PERFOMANCE TEST OF RF PHOTO-CATHODE GUN AT THE PAL*

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Abstract

A photo-cathode (PC) RF gun with 1.6 cell cavity is installed for injector development of the PAL-XFEL and a fs-FIR (Femto-second Far Infrared Radiation) facility being built at the Pohang Accelerator Laboratory (PAL). The short, intense, and low emittance electron beams are produced by the RF PC gun. Performance test of the gun is done including the measurement of RF characterizations such as a resonant frequency and a mode separation. The diagnostics of the beam parameters such as phase, charge, and energy, and emittance are performed. In this article, we present the results of measurement on the RF characterizations and the beam parameter diagnostics of the PC RF gun at the PAL.

INTRODUCTION

Low emittance and high peak current at an injector based on a PC RF gun is important for design and commissioning of a free electron laser (FEL) facility [1-3], international linear collider (ILC) and other applications. The development of a high peak current, low emittance electron source with laser driven PC RF gun has been studied during the past several decades [4-5]. In self-amplified spontaneous emission free electron laser (SASE FEL) at the PAL, an electron beam with a normalized rms emittance of 1.2 mm-mrad and a bunch charge of 1 nC is desired to reach saturation in a single pass at 3.0 Å [6].

To meet these requirements, the S-band PC RF gun has been installed in Gun Test Stand (GTS) at the Pohang Accelerator Laboratory as the photocathode gun R & D for PAL X-FEL (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 magnet in order to obtain the required minimum emittance. The PC RF gun generates short electron bunches with short laser pulses from a copper cathode.

In this paper we will concentrate on the measurements results of the RF characterizations and the beam parameter diagnostics of the PC RF gun at the PAL GTS.

EXPERIMENTAL SETUP

An experimental setup with the photocathode (PC) RF gun for research and development of 4th generation light source (4GLS) is installed. The setup consists of photo-cathode RF gun for high charge and low emittance photo-electron beam generation, solenoid magnet for emittance compensation of the electron beam, emittance meter (E-Meter) for diagnostics of the electron beam, auxiliary characteristic equipments such as an integrated current transformer (ICT), a Faraday cup, screens, and a spectrometer. The experimental setup of the GTS at the PAL appears in Figure1.

Microwave Characterizations

A BNL GUN-IV type 1.6 Cell photo-cathode RF gun with a resonant frequency of 2.856 GHz is fabricated. The Cathode is fabricated by precision machining with mirror polishing. The exact cavity dimension for the resonance frequency is obtained by repeating rough cutting and measuring with aluminium model cavity. Then the real cavity is fabricated with tuned dimension. The cavity dimension is determined by simulation with 2D code SUPERFISH to achieve 2.856 GHz resonant frequency and electric field symmetry.

For successful fabrication of the RF gun, microwave characterizations are very important. The gun cavity is tuned at 2856.25 MHz at 25 ºC under vacuum inside of the cavity. Temperature of the cavity cooling water is slightly increased for final tuning of the resonant frequency: 2856.0 MHz at π -Mode. Optimum temperature of the cavity cooling water is 32.0 ºC with 3.4 MHz mode separation. Coupling coefficient between the waveguide and the cavity is tuned to be 1.22 with unloaded quality factor of 9000. Figure 2 shows the measured cavity parameters using HP 3510C Network Analyzer. Temperature coefficient of the cavity is measured as - 42.37 kHz / ºC as shown in Figure 3. In Table 1, we summarize final tuned microwave parameters of the cavity under vacuum for installation at the GTS.

Table 1: Final tuned cavity microwave parameters under vacuum at temperature with 32.0 ºC for the GTS at PAL

Parameter	**Unit**	**Values**
Resonant Frequency at π -Mode	MHz	2856.0
Mode Separation	MHz	3.4
RF Pulse Width	μs	2.0
Coupling Coefficient		1.22
Quality Factor		9000
Temperature Coefficient	kHz / ºC	- 42.37

Laser System

The laser system for the PC RF gun is installed in the clean room with class 1000 dust control and 0.25ºC

