# RF AND COUPLER DESIGN OF A MICRO-PULSE ELECTRON GUN*

L. Liao, M. Zhang, Q. Gu, M. Zhao,
SINAP, CAS, Shanghai 201800, China

*Abstract*

The RF parameter design of a micro-pulse electron gun (MPG) should be inclined to benefit both the resonance condition of multipacting effect and beam quality, and in particular it is found that the axis electric field of cavity is essential to yield high quality beams. The high RF power density is delivered to the cavity by a small hole in the top of cavity. The size of coupling hole is carefully regulated to overcoupling by using CST MICROWAVE STUDIO. Also the configuration of whole gun is presented. Because of its simple structure and operation, the MPG will play a major role in some cost-effective accelerating systems.

## INTRODUCTION

The micro-pulse electron gun (MPG) is a kind of RF gun by taking advantage of multipacting effect in the standing wave cavity [1-3]. The amplification of multipacting was recognized as a useful way to drive a electron tubes [4], also in MPG, the initial electrons is exploded to a large number of secondary electrons until saturation. Owing to the material properties and phase focusing mechanism [5], the electrons would bunch to a sheet in the cavity so as to output at the exit of anode.

On the basis of novel cavity structure we conceived at the design of a micro-pulse electron gun (MPG) [6], it might be expected that the gun would give rise to high current and short pulse electron beams and the results were shown by a PIC code VORPAL simulation [7]. An important practical consideration is how to take space charge effect into consideration, hence the simulation results are of considerable importance in getting feedback on the RF parameters design. The link between beam quality and cavity voltage is presented in this paper, which is different from the results obtained from the pure theoretical analysis.

Also the tuning process of the coupling hole design is presented. Similar to the previous work [8-9], the coupling hole design is based on the one port magnetic coupling method [10]. The coupling coefficient is tuning to overcoupling by CST MICROWAVE STUDIO. Here the coupling coefficient is higher than that in the design in order to increasing the input power at the experiment.

## RF PARAMETERS DESIGN

In order to realize the operation of MPG, the RF parameters should meet the requirement of the resonance condition. Hence the RF parameters are of considerable importance for MPG, especially the gap distance D and cavity voltage $V_{rf0}$. It is evident that the gap distance D is connected with $V_{rf0}$, someone can get the information from the reference [3]. It is importance to note that MPG still be preferable for two-surface impact, so the values of D and $V_{rf0}$ are calculated directly from Fig. 1 as shown below.

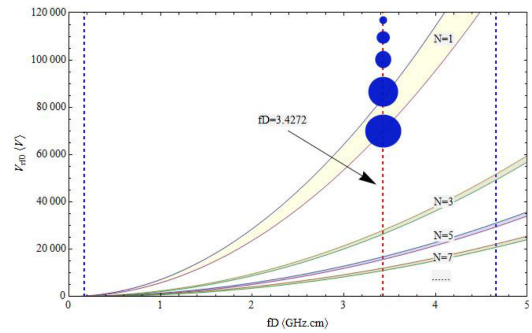


Figure 1: Susceptibility curves of first order and higher order two-surface multipacting. The two blue dash line represents the susceptibility area of MgO material. The pulse width is shown as a diameter of a blue circle, and the large circle represents the large FWHM width of micro-pulse.

The calculation in Fig. 1 is at the absence of space charge effect, which will result in the discrepancy between the calculation and the simulations. The blue circle in Fig. 1 represents the effect of cavity voltages, moreover, it is easy to find that the susceptibility range is enhanced. The upper bound of cavity voltage for multipacting is extend to as high as about 10 MV/m, also the lower bound. One explain to this phenomenon is the effect of the space charge effect and other multipacting modes [11]. Hence it is essential for us to investigate the cavity voltage in the gun.

Figure 2 shows the micro-pulse full width at half maximum (FWHM) versus maximum accelerating electric field in the axis. Increasing the cavity voltage leads to decreasing the width of pulse, but the width is limited by the upper bound. If the maximum electric field in the cavity is set at about 10 MV/m, the multipacting is quenched as well as the operation of the gun.

