HIGH-POWER RF TEST OF AN RF-GUN FOR PAL-XFEL

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Abstract

A photocathode RF-gun for the X-ray free electron laser (XFEL) at the Pohang Accelerator Laboratory (PAL) has been fabricated and tested at PAL. This RF-gun is based on a 1.6-cell cavity with dual-feed waveguide ports and two pumping ports. The RF gun was designed by PAL and POSTECH. The RF-gun has been successfully tested with a cathode electric field gradient up to 126 MV/m at a repetition rate of 30 Hz. This paper reports the recent results on the beam test of the RF-gun with high power RF at the gun test facility. We present and discuss the measurements of the basic beam parameters such as charge, energy, energy spread, and transverse emittance.

INTRODUCTION

Since 2005, PAL and Pohang University of Science and Technology (POSTECH) has developed S-band photocathode RF-gun. The GTF at PAL has been built to achieve high quality electron beams and to study their characteristics.

The first photocathode RF-gun developed at PAL are based on S-band BNL GUN-III type RF-gun. It was commissioned and tested with a 2 μs RF pulse length at 5 Hz repetition rate and an maximum energy of 3.7 MeV. At this gun, a normalized transverse emittance of 1.7 ± 0.29 mm-mrad in the vertical plane has been measured for a 100% rms phase space distribution [1]. This RF-gun had been installed in the fs-THz beam line at PAL in 2006. In 2007, the second phase of GTF has started for the XFEL project. For this project, the beam parameters requested at the gun are 1.0 mm-mrad transverse emittance at a 1.0-nC bunch charge. The second photocathode RF-gun was operated with a 2-μs RF pulses length at a 10-Hz repetition rate and a maximum energy of 5.2 MeV. The second RF-gun also has been installed at the fs-THz beam line at PAL in 2009. The transverse emittance of 1.5 mm-mrad had been measured with 200 pC bunch charge [2]. For PAL-XFEL, we have proposed and fabricated the third RF-gun with two RF ports and two pumping ports at the second cell which called Four-port RF-gun in 2010. From 2010 to 2011, the Four-port RF-gun was successfully fabricated and its low-power test was done [3]. In 2011, the RF gun was installed at the GTF at PAL for beam test with high-power RF [4]. Now, the goal of the photocathode RF-gun for PAL-XFEL is to produce a electron beam with a transverse emittance of 0.5 mm-mrad, a bunch charge of 200 pC, and a repetition rate of about 60 Hz.

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GUN TEST FACILITY

Figure 1 shows the layout of the GTF at PAL to study the performance of the photocathode RF-gun. The GTF system consists of an RF-gun, a solenoid magnet, a mirror chamber, an integrated current transformer (ICT), four screen chambers, a spectrometer, three steering magnets, an emittance slit chamber and several motion devices. Downstream of the RF-gun, an emittance compensation solenoid is mounted. Inside the solenoid bore, a steering coil is installed. Downstream of the solenoid, an ICT is installed to measure electron bunch charge. There are four screens to measure the transverse beam profile. The screen is composed of a 15-μm layer of YAG:Ge doped on a 100-μm-thick aluminum substrate to prevent charge buildup. At 1200 mm downstream of the cathode, a spectrometer dipole magnet with bending angle of 60° is installed to measure the beam energy and its spread. Four digital charge coupled device (CCD) cameras are located at each screen chamber to measure the electron beam image and synchronized to the electron beam. At 2400 mm downstream of the cathode an emittance slit chamber is mounted.

HIGH POWER BEAM TEST

Dark Current

The amount of the electron bunch charge has been measured with the ICT. The sensitivity of the ICT is 5 Vs/C. The measured voltage is directly integrated within an electron pulse duration and is converted to the bunch charge. The dark current measurement is shown in Fig. 2. In this

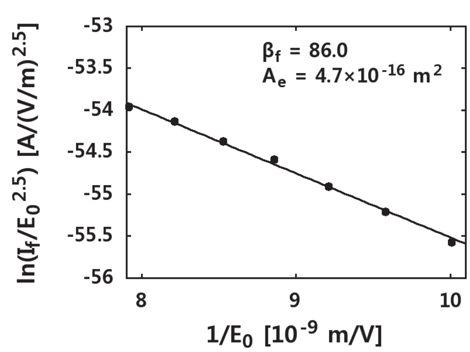

Figure 2: Dark current as a function of maximum surface electric field. The solid line represents a linear fit.

figure, I_f is the dark current, E_0 is the maximum field gradients, β_f is the field enhancement factor, and A_e is the ef-

