BEAM MEASUREMENT OF PHOTOCATHODE RF-GUN FOR PAL-XFEL

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Abstract

The Injector Test Facility (ITF) at Pohang Accelerator Laboratory (PAL) was constructed to develop an injector for the PAL X-ray free-electron laser (PAL-XFEL) project. The PAL-XFEL design requires the injector to produce an electron beam with a slice emittance of 0.4 mm-mrad at the charge of 200 pC. A 4-hole type RF-gun has been successfully fabricated and tested at ITF. In this paper we report the recent beam-measurement results using the RF-gun at ITF. Emittance measurements have been carried out by changing laser and RF parameters.

INTRODUCTION

Pohang Accelerator Laboratory X-ray Free Electron Laser (PAL XFEL) is now under construction [1].This construction will be finished at the end of 2015. There will be a hard X-ray (0.1nm) beamline with self-seeding scheme with 10 GeV electron beam. There is a 3 GeV branch also to make 1 nm soft X-ray radiation. As part of the PAL-XFEL project, the Pohang Accelerator Laboratory (PAL) constructed the Injector Test Facility (ITF) [2].

The schematic diagram of the ITF beam-line is shown in Fig. 1. The ITF beam-line consists of the RF-devices, magnets and several diagnostic devices. In the 4-hole type RF-gun ('GUN') an electron beam is generated [3]. Downstream of the 'GUN', the emittance compensation solenoid ('S1') which enables the correction of space charge emittance growth is mounted. Downstream of the solenoid, the Turbo Integrating Current Transformer ('ICT1') is installed to measure electron bunch charge. YAG screen #1 ('Y1') is located at the downstream of 'ICT1' to measure the transverse beam profile. Then the electron beam is accelerated by two 3-meter J-type S-band linacs ('ACC1' and 'ACC2') for which enough to accelerate the beam up to 140 MeV. After acceleration the emittance will be measured using the quadrupole #3 ('Q3') and screen #5 ('Y5'). Finally the electron beam will be dumped at the end of the beam-line or after screen #6 ('Y6'). All diagnostic devices are synchronized to the electron beam. The important divice for each measurements is described in Table 1. The control system of ITF is based on the Experimental Physics and Industrial Control System (EPICS).

Table 1: Electron Beam Diagnostics

Measurement	Main Divice	Additional Divice
Size	Y1 to Y5	-
Position	B1 to B5	Y1 to Y5
Charge	ICT1	B1
Energy	D2 + Y6	D1 + Y7
Bunch Length	T-CAV + Y5	-
Arrival Time	BA	-
Emittance	Q3 + Y5	-

EXPERIMENTAL RESULT

Image

The beam size, position and profile are measured using YAG crystals imaged with CCD cameras for image processing. The screen system is manufactured form RADIA BEAM. The images were acquired with an 14-bit CCD camera synched to the electron beam. The lens was set to give a calibration of 8 μm per pixel to allow a compromise between capturing the full variation of the beam size and maximizing the resolution of smallest spot size. Typically five images of the beam are taken at each processing. Typical image of the each screens as shown in Fig. 2.

Charge

Bunch charge is measured using the Tubo Integrating Current Transformer ('ICT1') which is made by BERGOZ. The quantum efficiency (QE) of the photocathode is defined by the ratio of photons hitting the cathode surface and generated electrons. This ratio is expressed as

$$QE = 4.47 \times 10^{-6} \frac{Q_{\text{e-beam}}(\text{pC})}{U_{\text{laser}}(\mu\text{J})}, \qquad (1)$$

where $Q_{\text{e-beam}}$ is the photoelectron charge, and U_{laser} is the laser pulse energy. In this case the wavelength of laser is 256 nm. Measurement of bunch charge versus laser energy is shown in Fig. 3. The slope of fitting line gives the quantum efficiency of the copper cathode, which is 1.26×10^{-4}. We also measure bunch charge as a function of laser injection phase as shown in Fig. 4.

