NEW RF-GUN DESIGN FOR THE PAL-XFEL*

J. Hong†, J.-H. Han, S.-J. Park, H.-S Kang, K. Gil, PAL, Pohang, Kyungbuk
M. S. Chae, I. S. Ko, POSTECH, Pohang, Kyungbuk

Abstract

We are developing an S-band photocathode RF-gun for the X-ray free electron laser (XFEL) at the Pohang Accelerator Laboratory (PAL). This RF-gun is a 1.6-cell RF-gun with dual-feed waveguide ports and two pumping ports. We have done the complete RF and thermal analysis of a new gun. The new RF-gun is designed to operate at a maximum field gradient of 130 MV/m with a RF pulse width of 3 μs, a repetition rate of 120 Hz. In this paper we present features and RF simulation results and thermal analysis results of the new RF-gun.

INTRODUCTION

In 2005 the first photocathode RF-gun has been fabricated at the PAL. The lowest normalized transverse rms emittance at the position from the cathode of 1.4 m was attained 1.7 mm-mrad with 300-pC beam charge, 3.7-MeV beam energy and 0.79-mm beam spot size. This was the first RF-gun fabricated with high-brightness in the country. However, there are a lot of dark current and electric discharges [1]. To avoid such problems of the first RF-gun we modified the design and fabricated the second rf gun in 2007. There were several improvements on the vacuum seals and the tuning methods. This RF-gun was operated with a peak accelerating field of 110 MV/m and achieved a maximum beam energy of up to 5.2 MeV for a laser injection phase of 34° [2]. For PAL-XFEL we have proposed and fabricated the third RF-gun with two RF ports and two pumping ports which called Four-port RF-gun in 2010. From 2010 to 2011 the Four-port RF-gun was successfully fabricated and finished its low-power test. In 2011 the RF gun had been installed at the GTF in PAL for high-power beam test [3, 4]. The RF-gun was operated with maximum field gradient of 126 MV/m and has achieved a maximum beam energy of up to 5.6 MeV for a laser injection phase of 34°. The relative beam energy spread is about 0.1% rms. Measured transverse emittances are $\epsilon_x = 0.74 \pm 0.15$ mm-mrad and $\epsilon_y = 1.32 \pm 0.30$ mm-mrad [5]. Now the goal of the photocathode RF-gun for PAL-XFEL is to produce the electron beam with transverse emittance of 0.5 mm-mrad, beam charge of 200 pC and its repetition rate of 60 Hz. This paper gives brief summary of the new RF-gun design.

FEATURES OF NEW RF-GUN

The design has been optimized to allow good performance of an RF-gun. The features incorporated into the new RF-gun are as follows:

- To increase 0 and π-mode separation relatively large coupling iris radius and short coupling iris length are introduced.
- To reduce the shunt impedance rounded cell profile is seclected.
- To reduce the maximum surface electric field iris shape are changed by elliptical.
- To probe the full-cell field two probing ports are added.
- To lower the vacuum level two additional pumping ports are added.
- To be uniform the RF heating cooling channels are modified.

The three dimensional drawing of new photocathode RF-gun is shown in Fig. 1.

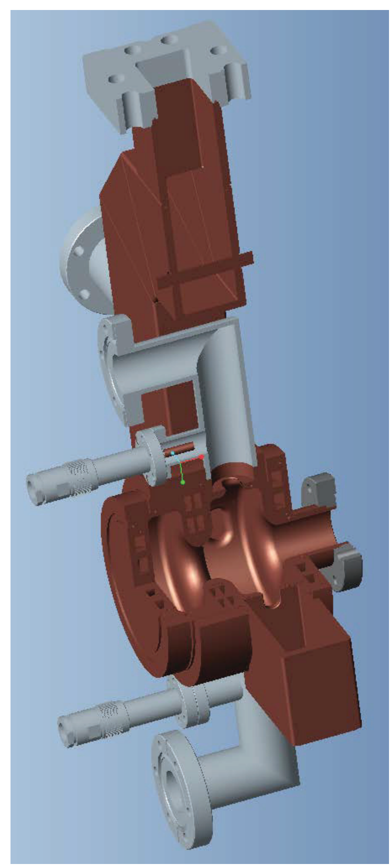

Figure 1: Three dimensional model of new photocathode RF-gun.

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† npwinner@postech.ac.kr

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RF-GUN SIMULATION

Field Simulation

To design the RF-gun we conducted RF simulation using SUPERFISH [6] and the Transient Solver of CST Microwave Studio [7]. First using the SUPERFISH two dimensional field simulation was carried out. During SUPERFISH simulation the geometry was modified so as to decrease the effect of surface fields and to increase the effect of mode separation. We can optimize the iris shape and rounding of the cell-edge. Rounded cell shape is selected to increase the quality factor. This geometry also reduce the surface fields thus the dark current and the thermal stress as well. Elliptical iris shape has also same effects. The field profile and the surface electric field are shown in Figs. 2-3. Figure 3 shows the peak electric surface field is 1% lower than the field on the cathode. The simulation results of the SUPERFISH are described in Table 1.

Next using the CST Microwave Studio three dimensional time transient simulation was carried out. The Transient Solver simulation gives us the s-parameter of two ports (S_{ij}), electric field profile and magnetic field profile. Figure 4 shows the simulation model of the new RF-gun and its electric field profile at the operating frequency of 2856 MHz. In this simulation we optimized the coupling length and the probe length. The coupling coefficient is increased from the critically coupled design to an overcoupled design. The consequences of an overcoupled design are shorter filling time and a larger reflected power. The design value of coupling coefficient is 1.5. In our coupling design, changing the design value is easy.