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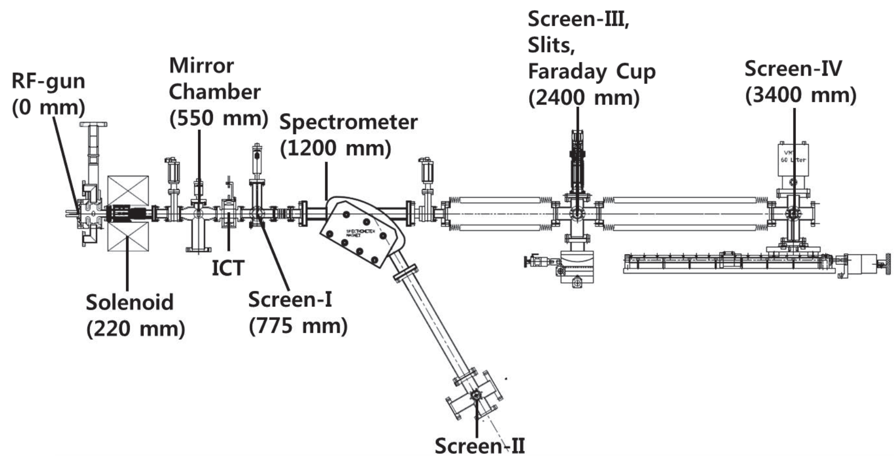

Figure 1: Layout of the GTF at PAL.

fective emitting area. Dots represent the experimental data, and the solid line is a linear fit. The measured field enhancement factor and effective emitting area are about 86 and 4.7×10^{-16} m^2, respectively. The field enhancement factor is consistent with the ones measured at the previous RF-gun at PAL. The effective emitting area is one order of magnitude lower than for the case of the previous RF-guns.

Bunch Charge

We measured the bunch charge as a function of the laser injection phase, as shown in Fig. 3. In this figure, circles, squares, and triangles indicate the experimental data at maximum field gradients of 126 MV/m, 122 MV/m, and 117 MV/m, respectively. Solid lines are guides for visibility. A UV laser pulse with a 20-μJ average energy and a 3-ps pulse length (rms, Gaussian distribution) was used. The shape of the UV laser is ellipse like shape ($L_x = 2$ mm, $L_y = 1$ mm).

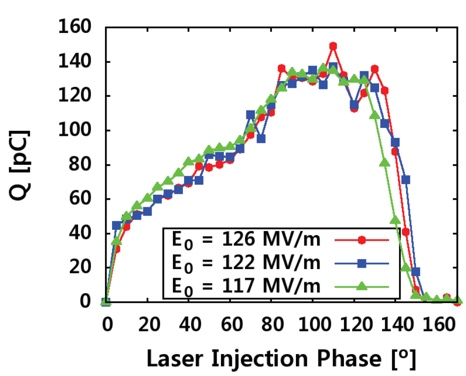

Figure 3: Measured bunch charge vs. laser injection phase.

Energy and Energy Spread

The electron beam energy can be estimated from the current of the spectrometer dipole when the electron beam is imaged on the center of Screen II. The energy spread determines the rms size of the beam image on Screen II. Measured beam energies and their spreads as functions of injection phase are shown in Figs. 4 and 5. In these figures, circles, squares, and triangles indicate experimental data at maximum accelerating fields of 126 MV/m, 122 MV/m, and 117 MV/m, respectively. Solid lines are just guides for visibility. The UV laser parameters are the same as the ones used for the bunch charge measurements.

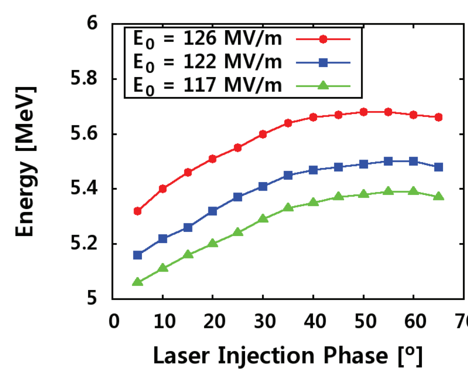

Figure 4: Measured beam energy vs. laser injection phase.