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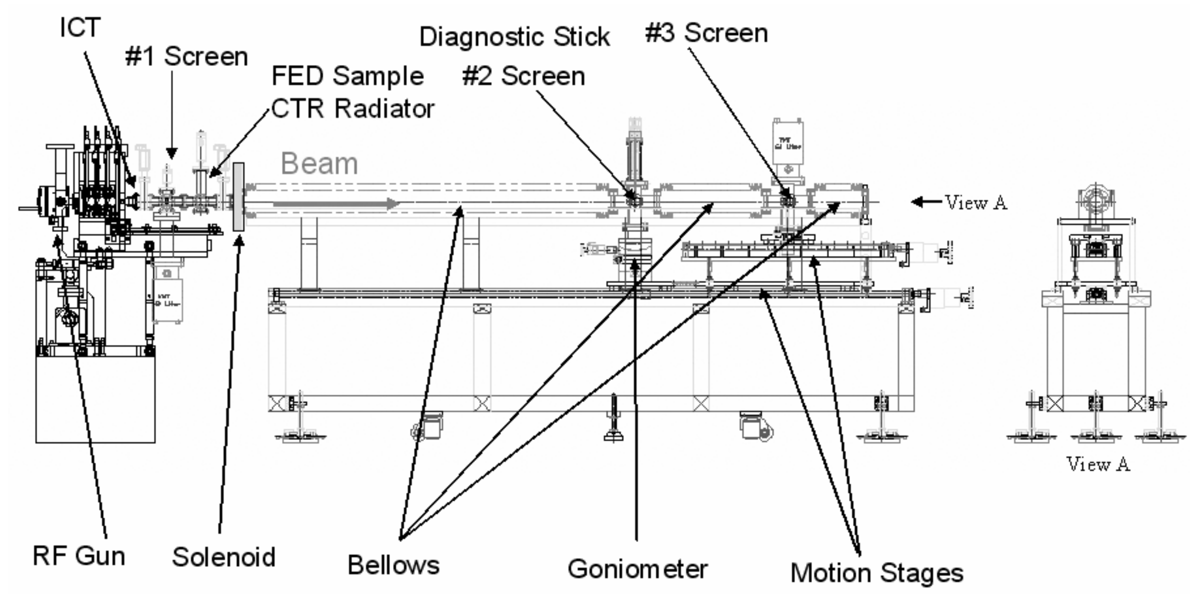

Figure 1: Schematic diagram of experimental setup of the gun test stand (GTS) for photo-injector developments of the PAL-XFEL.

temperature stability at the PAL. The performance of the laser system immediately determines the electron beam performance. The laser system consists of the Spectra-Physics "Tsunami" oscillator, regenerative amplifier with gain medium of Ti:Sapphire, second and third harmonic generator, and a pulse stretcher. The output wavelength of the laser system is 267 nm (UV region) and the peak energy at the wavelength of interest is 250 μJ. The pulse width can be changed from 0.5 ps to 10 ps by dispersive pulse broadening through prism pairs. The laser pulse length is measured using an auto-correlator at infra-red (IR, 800 nm) region and using a cross-correlator at UV region [7]. The repetition rate of our laser system is 10Hz and the output of the laser illuminates the cathode repeatedly. It is running stably in dedicated clean room with the temperature stability better than +/- 1 ºC per day. Laser incident angle is 67.5 ° against a normal direction of the cathode surface. This direction can be modified to normal direction due to time slew compensation problem. We use Anamorphic prism pairs and grating of 3600 grooves per millimeter for time slew compensation and geometric compensation. The grating has low efficiency about laser beam transmission.

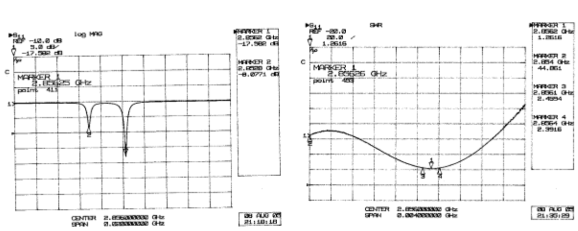

Figure 2: Cavity parameters using HP 3510C Network Analyzer. S11 parameter (left), standing wave ratio (SWR) representation of the cavity (right).

