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DESIGN OF A 217 MHZ VHF GUN AT TSINGHUA UNIVERSITY

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Abstract

A 217 MHz VHF gun operating in CW mode is designing at Tsinghua University. The cathode gradient is designed to be 30 MV/m to accelerate the electron bunches up to 878 keV. The cavity profile is optimized in CST to minimize the input power, peak surface electric field, and peak wall power density. The multipacting analysis and the thermal analysis are also presented in this paper. Further gun shape optimization and mechanical design are ongoing.

INTRODUCTION

The high brightness electron beam has enabled the success of a lot of accelerator-based machines such as: free electron lasers (FELs), Thomson scattering sources, and ultrafast electron diffraction (UED) and microscopy (UEM) in the past few decades. Recently, the developments of the above machines have dramatically required the electron beam with not only high brightness but also high repetition rate. Therefore, electron guns capable of operating at MHz-class repetition rates are intensely studied in the past few years, and several groups around the world have proposed different schemes including the direct current (DC) gun [1], Superconducting RF gun [2] and very high frequency (VHF) gun [3].

A VHF gun operating at 186 MHz, called APEX gun [3], has been developed at LBNL and a close version of this gun has been selected as the electron source for the LCLS-II. The gun can operate at continuous wave (CW) mode with a cathode gradient of 20 MV/m and a voltage of 750 keV. The LBNL's work has shown that the VHF gun is a promising source producing electron beam with both high brightness and high repetition rate. Stimulated by the LBNL's work and the VHF gun design experience of other groups, Tsinghua University (THU) is designing a VHF gun. A preliminary design of this gun is presented in this paper.

CAVITY PROFILE

The gun frequency should be compatible with the frequency of SRF linacs (1300 MHz) in XFEL. Therefore, the gun frequency should be 1300/n MHz, and n is an integer.

In VHF section, 217 MHz, 186 MHz and 162.5 MHz are the candidates. Based on the Kilpatrick equation, higher frequency has the potential to achieve higher cathode gradient under the breakdown limit. Besides, 186 MHz is not compatible with the XFEL timing system. Overall, we choose 217 MHz as our gun resonant frequency.

The CST MICROWAVE STUDIO was employed to optimize the gun shape. The cavity profile is parameterized in CST, as shown in Fig. 1.

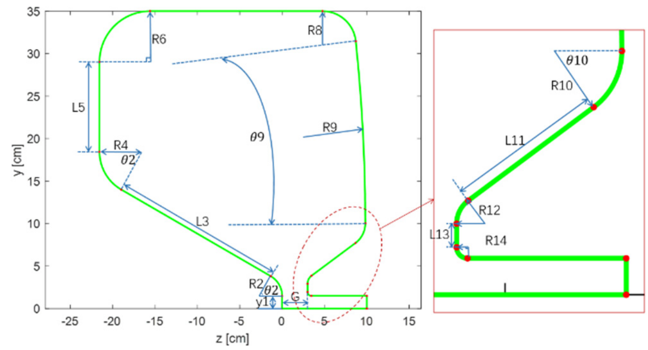

Figure 1: Cavity profile parameterized in CST.

All parameters presented in Fig. 1 were optimized simultaneously in CST optimizer. The optimization goals were set as follows: The frequency is fixed at 216.67 MHz, and all rf goals were scaled with the cathode gradient of 30 MV/m. The gun voltage should be larger than 800 kV to maximize the beam energy at the exit of the gun. The input power should be less than 100 kW and the peak surface power density should be less than 30 W/cm^2 to relax the cooling requirement. The peak surface electric field should be less than 38 MV/m to reduce the breakdown possibility.

The gun rf parameters after optimization are presented in Table 1. All rf parameters meet the design goals stated above.

Table 1: Gun rf Parameters After Optimization

Parameter	Value	Unit
Frequency	216.67	MHz
Cathode gradient	30	MV/m
Input power	95.6	kW
Peak surface electric field	37.3	MV/m
Peak surface power density	25.9	W/cm^2
Voltage	878	kV
Stored energy	2.4	J
Quality factor	33830	
Shunt impedance	7.9	MΩ

The cavity profile and the corresponding electric and magnetic fields in the gun are shown in Fig. 2.

THERMAL ANALYSIS

Nineteen water cooling channels are designed on the gun to deal with the heat from the dissipated power on the cavity inner wall. The flow rate and dimension of each channel were carefully adjusted based on the local wall power density. The thermal load of the gun was calculated in ANSYS Multiphysics Simulation. The initial water temperature was set to be 300 K. The maximum water in-out pressure of all channels is less than 0.1 MPa. The water

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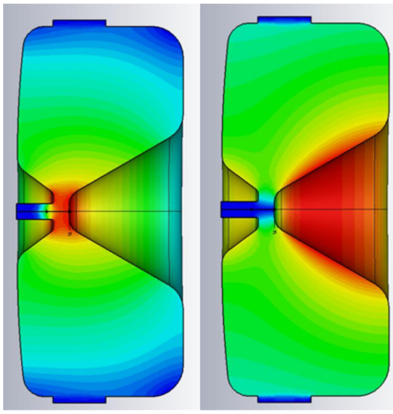

