

# MEASUREMENT OF CELL-CELL COUPLING COEFFICIENT IN PHOTOCATHODE RF GUN\*

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## Abstract

A photocathode RF gun is being developed in Tsinghua University. We measure the single cell frequency and the cell-cell coupling coefficient by a detuning method with high accuracy. This note presents the principle of the method and several examples.

## INTRODUCTION

The 1.6 cell photocathode S-band gun has been used as the electron sources with high beam quality for many years. A lot of scientific research programs benefit from this type of photocathode RF gun, such as the compact x-ray source in Tsinghua University [1] and the LCLS in SLAC [2].

The achievement of a photocathode RF gun with good performance needs careful measurements and tunings of the RF cavities. However as is known the half cell of a photocathode RF gun makes the measurements of the RF properties difficult because of the cathode with no beam pipe. We can measure the full cell frequency by detuning the half cell. But if we want to obtain the frequency with high accuracy we have to detune the half cell by a large amount, which risk damaging the surface of the cathode [3]. The cell-cell coupling coefficient in photocathode RF gun is another very important parameter which influence the frequencies of both 0-mode and  $\pi$ -mode as well as the field balance [4]. Ref [4] give a full description of the tuning procedure for a photocathode gun, which can be used to calculate the cell-cell coupling coefficient with no approximation. However we have to measure the frequencies of the 0-mode and the  $\pi$ -mode, the quality factors and shunt impedances of the full cell and the half cell and the field balance for eventually calculating the cell-cell coupling coefficient.

In this paper we introduce a simple method to measure the frequencies of the full cell and the half cell and the cell-cell coupling coefficient. Only a small extra metal stick is used to detune the half-cell by a small amount. We start from the equivalent RLC circuit of the RF gun. Then we design a simplified model to show how we measure the RF gun.

## BASICS OF MEASUREMENT

We can analysis an RF structure by the method of equivalent RLC circuit. The equivalent RLC circuit of the

RF gun is shown in the Fig. 1. The two cells are coupled by the equivalent capacitor  $C$ . The two cells of the RF gun is different from each other. So they have different equivalent capacitors and Inductors.

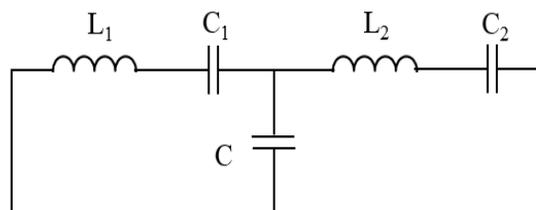


Figure 1: The equivalent RLC circuit.

We can easily obtain the relationship of the frequencies with cell-cell coupling coefficient [3]:

$$\frac{(f^2)^2}{f_h^2 \cdot f_f^2} - \left( \frac{1}{f_h^2} + \frac{1}{f_f^2} \right) \cdot f^2 + 1 - \frac{k^2}{4} = 0 \quad (1)$$

Here  $f$  is the frequency of the operating mode. The  $f_h$  and the  $f_f$  are the resonant frequencies of the half cell and the full cell. The solutions of equation (1) are the frequencies of the 0-mode and the  $\pi$ -mode. We can get:

$$f_0^2 + f_\pi^2 = f_h^2 + f_f^2 = x \quad (2)$$

$$f_0^2 \cdot f_\pi^2 = \left( 1 - \frac{k^2}{4} \right) \cdot f_h^2 \cdot f_f^2 = y \quad (3)$$

We define two new variables  $x$  and  $y$  here. During the experiment we use a small metal stick to detune the half-cell through a laser port. So we change the frequency of the half cell while keeping the frequency of the full cell unchanged. The relationship between  $x$  and  $y$  are given:

$$y = \left( 1 - \frac{k^2}{4} \right) \cdot f_f^2 \cdot x - \left( 1 - \frac{k^2}{4} \right) \cdot f_f^4 = ax - b \quad (4)$$

Both of the variable  $x$  and  $y$  vary with the amount of the detuning and they have a simple linear relationship. We can easily obtain the slope and intercept of the straight

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line of  $x$  and  $y$ . We can get the frequencies and the cell-cell coupling coefficient:

$$f_f = \sqrt{b/a} \quad (5)$$

$$f_h = \sqrt{\left(f_0^2 + f_\pi^2\right)_{\text{nodetuning}} - b/a} \quad (6)$$

$$k = \sqrt{4(1 - a^2/b)} \quad (7)$$

## SIMULATION OF THE MEASUREMENT

We design a simplified CST model to simulate the measurement process analysed above. The model has no waveguide coupler, laser ports or vacuum ports. We mainly focus on the coupled cells. The resonant frequency of the RF gun is 2856.407MHz and the ratio of the on-axis maximum field in two cells is 1.033 as is showed in Fig.2.