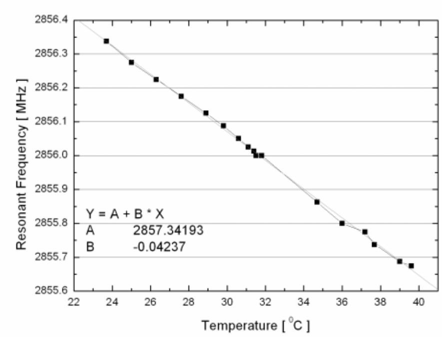

Figure 3: Measured temperature coefficient of the cavity. The temperature coefficient is measured as - 42.37 kHz / ºC.

PERFORMANCE TEST

An ICT and a Faraday cup have been installed for beam charge measurement at the gun exit. Position of the ICT is about 45 cm from the cathode. The phosphor screen #1 is located after the ICT at 56 cm from the cathode. The screen can measure the beam size along to focusing solenoid fields. The minimum beam size at the #1 screen is 175 μm. Screens #2 and #3 on the E-Meter can move the position from 1.3 m to 2.8 m from the cathode along the beam pass. The #2 screen chamber consists of a Faraday cup for beam charge measurement, slits with slit width of 30, 40, and 50 μm for beamlet making, and the phosphor screen. The #2 screen can measure the beam size at each position for transverse emittance measurement, and the #3 screen measures beamlet size of the position. The beam transverse size at the #2 screen is measured to be 450 μm.

Dark Current

Dark current from the gun cavity is a serious problem. The dark current is induced by field emission due to strong electric fields at the surface. We use 2.0 μs RF pulse width. The dark current emission can be classified into three steps. First, dark current is rapidly increased from the instantaneous turn-on of the RF power to filling the rf field in the gun cavity. The filling time of the gun cavity is about 0.7 μs. Laser injection time is within the stable region between the filling of the fields into the cavity and just before turn-off of the RF power. Second, the dark current from the gun cavity is saturated until turn off the RF power and then quickly vanishes at the moment of turn-off. As the Figure 4 indicates, the dark current is very sensitive to the RF input power above the threshold RF power. Energy of the dark current is slightly below the photo-current energy due to random acceleration process of the dark current during RF power on time.

Laser Injection Phase vs Beam Charge

Generally, laser injection phase is reported 30 degrees for optimum beam dynamics [4-5]. Depending on the laser injection phase, beam energy and emission charge from the cathode changes quite much due to different beam dynamics in the cavity. As shown in Figure 5, laser injection phase vs photo electron charge depending on the laser beam energy is measured using the ICT.

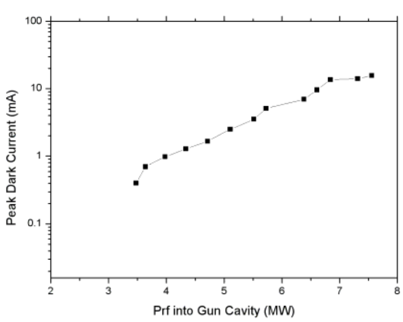

Figure 4: RF power into the gun cavity vs peak dark current.

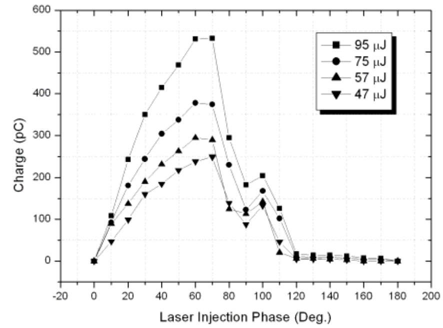

Figure 5: Laser injection phase vs photo electron charge depending on the laser beam energy.

SUNMMARY AND FUTURE WORK

The gun test stand for the PC RF gun R & D has been installed at the PAL. Various cavity characteristics and the dark current problrm have been investigated. Further performance test at the GTS will include a 6-D phase-space characterization as the longitudinal and transverse emittanc measurements. The evolution of the transverse emittance after gun exit will be measured using E-Meter. Beam energy will be also measured using spectrometer located at about 100 cm from the cathode. Further studies on the GTS would clarify the photo-injector performance for the PAL-XFEL.

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