Energy

Beam energy and energy spread are measured using the dipole spectrometer. In ITF, there are two types of spectrometers. One is the 90° dipole spectrometer ('D1'+'Y7') for low-energy measurement. The other is the 30° dipole spectrometer ('D2'+'Y6') for high-energy measurement. The electron energy, U and the energy spread, $\frac{\Delta U}{U}$ at the exit of the RF-gun can be written as [4, 5]

$$U = m_e c^2 \left[1 + \frac{\alpha}{2}\left(kL\sin(\phi_f) + \sin(kL)\sin(\phi_f + kL)\right)\right], \qquad (2)$$

$$\frac{\Delta U}{U} = \frac{1}{U}\frac{dU}{d\phi_0}\Delta\phi_0, \qquad (3)$$

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ISBN 978-3-95450-133-5

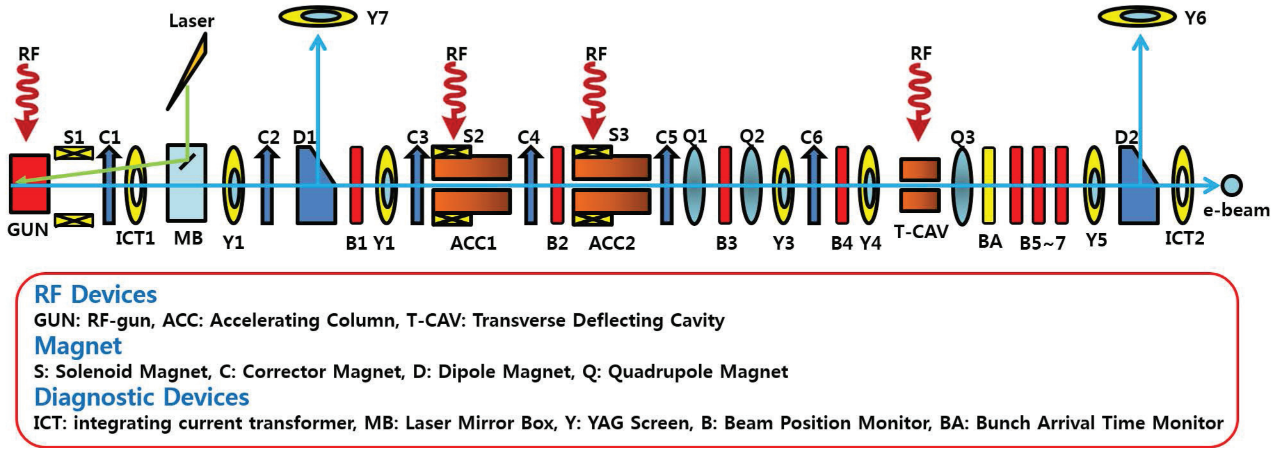

Figure 1: Schematic diagram of the ITF beam-line.

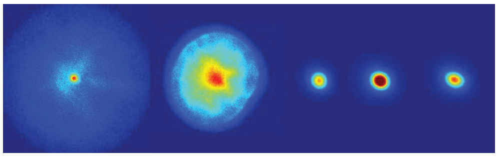

Figure 2: Typical image of the each screens (Left to right: 'S1' to 'S5').

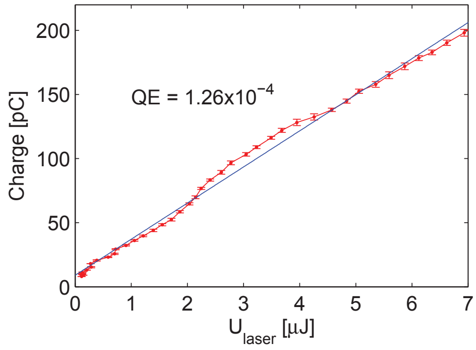

Figure 3: Measured bunch charge versus laser pulse energy. The solid line represents a linear fit.