* Work supported by National Basic Research Program of China (973 Program) (Grant No. 2011CB808300)

ISBN 978-3-95450-171-7

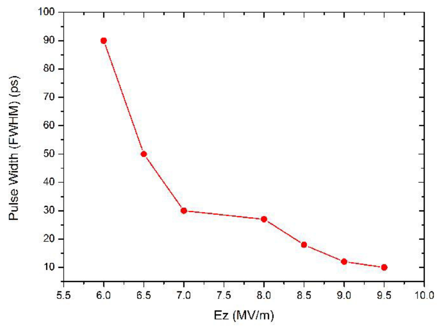


Figure 2: Width of the micro-pulse (FWHM) versus accelerating electric field Ez.

## COUPLING HOLE DESIGN

For a single cavity structure, the one port magnetic coupling is preferred here. In order to couple microwave power into the cavity by input waveguide, the coupling hole is designed to a critical value without consideration of the electron beams. For MPG, the peak current at the exit of anode is much higher, hence the beam loading can't be ignored in the coupling hole design. Corresponding to the designed cavity voltage, the output peak current is limited to a value of 35 A, hence the coupling coefficient β can be calculate by

$$\beta=1+P_b/P_c \quad (1)$$

where $P_b$ is the power taken away by the electron beams, $P_c$ is the power dissipation around cavity boundary.

Therefore the β can be calculated from Eq. (1), and the result is 5. As discussed above, Increasing the cavity voltage is benefit to the beam quality, and in order to boost the cavity voltage in our high power test, hence the β is set to 7. To practically necessitate the use of CST WM, it is easy to transfer the β to the value of $S_{11}$, the equation is given by

$$\beta=(1+|S_{11}|)/(1-|S_{11}|) \quad (2)$$

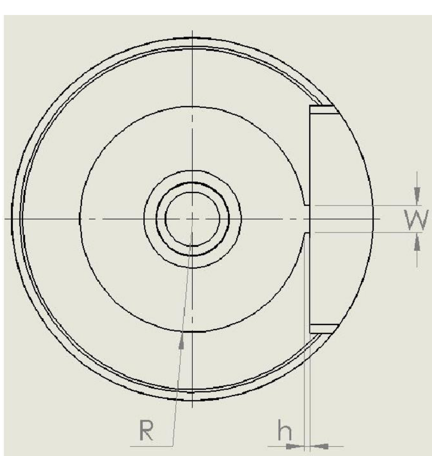


Figure 3: The sketch of the coupling hole size.

Figure 3 shows the sketch of the coupling hole size. The value of $S_{11}$ is determined by the coupling hole size h and w. The choice of cavity radius R is optimized to minimize the deviation of the frequency. These three parameters are essential to the tuning process. The value of h is set to 2 mm, which is partly determined by the state of the art. The values of R and w determine the resonance frequency and the value of $S_{11}$. Figure 4 gives the tuning history for different R and w. The area of circles represent the deviation of $S_{11}$ magnitude and frequency, and the smallest circles is on the behalf of the trends to the anticipated results. It is easy to know that the preferable results can be achieved by giving values as shown in Table 2. Figure 5 shows the tuning result of the coupling hole. In this case, the frequency deviation from 2856 MHz is 0.3 MHz, which can be accepted in our gun design. Table 1 shows the optimization coupling hole size for $S_{11}$=0.75 (corresponding to β=7).

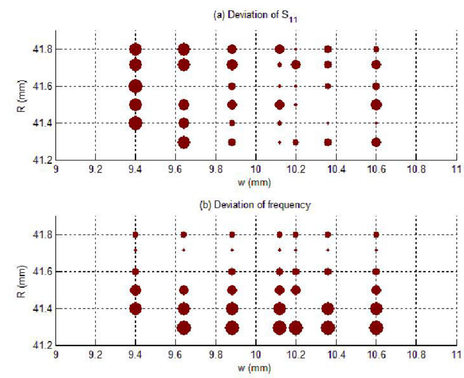


Figure 4: The tuning history for the coupling hole size. (a) The deviation of standard $S_{11}$ magnitude ($S_{11}$=0.75) are shown as the area of a circle. (b) The deviation of frequency ($f$=2856 MHz) are shown as the area of a circle.

