SIMULATION STUDY ON EMITTANCE INCREASE DUE TO RF ASYMMETRY*

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Abstract

Due the field asymmetry in RF gun due the holes in full cell cavity, the emittance of electron beam can be increased. To generate the low emittance electron beam for XFEL, the elimination of the each field components is very important. The RF field can be decomposed as dipole and quadrupole components. The effect on the emittance increase of each component is studied in this presentation by numerical method. The 3D field map is constructed by Matlab code as input of Parmela code with each component distribution of the RF field. In this paper the emittance increase of electron beam by the each component of the RF field will be presented.

INTRODUCTION

In high gradient RF photoinjector, transverse forces in the cavity can induce transverse emittance increase [1]. BNL GUN III has a side coupling hole to provide RF power into the RF-gun. But one side coupling scheme causes the RF asymmetry at the coupler cell, that is, the asymmetry of the electric field inside of the cavity. This asymmetric field can be expanded into multipole fields [2]. Especially, the dipole and quadrupole fields are main cause of the emittance increase [3]. These kind of multipole fields were induced by asymmetric geometry of the gun from the beginning. Therefore, additional holes at the symmetric position will be useful to suppress multipole fields. From this idea, we made each gun model with zero, single, double and quadruple holes. After constructing 3D field map, the effect of the number of hole on the emittance increase was investigated.

THEORY

The transverse normalized emittance increase is given by [1]

$$\Delta\varepsilon_y = \sigma_y \frac{\Delta p_y}{mc} \tag{1}$$

where σ_y is the beam size in the middle of the full cell.

Under the framework of Panofsky-Wenzel theorem, the change in momentum can be expressed as [2],

$$p_\perp = \left(\frac{e}{\omega_0}\right)\int_0^L (-i)\nabla_\perp E_z dz \tag{2}$$

where L is the length of the full cell, ω_0 is the resonance frequency of cavity.

From the equation (1) and (2), we get

Table 1: Parameters used in simulation

Number of Particles	20000
Total Charge	1nC
Longitudinal Profile	10ps
Transverse Profile	2.4mm
Initial Cathode KE	1eV
E_0 at Cathode	120MV/m
Length of gun	15cm

$$\frac{\Delta p_y}{mc} = \frac{1}{mc}\frac{e\lambda}{2\pi c}\int_0^L \frac{\partial E_z}{\partial y} dz \tag{3}$$

We can expand electric field in the coupler cell with multipole field series [4],

$$E_z = E_0 \sin(\omega t)\cos(kz)\sum_{n=0}^{\infty} a_n r^n \cos(n\phi) \tag{4}$$

where E_0 is the peak value of electric field, ω is the microwave frequency and a_n is the Fourier coefficients of multipole mode.

After some mathematical calculation, we can get the estimation of emittance increase as,

$$\Delta\varepsilon_y = \frac{eE_0 L}{2mc^2} n a_n r^{n-1}\sigma_y \sigma_z \tag{5}$$

More specifically, emittance emittance for first three modes are,

$$n=1 \quad \varepsilon_{n,rms}^{dipole} = \frac{eE_0 L}{2mc^2}\times a_1 \sigma_y \sigma_z \tag{6}$$

$$n=2 \quad \varepsilon_{n,rms}^{quadrupole} = \frac{eE_0 L}{2mc^2}\times 2a_2 \sigma_y^2 \sigma_z \tag{7}$$

$$n=3 \quad \varepsilon_{n,rms}^{sextupole} = \frac{eE_0 L}{2mc^2}\times 3a_3 \sigma_y^3 \sigma_z \tag{8}$$

According to these formulas, expected emittance increase values are 3.54, 0.225, 0.0138 mm-mrad for dipole mode, quadrupole mode, sextupole mode respectively. All these results are values in the full cell region which of length is 32.5cm and Fourier coefficients are obtained from the field analysis with the help of FFT function in Matlab.

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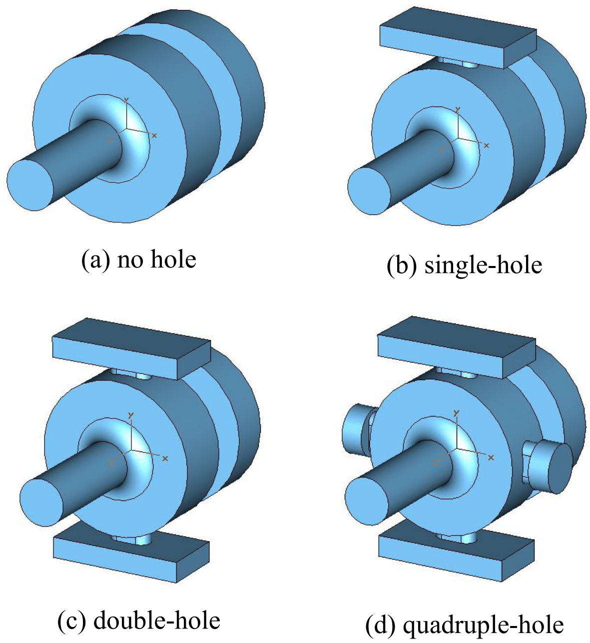