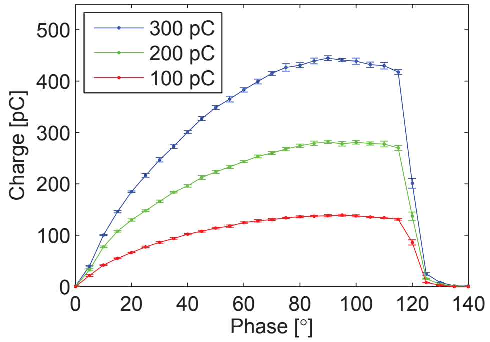

Figure 4: Measured bunch charge versus laser injection phase.

where m_e is the electron mass, and c is the speed of light, k is the wavenumber. $L = 0.105$ m is the length of the rf gun cavity, $\Delta\phi_0$ is the laser pulse length. In these equations, α and ϕ_f are seen the reference [4]. Measured energies and their spreads as a function of injection phase at the high-energy spectrometer ('D2'+'Y6') are shown Fig. 5. In these figures, dashed lines are just guides to the eye and solid lines represent the calculated values from Eqs. (3). These solid lines show a good agreement with the experiment results.

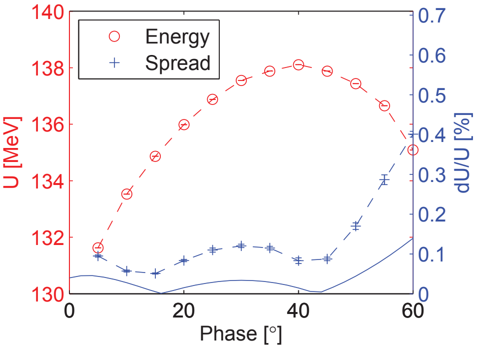

Figure 5: Measured electron energy and energy spread versus laser injection phase at the high-energy spectrometer.

Emittance

Downstream of the 'ACC2' the projected emittance of the electron beam is measured using the single quad-scan technique whereby the rms beam size, σ is measured on 'Y5' and the quadrupole strangth , k of 'Q3'. To calculate the emittance, we use formula;

$$\epsilon = \frac{1}{dL^2}\sqrt{ac - \frac{b^2}{4}}, \tag{4}$$

where $d = 0.147$ m is the effective length of 'Q3', $L = 2.64$ m is the distance between 'Q3' and 'Y5', and a, b, c are determined by following equation;

$$\sigma^2 = ak^2 + bk + c. \tag{5}$$

Emittance measurements were made with 200 pC of charge using a longitudinal Gaussian pulse with a FWHM of 3 ps, at a laser phase of 40°, a gun energy of 5.75 MeV, and -10° off crest in ‘ACC1’ with a accelerating field gradient of 21 MV/m and ‘ACC2’ is not used. The square of σ versus k for one of the scans is shown in Fig. 6 as an example. The emittance as a function of ‘S1’ current when the laser shape are shape #1, #2, and #3 are shown in Fig. 7.

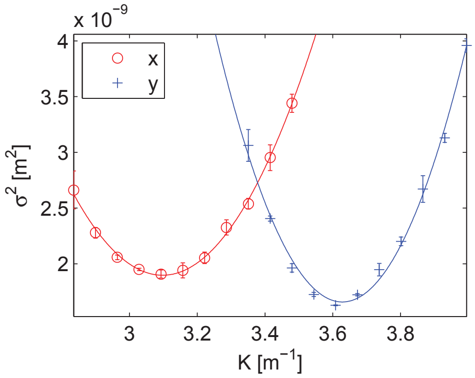

Figure 6: The square of σ versus k for one of the scans.

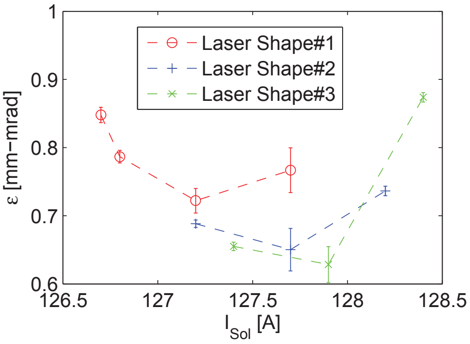

Figure 7: The emittance as a function of the solenoid current.