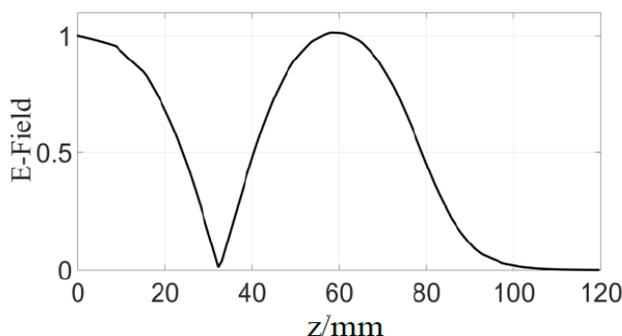


Figure 2: The on-axis electric field normalized by the maximum electric field at the cathode.

As is showed in the Fig. 3, we add a small hole on the half cell surface which is equal to the metal stick in the measurement. We change the depth of the small hole in the half-cell to detune the RF gun by different amount. Here we only detune the half cell by a small amount which can be regard as perturbation. So we assume that the small hole doesn't change the cell-cell coupling coefficient of the two cells. We can obtain a couple of  $x$  and  $y$  which are used to calculate the parameter  $a$  and  $b$  in the equation (4) from the CST simulation with the small hole in the model. The process of the simulation is the same as that of the RF measurement. During the measurement we use a small metal stick to detune the half cell from a laser port. That's why we add the small hole to the half-cell of the CST model.

With different depths of the small hole in the CST model we can collect enough data for the calculation of the frequencies and the cell-cell coupling coefficient. We can see the linear relationship of  $x$  and  $y$  in the Fig. 4. As we have known in the equation (4), the value of  $b$  is much larger than that of  $a$ . The fitted curve goes through all the

data obtained from the simulation which is predicted by the equation (4).

We can easily get the slope and intercept of the straight line which are corresponding to the parameter  $a$  and  $b$ . Now we can use the equation (5) (6) and (7) to calculate all the parameters we want to know. In the case of the CST model we design the frequencies of the half cell and the full cell are 2852.768MHz and 2854.003 MHz respectively and the cell-cell coupling coefficient is 0.00379. As is shown in the Fig. 5 we can put all the four frequencies with different depths of the small hole on the same figure with the frequency of the half cell as the x-axis variable.

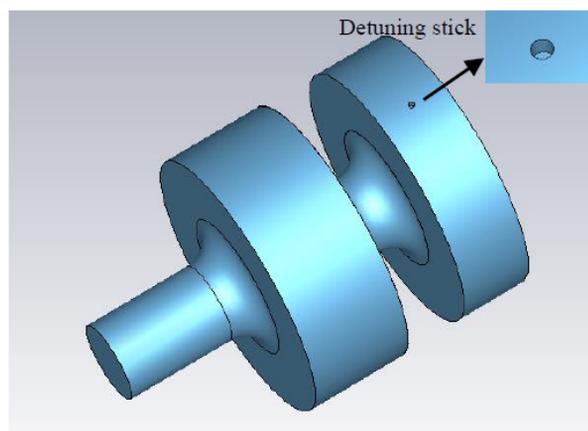


Figure 3: The CST model with a small hole in the half cell.

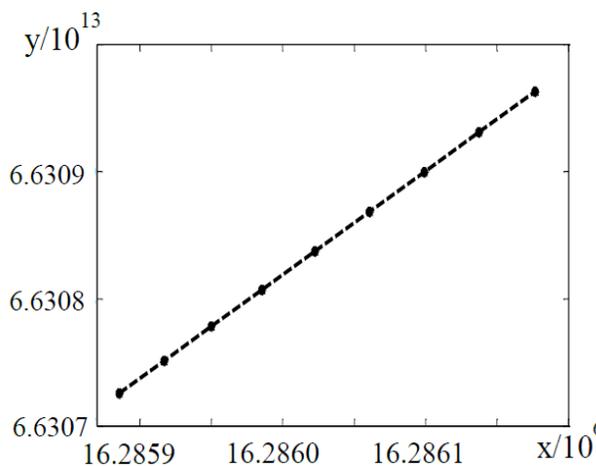


Figure 4: The data and the fitted curve obtained from the model with the values of  $x$  and  $y$  are normalized by  $10^6$  and  $10^{13}$  respectively.

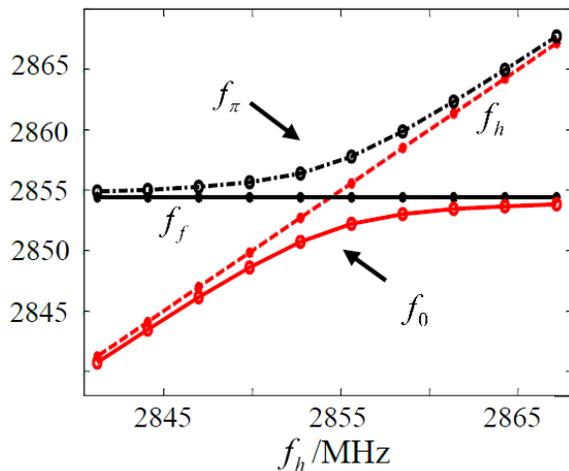


Figure 5: Variation of  $f_0$  and  $f_\pi$  with half-cell frequency for a constant full-cell frequency.