Figure 2: Left: electric field distribution in the gun. Right: magnetic field distribution in the gun.

velocities are between 1.24 to 6.10 m/s. The average water temperature rise is less than 12 K. The temperature contour on the gun profile is shown in Fig. 3. The maximum temperature on copper is expected to be 67.8 ℃. The maximum stress on copper is 65.2 MPa. The deformation of the VHF gun due to the thermal expansion and the atmospheric pressure is shown in Fig. 4. The deformation mainly occurs at the cathode plate upper corner and the anode nose. The maximum deformation is 140 µm, corresponding to a frequency detune of about 100 kHz. Four tuners will be installed equally spaced on the anode plate to modulate the frequency detune due to the heat. ANSYS simulation shows that a 10 kN force on each tuner is enough to eliminate the frequency detune.

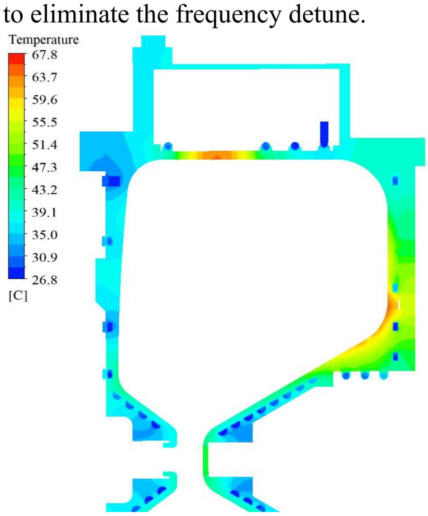

Figure 3: The temperature contour simulated in ANSYS.

MULTIPACTING ANALYSIS

An exponential multiplication of the electrons in the cavity, called multipacting (MP) [4], can take place under some gun gradients. Severe MP can impact the conditioning process and even damage the cavity inner surface. Therefore, the MP in our gun is carefully simulated in the CST PARTICLE STUDIO with the tracking solver. Some electrons are initially generated on the cavity inner wall. The rf field is imported from the MICROWAVE STUDIO to the PARTICLE STUDIO. The secondary electron yield is calculated by the Furman method incorporated in CST.

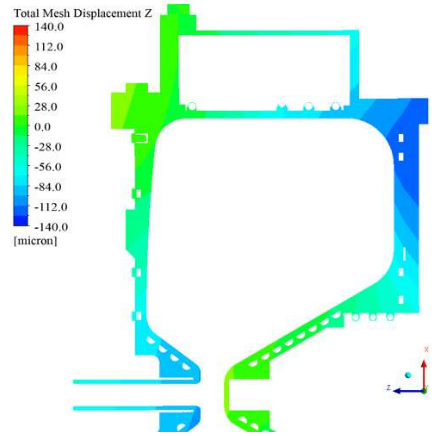

Figure 4: Contour plot of the deformation of the gun profile.

The evolutions of the total electron particles as a function of time under different cathode gradients are indicated in Fig. 5. The number of particles decreases with time when the cathode gradient is 19 MV/m, which means no MP occurs under this gradient. The number of particles increases exponentially with time when the cathode gradient is 16 MV/m, indicating that a MP occurs in the gun.

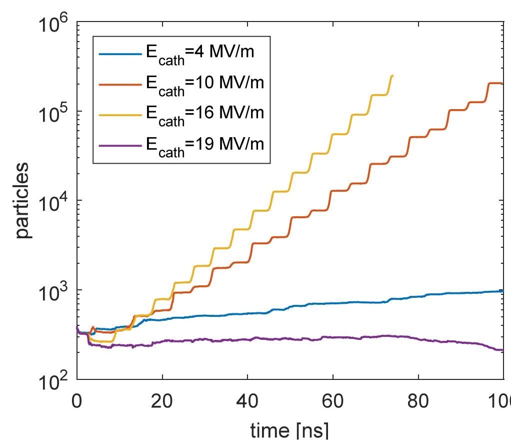

Figure 5: The evolution of the total electron particles with time.

The trajectories of the particles in the gun when the cathode gradient is 16 MV/m are shown in Fig. 6. We found that the MP occurs mainly at the upper corner of the anode plate.

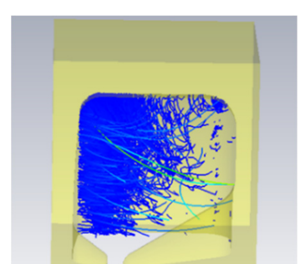

Figure 6: Multipacting occurs when the cathode gradient is 16 MV/m. Most of the particles locate at the upper corner of the anode plate.

