

## DEVELOPMENT OF PHOTOCATHODE RF-GUN AT PAL

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### Abstract

We are developing two types of S-band photocathode RF-guns for the X-ray free electron laser (XFEL) at Pohang Accelerator Laboratory (PAL). One is a 1.6-cell RF-gun with a dual side coupler and two pumping ports. This RF-gun is similar to the earlier guns developed at PAL. The other one is a 1.5-cell RF-gun with a coaxial coupler and a cathode preparation system. This RF-gun is similar to the DESY-type L-band RF-gun. We have designed and fabricated two types of RF-guns. In this paper we introduce and compare two different RF-guns.

### INTRODUCTION

Pohang Accelerator Laboratory X-ray Free Electron Laser (PAL XFEL) is now under construction [1]. PAL XFEL is the 4th-generation light source based on the self amplified spontaneous emission (SASE) scheme. 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.

A photocathode RF-gun has been studied as an electron source with low emittance for future accelerators. The RF-gun for PAL XFEL is required to provide electron beams with their emittance better than 0.5 mm-mrad (projected normalized rms) at beam charge of 200 pC and its repetition rate of 60 Hz. Since 2005, we have concentrated in development of a photocathode RF-gun. The photocathode RF-guns developed at PAL are based on S-band RF-gun [2, 3]. From 2010 to 2011 the 4-hole Type RF-gun (Old-gun) was successfully fabricated and finished its low-power test [4]. After that, Old-gun was installed and tested at the gun test facility (GTF) at PAL. In this test, we have several problems in the GTF [5]. During the measurement, we could not perfectly care of the laser system and the temperature cooling system. The shape of UV laser looks like ellipse and the pulse power of UV laser was so unstable. And the laser power was too small. At the GTF, the horizontal (x) emittance are doubled as compared with the vertical (y) emittance. 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. In the middle of 2012, Old-gun had been installed at the ITF. After that, the ITF is operated for various beam experiments and devices testings for the successful

construction of PAL XFEL. However, there are some RF-gun problems such as dark current, electric discharges, and difficulty of gun align. To avoid the problems of Old-gun, we have designed two kinds of RF-gun. One is the upgrade version of 4-hole Type RF-gun (GUN-I) and another is the Coaxial Type RF-gun (GUN-II) [6].

### PHOTOCATHODE RF-GUN

#### GUN-I

A upgrade version of RF-gun with dual-side-coupler and two pumping ports has been designed. The design has been optimized to allow good performance and simple fabrication. The features incorporated into GUN-I are as follows:

- Dual feed coupler&Two pumping ports: To minimize high-order fields
- Field probes
- Fixed cathode: Simply Fabrication
- Long beam tube
- Large coupling iris radius&Short coupling iris length: To increase 0 and  $\pi$ -mode separation
- Elliptical iris: To reduce the surface E-field
- Rounded cell edge: To increase the quality factor, To decrease the thermal stress
- Modified Cooling channels: To be uniform the RF-heating

The three dimensional drawing of GUN-I is shown in Fig. 1. The manufacture of GUN-I, including the machining, brazing, cold test and tuning has been finished. The RF-parameters after cold test are: the operating frequency ( $\pi$ -mode) of 2856 MHz, the mode separation of 16.8 MHz, the quality factor of 13800, the coupling coefficient of 1.43, the field balance of 1.02, which match the parameters in RF-design. After cold test, GUN-I was successfully installed and conditioned at the ITF for PAL XFEL. The measured amplitude data of the full cell probe was collected using a low-level RF (LLRF) system.

