystal CeB_6 is employed as an electron emitter providing small emittance and uniform electron density. The fast pulse deflector shorten the extracted electrons of a few microseconds to that of a few nanoseconds. The electron pulses are further bunched by both the 238 MHz pre-buncher and the 476 MHz buncher to allow the 1-MeV electron beam. The experimental setups for emittance and beam profile measurements are installed on a movable diagnostic stand that is, later on, replaced by the beam bunching devices. The designs of the test bench will be discussed in this paper.

INTRODUCTION

Synchrotron Light Research Institute (SLRI) has initiated the development of a new pre-injector including an electron gun, a fast deflector, a pre-buncher, and a buncher as a beginning step before investigating a whole injector of a new light source. The new pre-injector aims to produce high quality electron beam with low emittance and short bunch matching to future accelerating components. The electron gun based on the thermionic cathode has been chosen due to a simple setup and operation as well as its low cost and long operational lifetime. Several key changes, such as removal of a pulsed grid and using hexaboride cathode instead of a tungsten, are required to modify the traditional thermionic electron gun in order to obtain electron beam with similar high quality to that from the RF photocathode gun. The operation of SACLA has successfully demonstrated in applying this concept to produce high quality electron beam for XFEL and Spring-8 synchrotron facilities [1].

OVERVIEW

The design of the electron-gun test bench is motivated by one of SASE-FEL at Spring-8 that has been in operation for more than a decade [2]. Figure 1 illustrates the layout of the electron-gun test bench. Electrons are produced from a thermionic cathode which is biased at −500 kV with a few microsecond pulse width. Extracted electron pulse of 500-keV energy is then shorten by a fast deflector to a few nanosecond range and the undesired electrons are absorbed to the collimator. A two-slit method, which is simple and straightforward, is used as a diagnostic system to measure emittance of the short-pulsed electron beam. This method requires three current transformers and two pairs of x-y slits. A beam profile monitor used to confirm the electron beam size is installed in front of a beam dump at the end of the transport line. One magnetic lens are mounted to focus the electron beam extracted from the anode, while the other focuses the short pulse electron beam traversing the fast deflector to the diagnostic system.

After the electron beam parameters have been measured, the diagnostic stand will be replaced by a pre-buncher and a buncher where three magnetic lens, located in between, are used to focus the electron beam. At the buncher exit, the electron beam energy will increase to 1 MeV with bunch length in range of picoseconds. The beam profile is measured by a streak camera and a cavity beam position monitor before deflected by a 90-degree dipole toward a beam dump. Because of high stability and convenience to perform alignment, a granite stand is used to support the electron-gun diagnostic system, see Fig. 2.

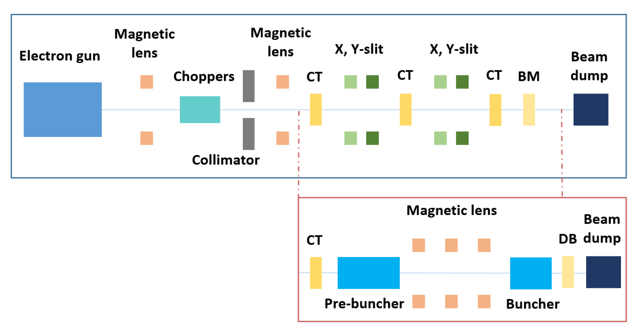

Figure 1: Layout of the electron-gun test bench.

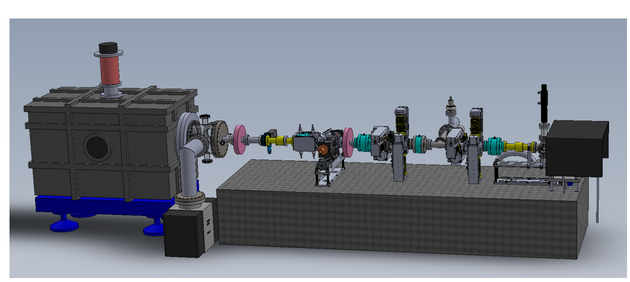

Figure 2: Design of the electron-gun test bench. A fast deflector and a diagnostic system are installed on the granite stand.

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ELECTRON GUN

An electron gun is an important component and its performance crucially affects to the quality of the electron beam. The target emittance of the electron gun is less than 1.0 π mm·mrad. According to $\epsilon_{n,rms} = r_c/2\sqrt{k_B T/m_e c^2}$, where k_B is the Boltzmann's constant and $m_e c^2$ is the electron rest mass energy; the normalized emittance $\epsilon_{n,rms}$ = 0.4 π mm·mrad can be obtained from the cathode with a radius r_c = 1.5 mm at temperature T = 1400 °C. The required current is greater than 1 A. In order to meet this criteria, the cathode made of rare-earth hexaborides, such as LaB_6 and CeB_6, is a good candidate and it has successfully been shown to achieve producing high electron beam current with a small cathode diameter and long operational lifetime. Comparing between these two crystals, the CeB_6 cathode is selected over the other due to lower work function, larger resistance to the negative impact of carbon contamination, and lower evaporation rate high temperature. The electron gun is designed to produce an electron beam of 500 keV to overcome the effect of the space charge during the extraction of electron beam. The design of the electron gun is shown in Figure 3.