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The curve of the number of particles as a function of time is fitted with the equation of $N_e(t) = N_0 \times 10^{\alpha t}$ when MP occurs. α is defined as the growth rate of MP to characterize the MP intensity. α as a function of the cathode gradient is shown in Fig. 7. There is no MP when the cathode gradient is larger than 19 MV/m, while the nominal cathode gradient in operation is 30 MV/m. Therefore, no MP occurs under normal operating gradient for our gun.

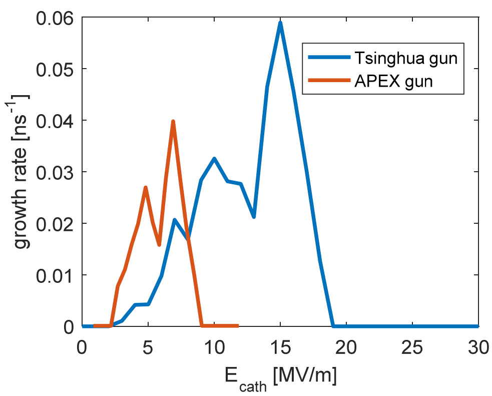

Figure 7: The growth rate of MP as a function of the cathode gradient.

The MP of the APEX gun is also presented in Fig. 7. The maximum growth rate for our gun is higher than the APEX gun. The maximum gradient of MP occurrence (18 MV/m) is still too close to the nominal gradient. Therefore, further optimization of the gun shape to reduce the MP is ongoing. As follows we tried two new gun shapes to optimize the MP performance, as shown in Fig. 8.

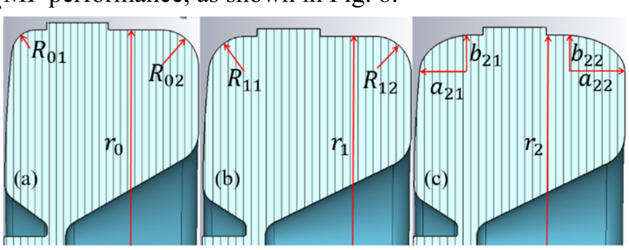

Figure 8: (a) The present gun shape. (b) new gun shape 1. (c) new gun shape 2.

Compared with the present gun shape, the new gun shape 1 has a larger fillet at the anode upper corner. The fillets of both the anode and cathode upper corners for the new gun shape 2 become elliptical. Moreover, the gun radii of both the new gun shape 1 and 2 are smaller than the present gun shape. Some key geometry parameters of the three gun shapes are listed in Table 2. The optimal rf parameters are also presented in Table 2. Compared with the present gun shape, the new gun shapes have smaller input power but larger peak surface power density. The other rf parameters are similar to the present gun shape. The peak power density is located on the cathode nose. Based on our thermal simulation the temperature of the cathode nose is low after the water cooling, so a peak surface power density less than 29 W/cm^2 is acceptable.

The growth rates of MP for the three gun shapes are plotted in Fig. 9. The MP performance of the new gun shapes are significantly improved compared with the present gun shape. Especially for the new gun shape 2, the maximum gradient of MP occurrence is reduced to 15 MV/m. The thermal simulation and mechanical design of the new gun shape are still ongoing.

Table 2: Gun Parameters of the Three Gun Shapes

Parameter	Present gun	New gun shape 1	New gun shape 2
geometry	r_0=35mm R_{01}=3.94mm R_{02}=5.96mm	r_1=33.5mm R_{11}=6mm R_{12}=5.81mm	r_2=33.5mm a_{21}=8.38mm b_{21}=6mm a_{22}=10mm b_{22}=5.7mm
Frequency	216.67 MHz	216.67 MHz	216.67 MHz
Cathode gradient	30 MV/m	30 MV/m	30 MV/m
Input power	95.6 kW	90.47 kW	90.4 kW
Peak surface electric field	37.3 MV/m	37.95 MV/m	37.0 MV/m
Peak surface power density	25.9 W/cm^2	28.32 W/cm^2	28.45 W/cm^2
Voltage	878 kV	871 kV	868 kV

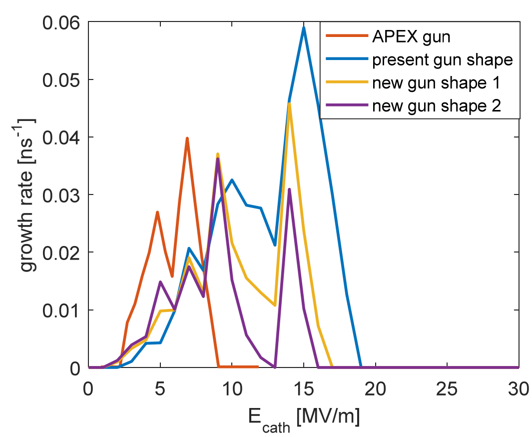

Figure 9: Growth rates of MP for different cathode fields and gun shapes.

CONCLUSION

A 217 MHz VHF gun operating at CW mode is designing at Tsinghua University. The gun shape optimization, the thermal analysis, and the multipacting simulation are presented in this paper. Further mechanical design is still ongoing.

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