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# PERFORMANCE OF S-BAND PHOTOCATHODE RF GUN WITH COAXIAL COUPLER

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*Abstract*

To improve the characteristics of electron beams, new S-band photocathode RF gun with a coaxial coupler has been developed and fabricated at the Pohang Accelerator Laboratory (PAL). This new RF gun is improved the field symmetry inside the cavity cell by applying the coaxial coupler, and the cooling performance by improving the cooling lines. The RF gun is installed in the injector test facility (ITF) for high power RF test. This paper reports the recent results on the RF conditioning process and the beam tests of the RF gun with high power RF at ITF. We present and discuss the measurement results of the basic beam parameters.

## INTRODUCTION

The Pohang Accelerator Laboratory (PAL) has developed two types of S-band photocathode RF guns to generate electron beams for the X-ray free electron laser (PAL-XFEL) [1–3]. The first gun is the four ports side coupled RF gun (GUN-I) and the second one is the coaxial coupled RF gun (GUN-II). Currently we are using GUN-I as an electronic source for PAL-XFEL [4,5]. In the case of GUN-II, an electron gun with a replaceable Cu plug has been fabricated in 2013. In 2015, an electron gun with fixed Cu cathode has been fabricated. Until we were interested again in 2018, GUN2 was out of our memory.

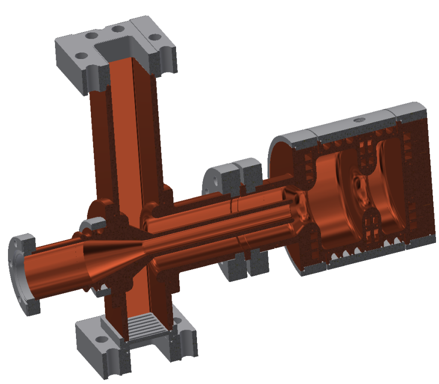

Figure 1: Cutaway view of GUN-II.

The electron gun used in this experiment is an electron gun with fixed Cu cathode. The 3-dimensional cutaway view of GUN-II is shown in Fig. 1. The features of GUN-II are as follows:

- Coaxial coupler is applied for axisymmetric E-field.
- Modified cooling channels to be uniform the RF heating.
- Fixed Cu cathode is applied for easy fabrication and operation.
- Has a narrow (diameter = 14 mm) beam tube. (difficult laser transmission)
- Does not have an gun probe. (can not measure the gun power directly)

The RF parameters of GUN-II are listed in Table 1.

Table 1: RF Parameters

| Property | GUN-II | Unit |
|---|---|---|
| Operating Frequency | 2856 | MHz |
| Mode Separation | 20 | MHz |
| Quality Factor | 14400 | |
| Coupling coefficient | 1.1 | |
| Field Belance | 1.02 | |

## TEST SETUP

From August 2015, the important devices in the injector test facility (ITF) were moved to PAL-XFEL. Moved devices are an electron gun, two accelerator columns, a gun energy spectrometer, and a deflector, etc. Until the end of 2018, ITF was shutdown. In April 2019, ITF was restructured to perform the high power beam test for GUN-II. The schematic diagram of the new ITF beam-line for GUN-II is shown in Fig. 2. Electron beams are generated from the new GUN-II.

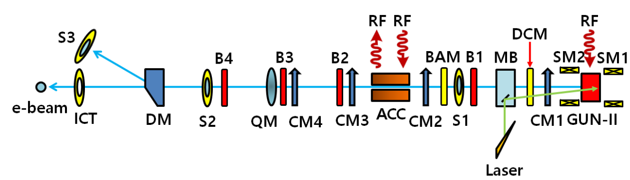


Figure 2: Schematic diagram of the ITF beam-line. Letter abbreviations in the figure are as follows: ACC for accelerating column, SM for solenoid magnet, CM for corrector magnet, DM for dipole magnet, QM for quadrupole magnet, BCM for beam current monitor, MB for laser mirror box, S for screen Monitor, B for beam position monitor, DCM for dark current monitor, BAM for bunch arrival-time monitor.

The main solenoid (SM2 in Fig. 2) and the bucking solenoid (SM1 in Fig. 2) was installed before and after GUN-II to focus the generated electron beams. Downstream of the main solenoid, the dark current monitor (DCM) was installed to measure the dark current. Downstream of the DCM, the laser mirror box for GUN-I (not GUN-II) which permits an UV laser beam to strike the gun cathode was installed. Now we do not have a laser mirror box for GUN-II. If we want laser cleaning and emittance optimization, we need a laser mirror box for GUN-II. The electron beam is accelerated by the new 3-meter dual-feed racetrack-type S-band

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accelerating column (ACC in Fig. 2) for which enough to accelerate the beam up to 70 MeV. After acceleration the emittance will be measured using the quadrupole magnet (QM in Fig. 2) and the screen #2 (S2 in Fig. 2). The end of the beam line the integrating current transformer (ICT) was installed to measure the electron bunch charge. To measure the bunch arrival-time, the new bunch arrival-time monitor (BAM, resonance frequency ~ 2826 MHz, loaded quality factor = 760) made of stainless steel was also installed. In the ITF beam-line four beam position monitors and four corrector magnets were installed to align electron beams. More information of ITF can be found in the Ref [6, 7].