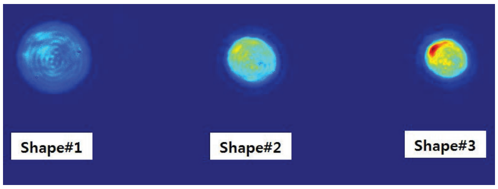

Figure 8: The laser images of the ‘Shape#1’, ‘Shape#2’, and ‘Shape#3’.

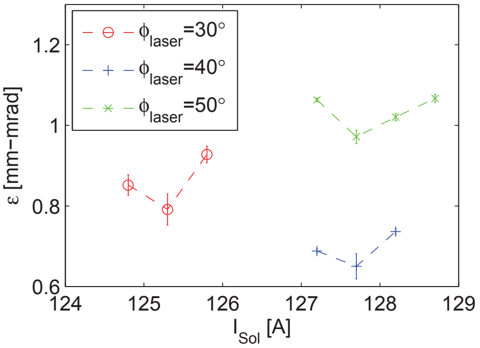

Figure 9: The emittance as a function of the solenoid current.

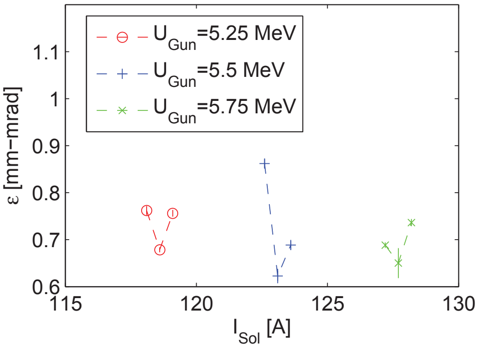

Figure 10: The emittance as a function of the solenoid current.

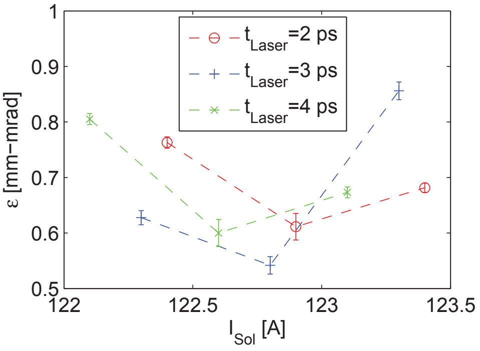

Figure 11: The emittance as a function of the solenoid current.

Figure 8 shows the laser images of ‘Shape#1’, ‘Shape#2’, and ‘Shape#3’. The emittance as a function of ‘S1’ current when laser shape are shape #1, #2, and #3 are shown in Fig. 9. The emittance as a function of ‘S1’ current when RF-gun energies of 5.25 MeV, 5.5 MeV, and 5.75 MeV are shown in Fig. 10. The emittance as a function of ‘S1’ current when laser pulse length of 2 ps, 3 ps, and 4 ps are shown in Fig. 11. Slice emittance for the horizontal direction was measured by streaking a bunch vertically using ‘T-CAV’ [6]

SUMMARY

This paper summarizes the current status of ITF gun operation. The detailed system parameters and typical electron beam parameters are described in Table 2. In these measurement, the quantum efficiency of the copper cathode is 1.26×10^{-4}. The relative beam energy spread for a laser injection phase around 40° is about 0.1% rms. The lowest transverse emittances are $\epsilon_x = 0.481 \pm 0.010$ mm-mrad and $\epsilon_y = 0.597 \pm 0.020$ mm-mrad. For the lowest trans-

Table 2: ITF System and Electron Beam Parameters

Parameter	Value	Unit
RF-gun		
Operating Frequency	2856	MHz
Mode Separation	17	MHz
Quality Factor	13200	
RF-pulse Width	2	μs
Repetition Rate	10	Hz
Laser		
Laser spot size	$\sigma = 0.14$	mm (rms)
Laser Pulse Length	2.9	ps (FWHM)
Laser pulse energy	7	μJ
Laser injection phase	38	$^\circ$
Electron Beam		
Energy	70	MeV
Energy Spread	0.1	% (rms)
Charge	200	pC
Length	3	ps

verse emittance, we need more optimization of various parameters. Studies to improve the laser profile and more optimization of various parameters will be conducted in the future. Measured results also will be compared with simulation results.

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