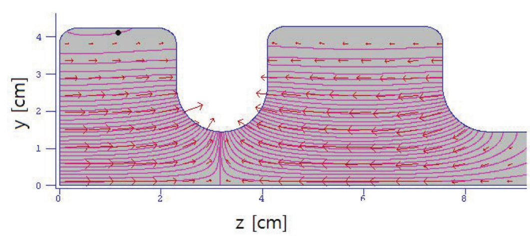

Figure 2: Field distribution in the RF-gun as calculated by using SUPERFISH.

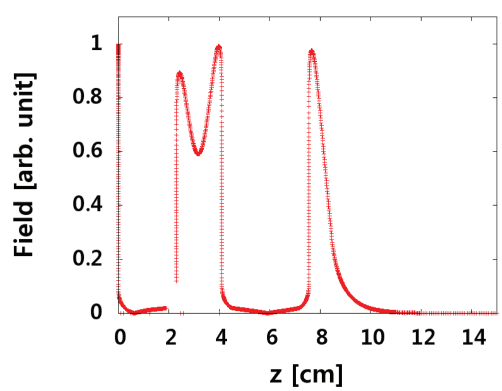

Figure 3: The surface electric field.

Table 1: Comparison of Parameters

Parameters	Old	New	Unit
f_π	2856	2856	MHz
Δf	9.5	16	MHz
P_l	10.9	10.2	MW
Q	13800	15700	

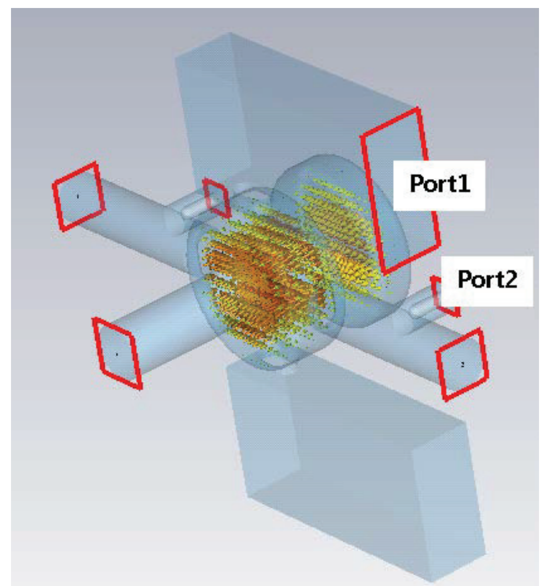

Figure 4: The simulation model of the new RF-gun and the electric field profile in the gun.

Thermal Analysis

Using the ANSYS [8] thermal analysis for RF-gun was carried out. For a 3.7 kW average input power the temperature distribution of the RF gun is plotted in Fig. 5. The maximum temperature gradient is about 26 °C. The hot spots are located at the input coupling holes.

Finally the pulsed heating is calculated from the equation below [9]

$$\Delta T_{max} = \frac{R_s}{K}\sqrt{\frac{D}{\pi}}\frac{1}{2}\int_0^{t_p} |H_{s,max}(t)|^2 \frac{dt}{\sqrt{t_p - t}}. \quad (1)$$

Here $H_{s,max}$ is the maximum surface magnetic field inside of the cell, R_s is the surface impedance, K is the thermal conductivity, D is the specific heat and t_p is the RF pulse width. According to this equation the maximum temperature rise due to the pulsed heating is about 30 °C at the coupling hole.

SUMMARY

The RF simulation and the thermal analysis of new RF-gun is completed. The final simulation results are described

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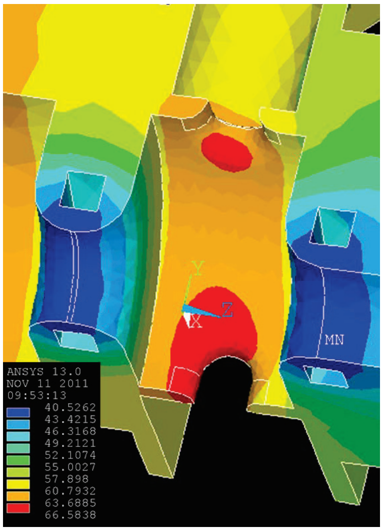

Figure 5: (Color online) Temperature distribution of the RF-gun. The maximum temperature gradient is about 26 °C

in Table 2. Now new RF-gun is under fabrication. Experimentation is tentatively scheduled in the first quarter of next year at the Injector Test Facility (ITF) at the PAL. And we are also developing alternative RF-gun with coaxial coupler (Fig. 6). Some weak points of the conventional RF-gun will be modified in next gun design.

Table 2: System and Beam Parameters at the GTF

Parameters	**Value**	**Unit**
Operating Frequency	2856	MHz
Mode Separation	16	MHz
RF Pulse Width	3	μs
Repetition Rate	120	Hz
Maximum Field Gradient	130	MV/m
Coupling Coefficient	1.5	
Quality Factor	15500	
ΔT_{max}	26	°C

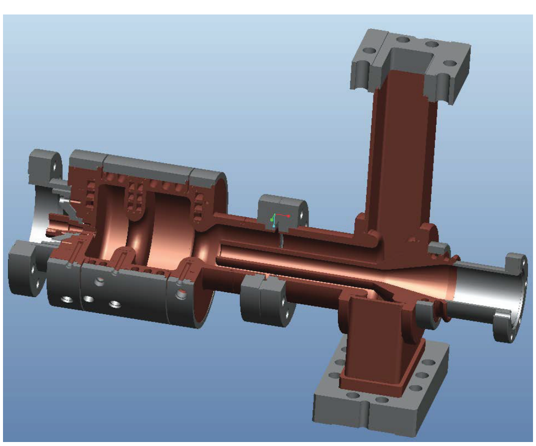

Figure 6: Alternative photocathode RF-gun.

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