EXPERIMENTAL APPROACHES FOR THE BEAM DYNAMICS STUDY IN THE PC RF GUN AT THE PAL*

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Abstract

A high-brightness electron beam is emitted from a photo-cathode (PC) RF gun for use in the FIR (Far Infrared) facility being built at the Pohang Accelerator Laboratory (PAL). The beam dynamics study for the PAL XFEL injector is essential to generate low emittance electron beam from the PC RF gun. The XFEL injector requires 1 nC beam with short bunch length and low emittance. These conditions are simulated with PARMELA code and then are realized on experimental conditions. The experimental conditions for the XFEL injector are measured with beam diagnostic devices such as ICT and Faraday cup for charge measurement, a spectrometer for beam energy measurement. In this article, we present the experimental approaches of the beam dynamics study for the XFEL injector.

INTRODUCTION

The Pohang Accelerator Laboratory X-ray Free Electron Laser (PAL X-FEL) is proposed with self amplifiered spontanous emision (SASE) lasging scheme that will use the final 3.7 GeV for the drive beam energy. The performance of the PAL XFEL in the 3.0 Angstrom regime is predicted on the capacity of 1 nC, 100 A beam at the end of the photoinjetor with transverse normalized rms emittance of 1.2 mm-mrad. For the low emittance beam, emittance compensation scheme is essential for the design and commitioning of the photoinjector [1-2].

To meet these requirements, the S-band PC RF gun has been installed in Gun Test Stand (GTS) at the PAL as the photocathode gun R & D for PAL XFEL (X-ray Free Electron Laser), fs-FIR (femto-second Far Infra-red Radiation), and FED (Femto-second Electron Diffraction) experiments. The PC RF gun consists of 1.6-cell cavity with single emittance compensation solenoid in order to obtain the required minimum emittance. The PC RF gun generates short electron bunches with short laser pulses from a copper cathode. The experimental conditions for the XFEL injector are measured with beam diagnostic devices such as ICT and Faraday cup for charge measurement, a spectrometer for beam energy measurement.

In this article, we present the experimental approaches of the beam dynamics study for the XFEL injector.

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BEAM DYNAMICS SIMULATIONS

The beam dynamics simulations in the cavity as a function of the laser injection phase are performed by the PARMELA code. The results of the simulations are represented the energy change in the cavity with 79 MV/m, 65 MV/m, and 53 MV/m electric field at the cathode as shown in Fig. 1 (a), (b), and (c), respectively. In the low laser injection phase, the beam energy is increased in the both cells. However, in the high laser injection phase, the beam energy is increased at first of the cells and decreased at second of the cells due to the deceleration forces. These phenomena are clearly appeared in the simulation with the low electric field at the cathode.

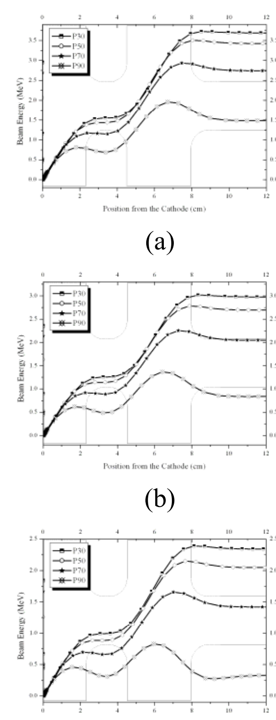

Figure 1: The beam energy simulation in the cavity as a function of the laser injection phase. These simulations are performed under the condition of (a) 79, (b) 65, and (c) 53 MV/m electric fields at the cathode.

Also, Fig. 2 shows the simulation results of the beam energy at the end of the cavity as a function of the laser injection phase with various electric fields in the cavity. The beam energy at the exit of the RF gun is decreased as the laser injection phase is increased with low electric field.

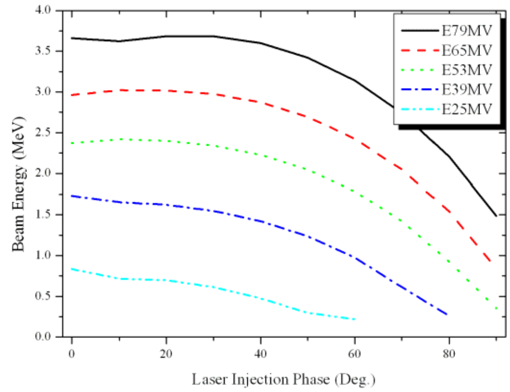

Figure 2: The beam energy simulation as a function of the laser injection phase with various electric fields in the cavity.