Figure1: simulation gun model with different number of holes

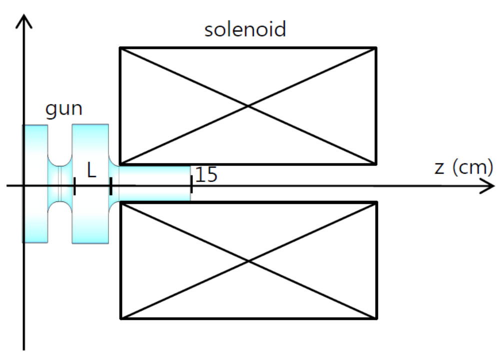

Figure 2: Gun & solenoid magnet layout

SIMULATION

3D RF gun models based on LCLS model were constructed in order to compare the results with verified results [5]. And then field components were extracted to make 3D input field map for Parmela simulation using with eigenmode solver of the program, CST Microwave Studio. Simulation gun models are shown in figure 1. After sorting field components to match with the order of Parmela input, 3D input field map was obtained. At this point, program ThreeDin which is included as a utility program of Parmela was not used. Instead of it, Matlab was used for further research. With the 3D field map for each model, Parmela simulation was conducted and the emittance increases were investigated and its results are shown in figure 3. Also the Fourier coefficients of each model with different number of holes are calculated by the use of FFT function in Matlab. The values are obtained at the center of the full cell and at the radius of 9mm. The parameters used in Parmela simulation and gun & solenoid magnet layout are shown in table 1 and figure 2 respectively.

First, gun model with no hole was simulated. The field formed in this model has only monopole mode component at least theoretically. Comparing this result with 2D model case, they showed similar emittance evolution as is shown in figure 3.

Next, in case of the model with single hole, result showed that the emittance increased widely and even one of emittance-minima was disappeared in our concerned region. This is due to the induced-dipole mode and other higher multipole modes.

In case of dual-feed model which has double hole, the emittance increase was dramatically decreased. By adding a same size hole at opposite position, dipole mode was almost killed as one can see in figure 4, meanwhile quadrupole mode was increased slightly.

Finally, with two additional holes which will be used as vacuum port and also help to suppress dipole and quadrupole modes, this model showed the result not much different from double hole model case except slightly decreased emittance in the region just right after the beam comes out from the gun.

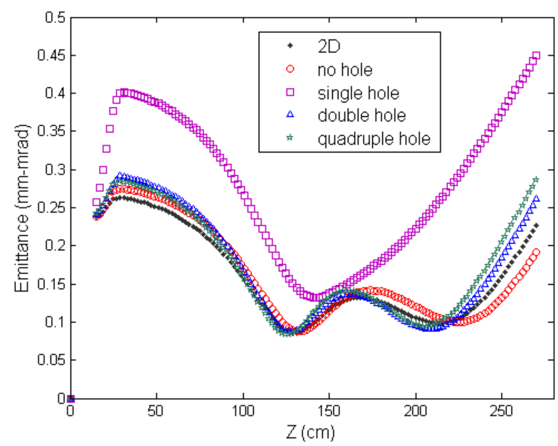

Figure 3: Emittance evolution

SUMMARY AND DISCUSSION

Here the effect of the multipole modes induced by asymmetric geometry of the gun on emittance increase was investigated with the help of 3D field solver. In case of single hole model, emittance was increased in whole concerned region due to its multipole modes. However, one can reduce dipole mode by adding one more holes at opposite position and also quadrupole mode by adding two more holes at the 90° positions with respect to the coupling hole. Only by suppressing first two multipole modes, emittance increase effect is almost disappeared.

Parmela input file used in this simulation was constructed by Matlab and Fourier coefficients for each gun model could be optained by using with useful built-in function, FFT in Matlab. We expect that we may have a possibility to manipulate the Fourier coefficient by force so that we can investigate the effect of each pure multipole field component on emittance increase. That will be our next future work.

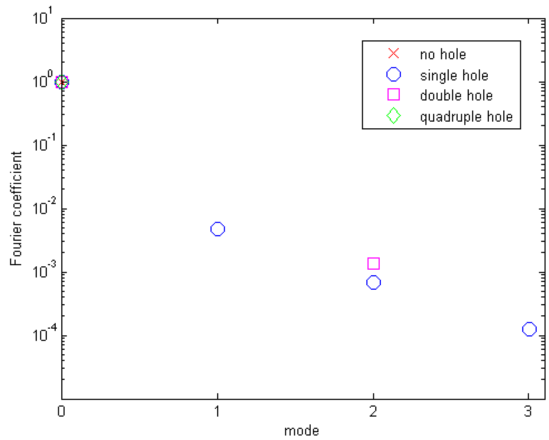

Figure 4: Fourier coefficient for each mode & model

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