### RF MEASUREMENTS

We measured and turned the RF gun for five times to make the frequency of  $\pi$ -mode at 2856MHz. The total measurement only need to measure and record several group of the frequencies of the 0-mode and  $\pi$ -mode. The experiment setup is showed in the Fig. 6. It is very convenient and safe to detune the RF gun by a small metal stick through a laser port.

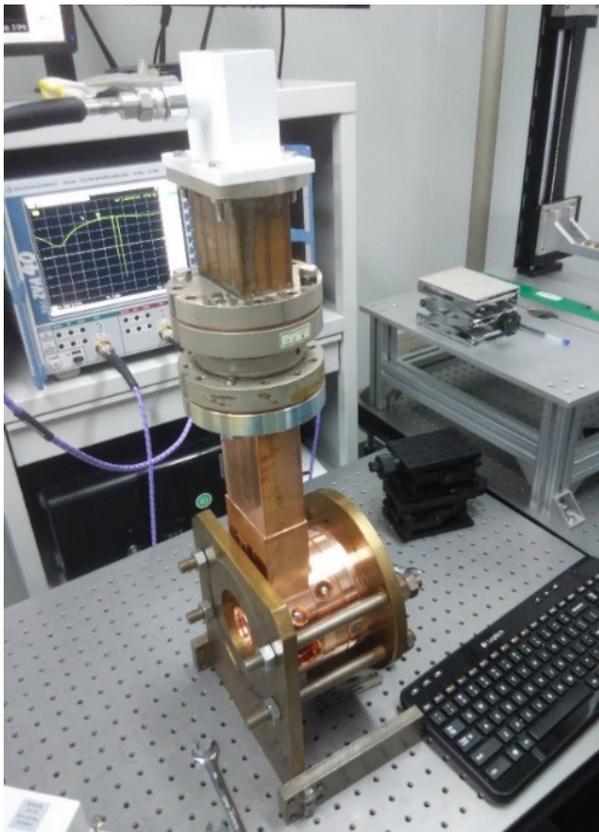


Figure 6: Experiment setup for RF gun measurement.

The results of all the measurements are showed in the Table 1 and the Fig. 7. The frequencies of the half cell and full cell are changed after the modification of the RF gun and the cell-cell coupling coefficient is of just a little change.

Table 1: The Results of the Measurements

	$f_\pi$ (MHz)	$f_f$ (MHz)	$f_h$ (MHz)	$k$ (MHz)
1	2864.1670	2852.7365	2858.8985	0.0109
2	2862.3790	2851.9837	2857.0293	0.0104
3	2859.3900	2852.0152	2851.6848	0.0106
4	2857.1500	2849.6896	2849.5654	0.0105
5	2856.0010	2849.9551	2846.7309	0.0105

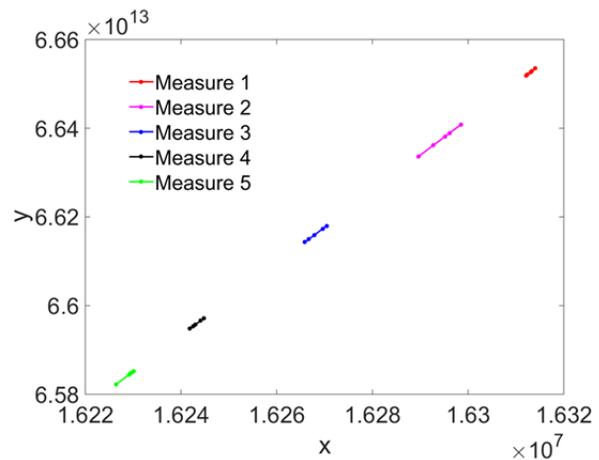


Figure 7: The fitted curves of the measurements.

With the help of excel program we can obtain the result immediately after the measurement. We modified the RF gun based on the results we measured and then made the decision about how to change the geometry of the RF gun.

### CONCLUSION

We introduce and explain a new method to measure the cell-cell coupling coefficient and the frequencies of the half cell and the full cell. The method is convenient using a small stick to detune the half cell of the RF gun by a small amount. The method have helped us make the decision about how to modify the RF gun and we have tuned several RF guns by this method successfully.

### REFERENCE

- [1] Du Yingchao et al., Generation of first hard X-ray pulse at Tsinghua Thomson Scattering X-ray Source, Review of Scientific Instruments 84, 053301 (2013).
- [2] L. Xiao et al., "Dual Feed RF Gun Design for the LCLS", Proc. PAC 2005, Knoxville, Tennessee, May 15-20, 2005.

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- [3] Guan Xin, The Research of Microwave Characteristic of Photocathode RF Gun [C], Tsinghua University, P34-36, 43.
- [4] Shankar Lal et al., A new two-step tuning procedure for a photocathode gun, Nuclear Instruments and Methods in Physics Research A 592 (2008) 180 - 188.