Design and Construction a Full Copper Photocathode RF Gun*

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Abstract

The design and construction of an all copper S-band one-and-half cell photocathode electron gun without a choke joint is described. The methods utilized to determine the field balance at the operational frequency without usage of the bead pulling perturbation measurement is given together with the computational data.

I. THE ATF INJECTION SYSTEM

One of the major development in accelerator technology in the last decade is the development of photocathode RF electron gun for Free Electron laser and other applications. At the Brookhaven National Laboratory Accelerator Test Facility(ATF), an S-band, one and half cell, photocathode RF gun is now in operation.[1]

As part of ATF R&D program, extensive study has been performed to investigated the various options of improving the ATF injection system.[2] It was found that the large divergence of the electron beam from the RF gun and the mismatch caused by the space charge are major sources of the emittance growth. Two simple techniques[3] were studied to reduce the beam divergence. Making the half cell field 80% of the full cell's, the beam divergence can be reduced by half. It is also possible to reduce the emittance growth due to the beam divergence in the injection line using an elliptical laser spot, it matches better to the strong focusing injection line. Recent study[4] suggested by using two solenoid magnets and place the RF gun directly at the entrance of the linac, significant emittance reduction can be achieved.

The distance between the cathode and linac is about 75 cm for the new injection system, the arrangement was made in such way, that the old injection system will be left untouched for RF gun studies, second gun was built for the new injection system.

II. THE FULL COPPER RF GUN

Comparing the BNL one-and-half cell gun [5] and Grumman-BNL multi-cell gun,[6] a modified BNL gun was chosen for its proved performance. The BNL one-and-half cell RF gun had achieved its designed parameters at both ATF[1] and other labs.[7] The BNL RF gun is operated routinely at lower field than designed value, because of the break down near the choke joint and the beam loading caused by the field emission current. The experimental results showed[1] that copper cathode can satisfy the demands of the the ATF experiments, modify the BNL one-and-half cell gun to a full copper RF gun will make it much more reliable. The full copper RF gun may also reduced beam loading effect. It was demonstrated that S-band linac structure can operate at field much higher than 100 MV/m,[8] the dark current beam loading could be reduced if the RF gun can be conditioning at higher field.

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III. THE RF GUN CAVITY CONSTRUCTION AND TUNING

The calculated frequency using SUPERFISH is about 15 MHz higher than 2856 MHz before any tuning work. Based on the experience of building the first BNL RF gun, following steps were taken for the construction of the full copper RF gun:

Target frequency. We first determined the target resonant frequency of the cavity in the air at room temperature(24°C) is 2856.3 MHz. From both calculation and measurement, the temperature coefficient of the resonant frequency is 50 KHz/deg., and the frequency change from air to vacuum is about 800 KHz. In order to operate the gun near 45°C of the SLAC-type linac operating temperature, the target frequency should be near 2856.3 MHz.

Tuning range. There is a loop type tuner at each cell, the tuning range of the half cell is about 1 MHz, and the full cell's range is about the half of the half cell's.

Size of the coupling hole. We estimated that to lower the resonant frequency from 2871 MHz near the target frequency and realize reasonable coupling between the waveguide and the cavity, a coupling hole size 1 cm by 2 cm is adequate for each cell(see Fig. 1).

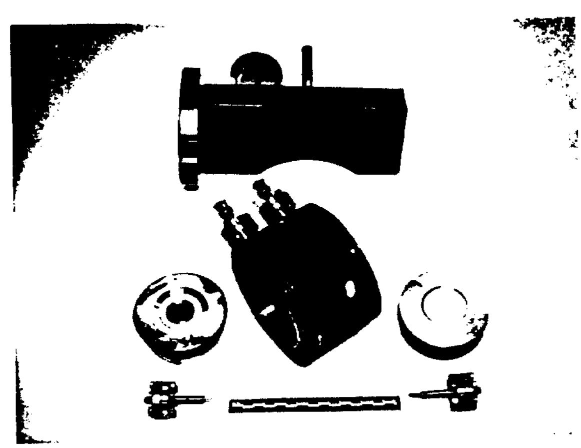

Figure 1: Parts for the RF gun.