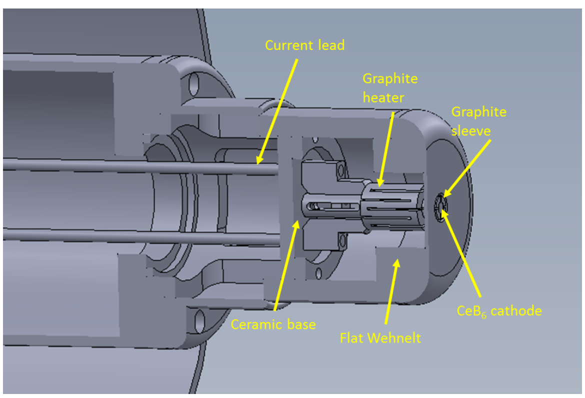

Figure 3: Assembly of the electron gun head.

FAST DEFLECTOR

A fast deflector plays an important role to allow the electron pulse of a few nanoseconds at peak to transport to the accelerating sections and is employed to reduce dark current of the electron gun that is observed downstream. The design of the deflector is similar to one operated at SACLA. Figure 4 shows a principle of a fast deflector. The fast deflector consists for a pair of coils creating magnetic field and two in-vacuum electrodes producing electric field. In the operation, the electrons are continuously steered off-axis and forced to dump on the collimator. When one electrode is applied by the high voltage pulse from a fast pulse DC power supply, the electric field is created to cancel the force acting on electrons with the same magnitude as the magnetic force and allow electrons to traverse through the collimator.

The electrode of 150 mm long and 50 mm wide made of aluminum is mounted with a gap of 25 mm. A collimator made of copper has been designed with several hole sizes in order to remove the beam edge causing emittance growth. Since the collimator is fixed both sides to the linear driver due to its weight, one hole must be sufficiently larger than the beam size to allow the beam edge to pass through. The collimator is also water-cooled to reduce heat generated by the electron bombardment. Maximum voltage given by the power supply is at 5 kV with rising time of 500 ps and pulse width of 2 ns.

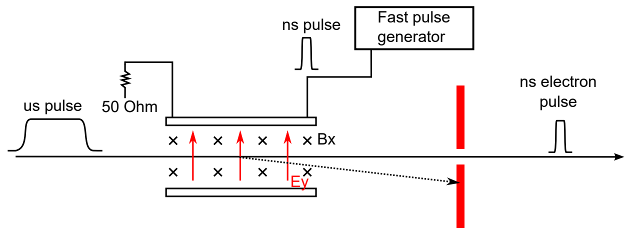

Figure 4: Concept of short electron pulse production.

PRE-BUNCHER AND BUNCHER CAVITY

Pre-buncher

The sub-harmonic buncher or a pre-buncher cavity has been designed with resonance frequency of 238 MHz, which is the 1/12 of S-band frequency 2856 MHz. This cavity is a pillbox type cavity with a nose structure. The buncher cavity that will be made of oxygen-free high conductivity copper has 49.15-cm inner diameter, 51-cm cavity length, and 8-cm nose gap. The 3D electric field distribution of the pre-buncher is shown in Figure 5(left). The nose is tapered for mechanical stability and prevents changing of frequency from vibration. The SUS ring is used at the RF input to reduce the influence of temperature change, when applying RF input, on the gap voltage and the frequency. Although this additional SUS ring decreases the unloaded quality factor (Q0) of the cavity, this Q0-valus is still in acceptable range.

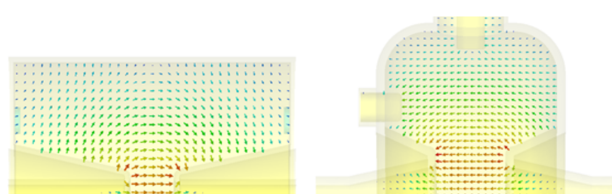

Figure 5: Electric field distribution of a pre-buncher (left) and a buncher (right).

Buncher

In order to keep electron bunched and accelerated, a buncher cavity is needed. The electron beam is further bunched by the buncher cavity and accelerated 500 keV to 1 MeV. The buncher is designed with the resonance frequency of 476 MHz, which is a double of the pre-buncher frequency. The cavity is a reentrant type single cell cavity. The beam pipe diameter is 20 mm, noise gap is 80 mm, cavity inner diameter is 376 mm, and hollow cavity length is

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200 mm. The nose is tapered for mechanical stability in consideration of frequency change due to external vibration as well. Figure 5(right) depicts the 3D electric field distribution of the buncher.