Table 1: The Optimization Coupling Size for $S_{11}$=0.75

| R (mm) | h (mm) | w (mm) | $S_{11}$ |
|---|---|---|---|
| 41.72 | 2 | 10.2 | 0.75 |

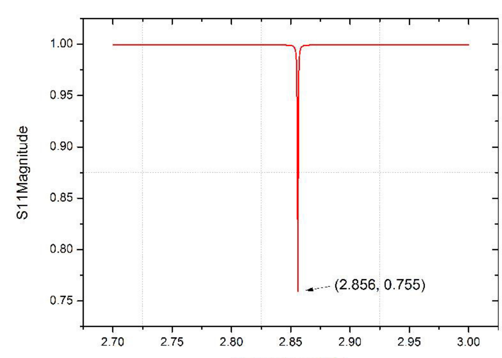


Figure 5: Frequency pass band of the coupling hole by using CST MW.

## CONFIGURATION

In this part, the assembly of each components is presented as shown in Fig. 6. The input waveguide connect with the cavity by the coupling hole. Also the choke structure is designed to avoid the coaxial radiation.



ISBN 978-3-95450-171-7

In Table 2, the structural parameters and RF parameters are given.

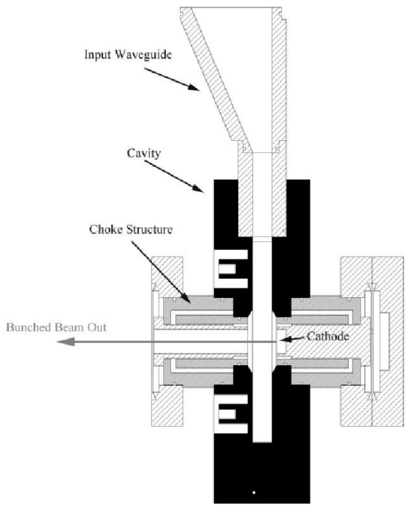


Figure 6: Structure of MPG.

## CONCLUSION

As the cavity voltage was recognized to be the solution to improve the quality of electron beams, the coupling hole sizes were optimized to make sure that the coupling coefficient is higher than the designed value that is 5 here. The assembly of each components as well as the structural parameters and RF parameters are also presented in this paper.

Table 2: Basic Parameters for the Gun

| Parameters | Units | Values |
|---|---|---|
| Cathode/Anode material | -- | MgO |
| Radius of cathode/anode | mm | 10 |
| Radius of cavity | mm | 83.44 |
| Gap distance D | mm | 12 |
| Frequency $f$ | GHz | 2.856 |
| Accelerating field Ez | MV/m | > 7.5 |
| Power source | KW | 100 |

## REFERENCES

[1] W. Peter, R. J. Faehl, M. E. Jones, Particle Accelerators 21, 59(1987).
[2] F. Mako, W. Peter, "A High-Current Micro-Pulse Electron Gun", PAC'93, 1993, p. 2702–2704 (1993).
[3] F. Mako. United States Patent, 2007.
[4] P. T. Farnsworth, Proceedings of the IRE 24 (1936).
[5] J. M. Vaughan, IEEE Transactions on Electron Devices ED-36, 1172(1988) .
[6] L. Liao, M. Zhang, Q. Gu, etc. Nucl. Instrum. Methods Phys. Res. A 729, 381(2013).
[7] VORPAL website: http://www.txcorp.com.
[8] D. Li, R. Rimmer, S. Kosta, "Calculations of External Coupling to A Single Cell RF Cavity", PAC'98, 1998, p. 977-979 (1998).
[9] K. Yokoyama, T. Kamitani, T.sugimura, etc, "Coupler Matching Techniques for C- Band Accelerating Section", PAC'05, 2005, p. 1431-1433 (2005) .
[10] E. Westbrook. "Microwave impedance matching of feed waveguide to the disk- loaded accelerator structure operating in the $2\pi/3$ mode", SLAC_TN-63-103, 1963.
[11] L. Liao, M. Zhang, M. Zhao. Chinese Physics C, 2014(submitted).

ISBN 978-3-95450-171-7