Figure 2 shows the forward, the reflected, and probe RF-powers collected by the LLRF. Here the forward power is about 1 MW. GUN-I has operated with a maximum field gradient of 120 MV/m and has achieved a maximum beam energy of up to 5.6 MeV for a 30° laser injection phase. We have measured the transverse emittance using a quadrupole scan technique at the ITF. The lowest measured transverse emittances are  $\epsilon_x = 0.67$  mm-mrad and  $\epsilon_y = 0.73$  mm-mrad up to now. This experiment was performed with the condition of a 140-MeV beam energy, a solenoid current

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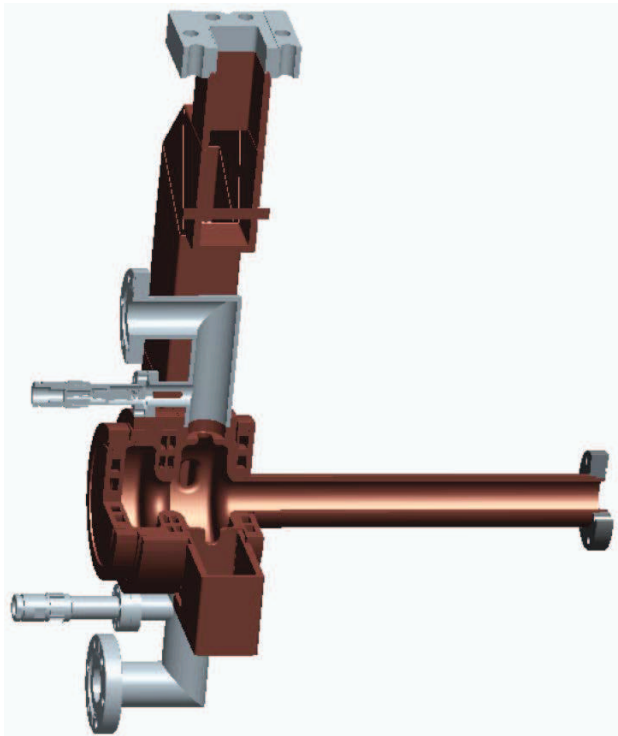


Figure 1: Three dimensional model of GUN-I.

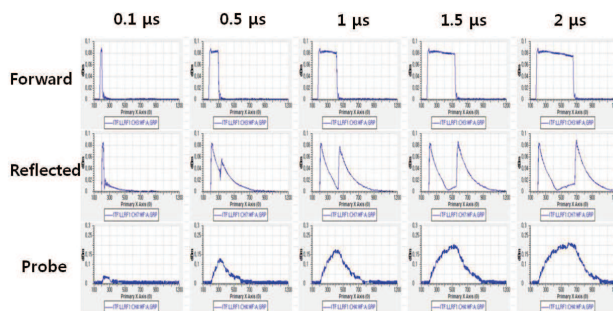


Figure 2: The measured amplitude of the full cell probe along with the forward and reflected rf power signals at the different RF-pulse length.

of 123 A, a bunch charge of 200 pC, and  $30^\circ$  laser injection phase. The UV laser with a 5-ps pulse length (rms, Gaussian distribution) and a laser spot size of 1 mm (full diameter, uniform distribution) was used. The system and beam parameters are listed in Table 1.

Figure 3 shows a typical beam image at the ITF. In this figure, the rms x size and the rms y size of beam image are  $179 \mu\text{m}$  and  $207 \mu\text{m}$ , respectively.

### GUN-II

GUN-II which is a coaxial-feed RF-gun with RF-coupler has been designed. The features incorporated into GUN-II are as follows:

- Coaxial coupler: Axisymmetric E-field, To eliminate the high-order fields

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Table 1: System and Beam Parameters at the ITF

Parameters	Value	Unit
Operating Frequency	2856	MHz
RF-pulse length	1.5	$\mu\text{s}$
Repetition Rate	10	Hz
Laser spot size	1	mm (full length)
Laser pulse length	5	ps (rms)
Laser injection phase	30	$^\circ$
Beam Energy	140	MeV
Charge	200	pC
Hor. (x) Emittance	$0.67 \pm 0.03$	mm-mrad
Ver. (y) Emittance	$0.73 \pm 0.04$	mm-mrad

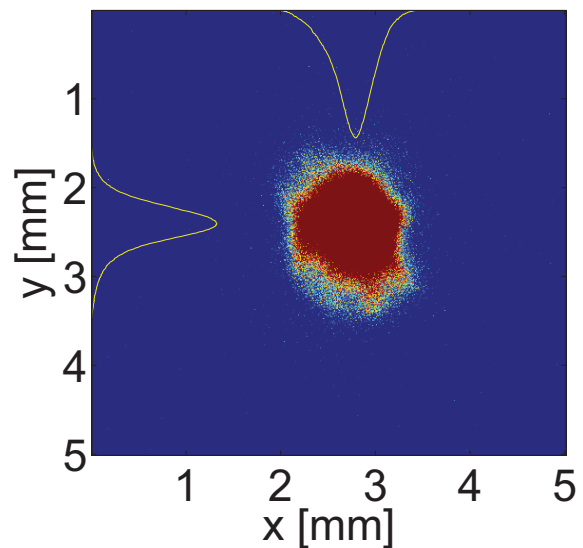


Figure 3: Typical beam image.