EXPERIMENTAL SETUP

The GTS has been constructed at the PAL as the photocathode gun R & D for PAL XFEL. Figure 3 shows the experimental setup of the GTS at the PAL with a 1.6 cell photocathode S-band (2,856 MHz) RF gun with a solenoid containing 8 pancake-like coils. After the gun, a solenoid for the transverse emittance compensation is directly mounted with four ceramic keys for thermal isolation. A steering magnet with maximum magnetic field of 80 Gauss is installed inside of the solenoid bore. The solenoid magnetic field strength and field profile are measured based on the hall probe method [2].

An integrating current transformer (ICT) to measure the beam charge is located immediately following the solenoid. After the ICT, there is a fluorescent screen to measure and monitor the beam profile. The screen is made of a 15 μm layer of YAG:Ce doped on 100 μm thick aluminum substrate to prevent charge build up, and is mounted on a vertically movable aluminum holder at 45° with respect to the beam axis. The position of the screen is 0.56 m from the cathode. A charge coupled device (CCD) camera is synchronized to the electron beam for a shot-to-shot measurement of the electron beam image.

At the downstream of the screen chamber, there is a spectrometer with 60° dipole magnet to measure the beam energy and the energy spread. When the spectrometer turns off, the beam goes straight to the downstream beam-line. When the spectrometer turns on, the beam goes to the beam analyzing screen. The beam analyzing screen is mounted on a fixed aluminum holder at 45° with respect to the beam moving direction. Figure 3 shows the drawings and the photograph of the spectrometer magnet. If the applied current of the magnet is increased, the magnetic field of the spectrometer is also increased. The beam energy is in proportion to the applied magnetic field strength on the spectrometer.

We have designed the emittance meter (E-Meter) which has a movable slit chamber and a screen chamber along the beam axis with independent bellows. The transverse emittance evolution after the solenoid in a drift space predicted by the emittance compensation theory and simulation is measured with this E-Meter. The E-Meter is shown in the right side of Fig. 3. The E-Meter consists of a slit chamber with 4-axis moving stage and a screen chamber to measure the beamlet size. The slit chamber is equipped with a single slit plate to make beamlet and a YAG screen to measure the main beam size [4]. The screen chamber is equipped with a YAG screen to measure the size of the beamlet made by the slit plate. The distance from the slit chamber to the screen chamber can be adjusted according to the beam divergence. If the beam has a large divergence, the distance should be short, and vice versa, to make an optimized image size on the

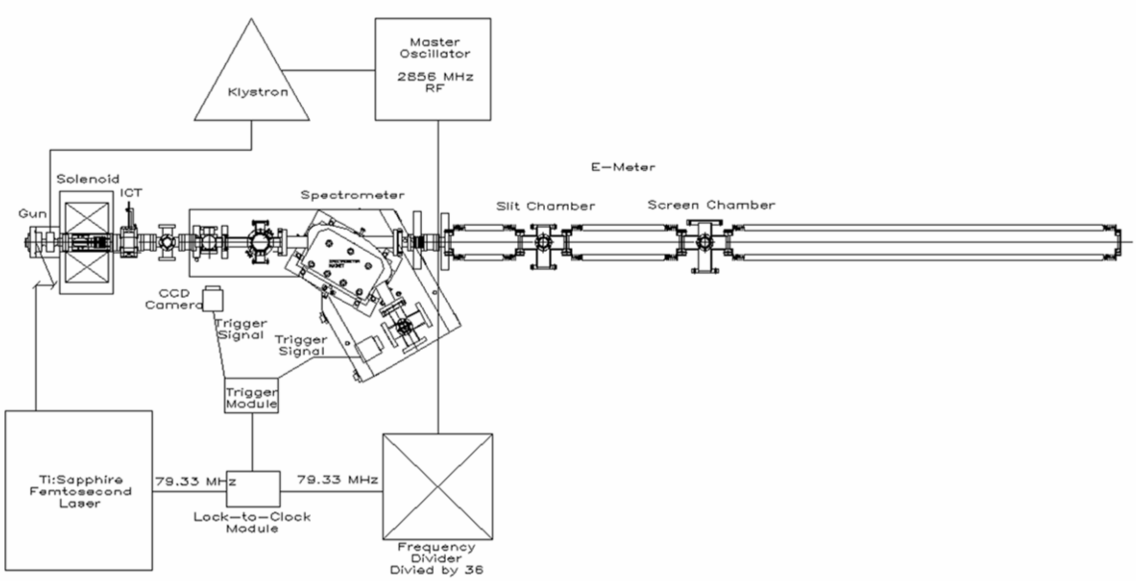

Figure 3: Schematic diagram of the gun test stand (GTS) at the PAL. The GTS consists of 1.6-cell PC RF gun with emittance compensation solenoid, a Ti:Sa femto-second laser, a spectrometer, and an E-Meter.