DIAGNOSTIC SYSTEM

Electron beam parameters required to determine the efficiency of the electron gun are electron beam current, energy spread, and emittance of the 500-keV electron beam as well as the electron beam profile. Two types of the diagnostic systems will be employed: a double-slit used for emittance measurement and an RF cavity beam profile monitor.

A double-slit method is employed to measure transverse emittance of the electron beam. The extracted electron beam current is measured by the current monitor that locates next to the first magnetic lens. The beam current monitor must be fast enough to monitor the short pulse of a few nanoseconds with repetition rate of 60 Hz. Two current monitors that measure current of electron passing through the slits are installed next to each pair of an x-y slit. The slit can be adjusted with a step of 10 μm. Since the electron beam is deflected by the 90-degree bending magnet toward a beam dump, such magnet can be used to measure the energy spread as well. Before the electron beam impinges on the beam dump, the electron beam profile can be obtained by a beam profile monitor or a screen monitor using scintillating material such as YAG:Ce together with a CCD camera.

For the beam profile monitoring system, a high precision with very small resolution of the beam position monitor is required. An RF cavity beam position monitor having a high beam-cavity coupling can fulfill this requirement with a high precision together with the resolution of less than 0.5 μm. The previous designs and experiments can achieve the nanometer-level resolutions [3]. RF-BPM also has capability to detect beam arrival time from the phase of an excited RF signal.

PREPARATION OF TEST AREA

Available area of 140 m^2 inside the accelerator multipurpose room has been allocated for setting up the electron gun laboratory. It is divided into three small areas: an electron-gun test area, a storage and preparation area, and a meeting area. The electron gun test stand in the middle of the electron-gun test area is covered by the local shield preventing secondary electrons and high energy photons. The MCNP code was used to calculate thickness of the shield. Distribution of secondary electrons and photons are illustrated in Fig. 6. The shielding cover will be constructed with dimension of 2-m wide and 4-m long and consisted of 2.5-cm thick lead sandwiched by 2-mm aluminum sheets. The simulated results obviously show that secondary electrons and high-energy photons are well confined inside the local shielding wall. The storage and preparation area is reserved for assembling small parts and testing cathode in the cathode test chamber. A crane to support load of at least 1.0 t will be used to move heavy items such as a local shielding cover, an insulating tank, a granite test stand, etc. Utilities provided are partly constructed for the previous usage. Three-phase electric power is already prepared and connected from the separated high-power transformer located outside the building. The high-power electric control panel will be installed once the layout is finalized. The cooling water system for the high voltage transformer and the pulse modulator as well as the beam dump will be newly constructed.

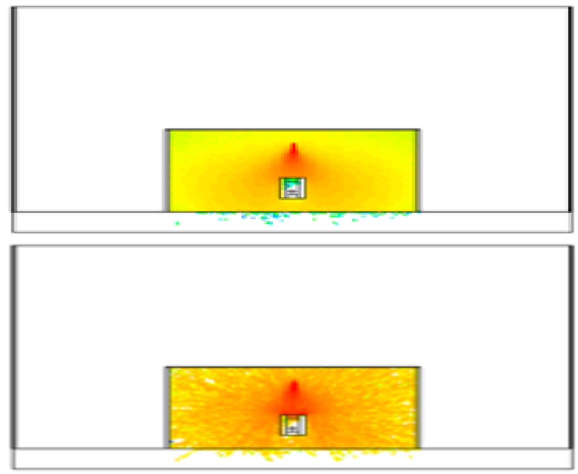

Figure 6: Distribution of secondary electrons (top) and photon (bottom).

CONCLUSION

SLRI has started to develop a prototype of a new pre-injector as the first step to prepare for building a new light source. Based on the SACLA design, the specification of the pre-injector consisting of a thermionic electron gun, a fast deflector, a pre-buncher, and a buncher have been determined. With a combination of high voltage pulse extraction and a fast deflector, a nanosecond electron beam of 500 keV could be obtained and the bunch length is reduced further to a few picosecond at 1 MeV electron-beam energy after an electron bunch passes through the pre-buncher and the buncher. The diagnostic devices have been selected to measure electron beam emittance and its profile. The test area has already been prepared for assembling the pre-injector test bench and testing all components.

REFERENCES

[1] T. Hara, K. Togawa, and H. Tanaka, "Progress in SACLA Operation", in *Proc. FEL'12*, Nara, Japan, Mar. 2012, paper MOOB03, pp. 5–8.

[2] K. Togawa *et al.*, "CeB_6 electron gun for low-emittance injector", *Phys. Rev. ST. Accel. Beams*, vol. 10, p. 020703, Feb. 2007. doi:10.1103/PhysRevSTAB.10.020703

[3] H. Maesaka *et al.*, "Performance of the RF cavity BPM at XFEL/Spring-8 SACLA", in *Proc. FEL'11*, Shanghai, China, Aug. 2011, paper THPA29, pp. 539-542.