- Changeable (in vacuum) cathode
- Gasket between Gun&Coupler: To adjust coupling coefficient
- Large coupling iris radius&Short coupling iris length: To increase 0 and  $\pi$ -mode separation
- Elliptical iris: To reduce the surface E-field
- Rounded cell edge: To increase the quality factor, To decrease the thermal stress
- Modified Cooling channels: To be uniform the RF-heating

The three dimensional drawing of GUN-II is shown in Fig. 4.

The manufacture of GUN-II has been finished and the results match the designed RF-parameters well. The RF-parameters after cold test are: the operating frequency ( $\pi$ -mode) of 2856 MHz, the mode separation of 20 MHz, the quality factor of 14400, the coupling coefficient of 1.05 (easily changeable), the field balance of 1.0.

Table 2: Comparison of Parameters

Property	4-hole Type Old-gun	GUN-I	Coaxial Type GUN-II	Unit
Operating Frequency	2856	2856	2856	MHz
Mode Separation	9.6	16.8 (17)	20	MHz
Quality Factor	12400	13800	14400	
Coupling coefficient	1.06 (1)	1.43 (1.5)	1.05 (1)	
Repetition Rate	60	10 (120)	- (1000)	Hz
Maximum Field Gradient @ Cathode	120	120 (140)	- (120)	MV/m
Coupling Type	Dual Feed Side	Dual Feed Side	Coaxial	
Cathode Type	Changeable Cu	Fixed Cu	Changeable (in vacuum)	
Iris Shape	Circle	Ellipse	Ellipse	
Cell-edges Rounding	x	4	5	mm
Probe	x	2 (in Coupler-cell)	x	EA

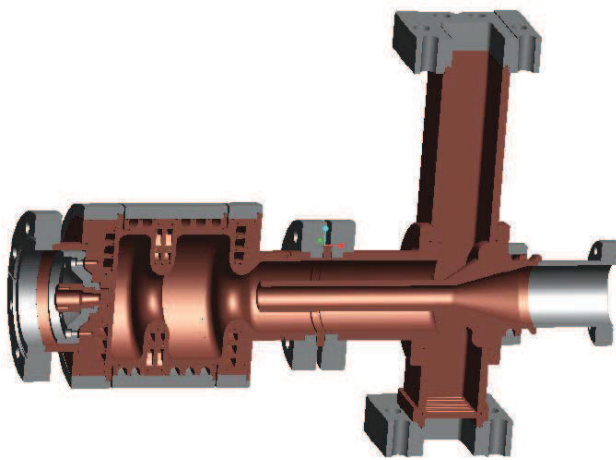


Figure 4: Three dimensional model of GUN-II.

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SUMMARY

This paper summarizes the current status of the RF-gun development at PAL. We have designed two kinds of RF-gun. One is the 4-hole Type RF-gun (GUN-I) and another is the Coaxial Type RF-gun (GUN-II). The manufacture of GUN-I and GUN-II has been finished. Table 2 compares the difference among Old-gun, GUN-I, and GUN-II. GUN-I was successfully installed and conditioned at the ITF. The lowest emittance measured to date at the ITF with 200 pC of charge is about 0.7 mm-mrad using a 5-ps laser pulse length and a 1-mm laser spot size up to now. However, this emittance is not enough for PAL XFEL. After optimizing the various parameters, we will be able to get a lower emittance (< 0.4 mm-mrad @ 200 pC).

To test GUN-II, we are building a new test beam line at the ITF. After building the new beam line, the high power experiments of GUN-II will be conducted in our future work.