screen. The position of the slit plate chamber and the screen chamber cameras can be monitored by two CCD, independently. The plates for single slit are made of tungsten with 0.5 mm thickness. There are three slits in the plate, which are fabricated by high power laser micro-drilling with silt sizes of 30, 40, and 50 µm, respectively. The slit plates in the slit chamber are vertically mounted with a stepping motor to be changeable at the specific experimental position. The sizes of the slit are determined by considering the signal to noise ratio of the beamlet on the screen and the acceptance angle when the beam goes through the slit plate [4]. We have designed to align the slit plate and the screen by the 4-axis moving stage of a goniometric motion, a rotary motion, x and y linear motions with high accuracy stepping motor on the slit chamber, respectively. Scanning the single slit is used usually with y directional linear motion which requires a precision moving control for the full measurement of small beam size [5].

EXPERIMENTAL RESULTS

The beam energy and the energy spread at position 1.2 m from the cathode are measured by a spectrometer magnet which consists of a 60° bending magnet and a screen for the beam profile measurement. The distance between the spectrometer magnet and the screen is 0.5 m. If the beam is entered with certain angle with respect to normal direction, an error of the beam energy come into the measured value. At our beam energy measurements the energy error is minimized by entering without the certain angle by two screens and two steering magnets in front of the spectrometer magnet. The energy spread of the beam is measured by the beam size on the screen. The beam energy can be estimated by measuring of the current of the spectrometer magnet when the beam is imaged at the center position on the screen. The beam energy can be analyzed by the spectrometer field integral [6],

$$E[GeV] = \frac{0.29979}{\theta} \int Bdl \, [T \cdot m / rad], \qquad (1)$$

where $\int Bdl$ is the integrated dipole field and θ is the geometrical bending angle. The beam energy with the laser injection phase is measured by the spectrometer magnet as shown in Fig 4. The laser injection phase with the maximum energy is measured to be 1° that is a correspondence between the simulation and the experimental result in low field gradient [6]. When the laser injection phase is changed by a phase shifter, the beam charge and the beam energy are changed. Thus the solenoid current for the beam focusing on the screen should be simultaneously changed. The relative energy spreads at the laser injection phase of 10° and 30° are measured to be 0.67 %, 2.20 % rms, respectively. The beam energy is decreased as the laser injection phase is increased, but the energy spread increases as the beam energy decreases. Figure 5 shows the beam energy as a function of the field gradient on the cathode surface at the laser injection phase of 1°.

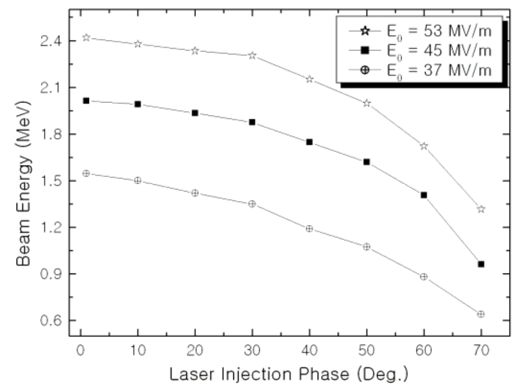

Figure 4: The beam energy as a function of the laser injection phase with different field gradients.

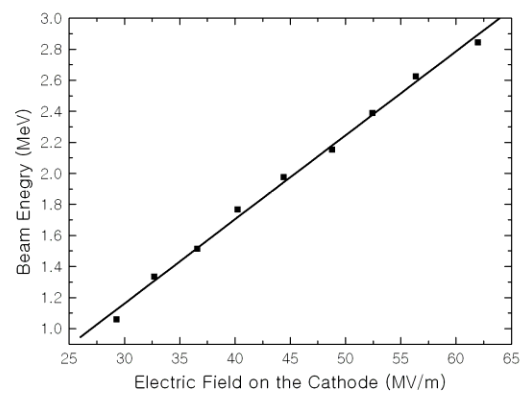

Figure 5: The beam energy as a function of the field gradient in the RF gun.

SUMMARY

An advanced beam diagnostic devices with 6-D beam measurements and the beam dynamics studies such as the emittance compensation will be continuously developed and performed with PC RF gun at the PAL.

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