Transverse Emittance

Transverse normalized rms emittance is measured at the GTF using the single slit scan technique. Two emittance slits (one for vertical measurement and the other for horizontal measurement) are made of tungsten with a silt size of 50 μm and a thickness of 1 mm. We have used to align the slit and screen III with the 4-axis moving stage of a goniometric motion, a rotary motion, x and y linear motions with high accuracy stepping motors on the slit chamber, respectively. The normalized rms emittance is calculated using the formula [5]:

$$\epsilon_{n,rms} = \beta\gamma\sqrt{< x^2 >< x'^2 > - < xx' >^2}. \quad (1)$$

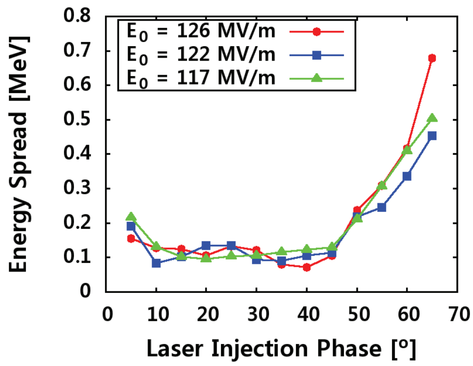

Figure 5: Measured beam energy spread vs. laser injection phase.

Figure 6 shows a typical beamlet image for a transverse (horizontal) emittance measurement. The measured trans-

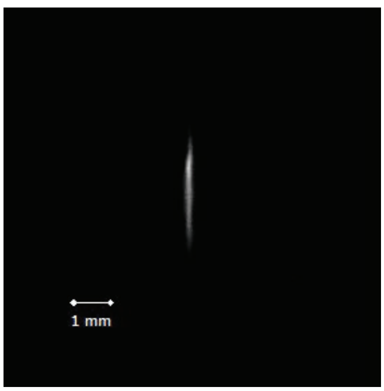

Figure 6: Typical beamlet image for a emittance measurement.

verse emittances are $\epsilon_x = 0.74 \pm 0.15$ mm-mrad and $\epsilon_y = 1.32 \pm 0.30$ mm-mrad. This experiment was performed with the condition of a 5.6-MeV beam energy, a solenoid current of 155 A, and a 100-pC bunch charge with 30° laser injection phase. The UV laser with a 30-μJ average energy and a 3-ps pulse length (rms, Gaussian distribution) was used. The shape of UV laser is ellipse like shape ($L_x = 2$ mm, $L_y = 1$ mm).

SUMMARY

This paper summarizes the current status of the GTF at PAL. The detailed system parameters and typical electron beam parameters are described in Table 1. The RF-gun operates with a maximum field gradient of 126 MV/m and has achieved a maximum beam energy of up to 5.6 MeV for a 30° laser injection phase. The relative beam energy spread for a laser injection phase around 30° is about 0.1% rms. The transverse emittances are $\epsilon_x = 0.74 \pm 0.15$ mm-mrad and $\epsilon_y = 1.32 \pm 0.30$ mm-mrad. In this test, we have several problems in the GTF. During the measurement, we could not perfectly care of the laser system and the temperature cooling system. The shape of UV laser looks like

Table 1: System and beam parameters at the GTF.

Parameters	Value	Unit
Operating Frequency	2856	MHz
RF pulse length	2	μs
Repetition Rate	30	Hz
Laser spot size	$L_x = 2$, $L_y = 1$	mm (full length)
Laser pulse length	3	ps (rms)
Laser pulse energy	30	μJ
Laser injection phase	30	°
Energy	5.6	MeV
Energy Spread	0.1	%
Charge	100	pC
Hor. (x) Emittance	0.74 ± 0.15	mm-mrad
Ver. (y) Emittance	1.32 ± 0.30	mm-mrad

ellipse and the pulse power of UV laser was so unstable. And the laser power was too small. The difference between the horizontal and the vertical emittance was caused by the difference size of the transverse UV laser. Large values of emittances and its errors are possibly caused by the instability of the whole system.

After the gun test with a limited time for beam measurements, the GTF has been dismantled. The space used for the GTF is being rearranged for RF linear accelerator tests. An Injector Test Facility (ITF) is being built with a new laser system and new RF components. At the ITF, the full performance of the RF-gun will be tested.

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REFERENCES

[1] J. H. Park, S. J. Park, C. Kim, Y. W. Parc, J. H. Hong, J. Y. Huang, D. Xiang, X. Wang, and I. S. Ko, Jpn. J. Appl. Phys. 46, 1751 (2007)

[2] J. Hong, S. Moon, Y. W. Parc, S. J. Park, C. Kim, Y. J. Park, S. H. Kim, M. H. Cho, W. Namkung, and I. S. Ko, J. Korean Phys. Soc., 58, 198 (2011)

[3] J. Hong et al., *Upgraded Photocathode RF Gun at PAL*, IPAC, Kyoto, Japan, 2010, p.1740 (2010)

[4] M. Chae et al., *The Status of a 1.6-cell Photocathode RF Gun at PAL*, IPAC, San Sebastian, Spain, 2011, p.142 (2011)

[5] M. Zhang, FERMILAB-TM-1988, October 1996.

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