## RF CONDITIONING

When high gradients are required, RF conditioning of a new RF component is mandatory. The RF network of ITF is sketched in Fig. 3. There are two modules of RF station

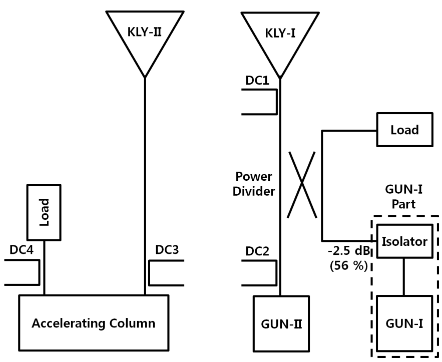


Figure 3: Schematic diagram of the ITF RF network. Letter abbreviations in the figure are as follows: KLY for klystron, DC for directional coupler.

in ITF. The first klystron (KLY-I) feeds GUN-I and GUN-II. GUN-I is a spare gun for PAL-XFEL. Therefore, we will not consider the GUN-I part in this paper. The second klystron feeds only the new accelerating column. GUN-II was conditioned up to 12 MW. In parallel, the accelerating column was conditioned up to 40 MW. The repetition rate was fixed to 10 Hz because of the limiting factor of the RF system. The pulse width is can vary from 0 up to 2.5 $\mu$s for GUN-II and from 0 up to 1.2 $\mu$s for the accelerating column, respectively. These pulses are long enough to fill the RF gun and the accelerating column. The RF conditioning procedure took eight days (eight hours a day) for GUN-II and nine days for the accelerating column. After RF conditioning, the vacuum level is $3 \times 10^{-10}$ mbar for GUN-II and $2 \times 10^{-8}$ mbar for the accelerating column, respectively.

The RF power is detected by using the directional couplers and measured by using the low-level RF (LLRF) system. Figure 4 shows measured RF power waveforms from directional couplers. Both klystron input pulses were not very uniform but could be the RF conditioning. In Fig 4 a) and b) the second peaks are the reflections of the RF pulse from the klystron because there is no isolator for GUN-II. Therefor the forward waveform and reflected waveform overlaps heavily.

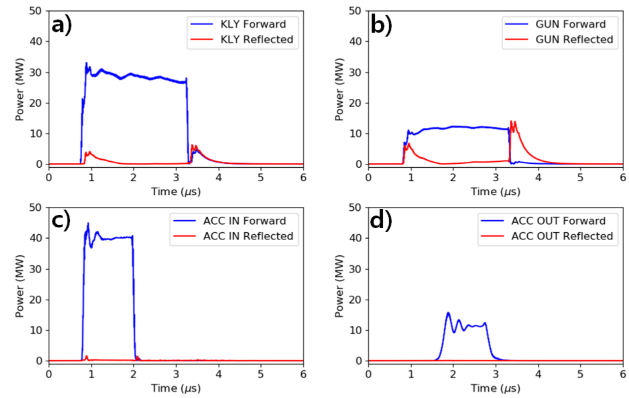


Figure 4: RF power waveforms from directional couplers after RF conditioning. a) DC1, b) DC2, c) DC3, and d) DC4 in Fig 4.

After the conditioning the DCM pickup was connected to the LLRF because the resonance frequency of DCM is equal to the operating RF frequency. The comparison of the measured the GUN-II DCM signal, the GUN-I DCM signal, and the RF induced GUN-I probe pickup signal is shown in Fig. 5. The DCM signals of the two electron guns are almost

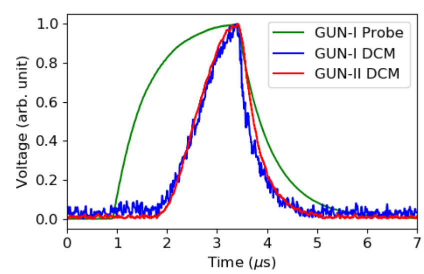


Figure 5: Comparison of the measured dark current induced DCM pickup signal and the RF induced gun probe pickup signal. The DCM and the gun probe signal is compared with two types of electron gun (GUN-I and GUN-II)

similar in shape. In this time, the absolute value could not be measured because DCM has not yet been calibrated.

## ELECTRON BEAM MEASUREMENT

After then, GUN-II generated the first electron beams. For the generation of electron beams, the UV laser (see Fig. 6 a), pulse energy = 20 $\mu$J, diameter ~ 1 mm) was used. The beam size and profile are measured using YAG crystals imaged with CCD cameras for image processing. Figure 6 b), c), and d) show typical images of each screen.

The electron beam energy and energy spread, including acceleration in the accelerating column, are measured by using the spectrometer (DM + S3 in Fig 2). The beam energy is about 70 MeV and the energy spread is less than 0.1 %. The gun spectrometer was not installed in this measurement. By analogy to RF power (10 ~ 12 MW), the beam energy of GUN-II will be at least 6 MeV.

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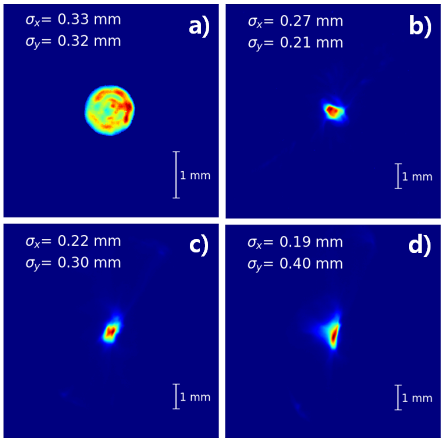


Figure 6: Image of CCD camera. a) UV laser and b) S1, c) S2, d) S3 in Fig 4.

Bunch charge is measured by using ICT. The measured ICT signal is shown in Fig 7. In this measurement, the bunch charge could occur about 200 pC without IR laser cleaning. This value is $4.5 \times 10^{-5}$ in the quantum efficiency.

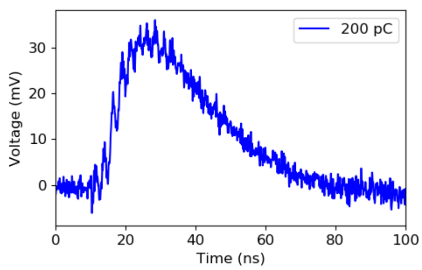


Figure 7: Measured ICT pickup signal for the bunch charge of 200 pC.

The pickup signal of the new BAM was measured with an oscilloscope under the same electron beam conditions. The measured BAM signal is shown in Fig 8. At the 200 pC bunch charge, the peak voltage is 2 V and the decay time is 40 ns. These values will be used for future R&D of a new BAM electronics.

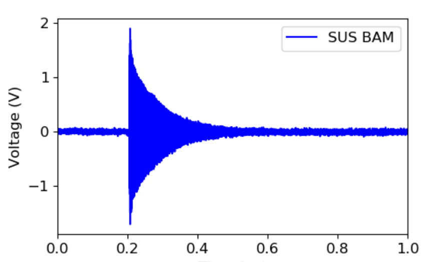


Figure 8: Measured BAM pickup signal for the bunch charge of 200 pC.

## SUMMARY AND DISCUSSION

GUN-II and the new dual-feed racetrack-type accelerating column were RF conditioned at PAL-ITF. And we generated the first electron beams. The first electron beams of GUN-II and the ITF system parameters are listed in Table 2.

Table 2: Electron Beams and ITF System Parameters

| Parameter | Value | Unit |
|---|---|---|
| **Electron Beam** | **(GUN / GUN+ACC)** | |
| Energy | 6 (estimate) / 70 | MeV |
| Energy Spread | - / 0.1 | % (rms) |
| Charge | 200 | pC |
| **RF** | **(GUN / ACC)** | |
| Peak power | 12 / 40 | MW |
| RF pulse Width | 2.5 / 1.2 | $\mu$s |
| Repetition Rate | 10 | Hz |
| **Laser** | | |
| Spot size | 0.32 | mm (rms) |
| Pulse Length | 3 | ps (FWHM) |
| Pulse energy | 20 | $\mu$J |

GUN-II employs the circular waveguide coupler and can reduce the emittance to 0.2 mm-mrad by optimizing the position of the main solenoid. By reinforcing the cooling line, the repetition rate can be increased up to about 1 kHz. Optimization of the laser mirror box for GUN-II will help in the UV laser transmission and the IR laser cleaning. After that, it will be possible to optimize the emittance for various parameters. In this measurement, the repetition rate of GUN2 was fixed to 10 Hz due to the limiting factor of the ITF RF system. In the future, if a high repetition rate RF source is applied, it will be possible to operate at higher repetition rate than GUN-I which is operating at 60 Hz in PAL-XFEL.

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