Frequency tuning. After the coupling holes were machined, the resonant frequency was about 8 MHz lower than the target frequency. We can either machine the cylinder of the cavity or the end wall of the each cell. We decided work on the end wall because its flexibility. Near

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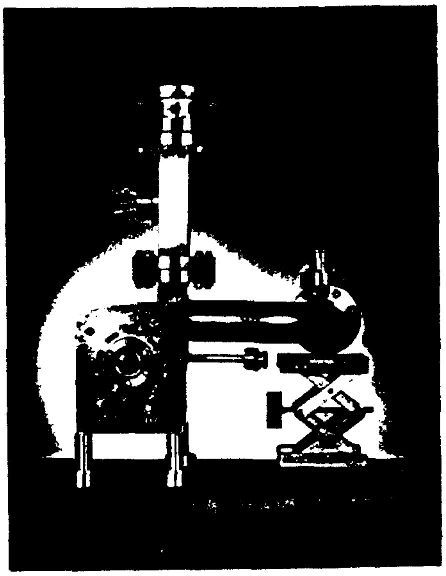

Figure 3: The ATF full copper RF gun.

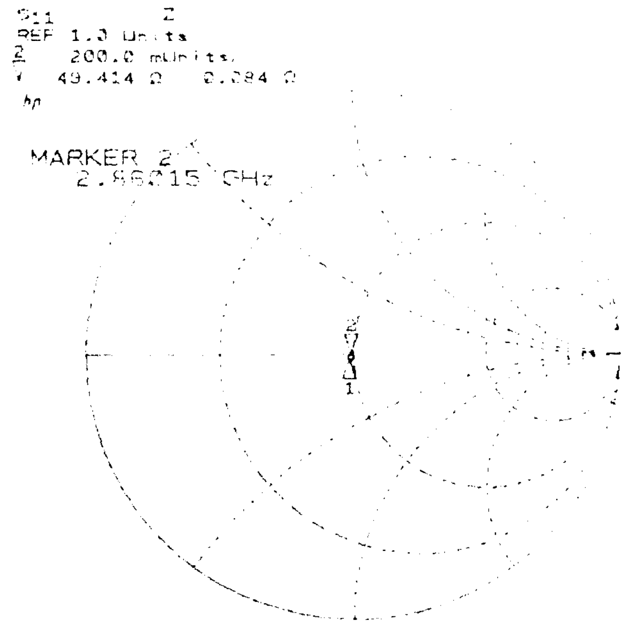

Figure 2: The Smith chart of the waveguide.

the cavity resonant frequency, the cavity can be described by an equivalent LC circuit whose resonant frequency is,

$$\omega = \frac{1}{\sqrt{LC}}. \qquad (1)$$

Changing the depth of the cathode (or anode) penetration into the cavity is equivalent to adjusting the capacitance, since the cathode is located in the strong electric field region. The resonant frequency can be reduced by increasing the capacitance through increasing the penetration of the cathode. Similarly, an increase of the resonant frequency can be achieved by decreasing the cathode penetration. The radius of the areas were machined off is about 2.3 cm(Fig. 1).

Critical coupling. After the gun cavity was tuned near the target frequency, the gun was under coupled. We can open the coupling to increase the coupling, which also affects the resonant frequency. The method we used to achieve the critical coupling is equivalent to add another reactive load to the waveguide, so the total load for the wave guide is resistive. We placed a cooper block across the broad side of the wave guide across from the coupling holes. By adjusting the thickness of the block and it's position, the critical coupling was obtained (Fig. 2).

Fianl assembly. The full copper RF gun was brazed together at SLAC(Fig. 3).

The Field balancing.The performance of the RF gun will be affected by the accuracy of balancing the fields between the two cells. The perturbation method is usually used to balance the field, it is reliable but inconvenient. We have been used following two techniques to balance the gun.

- **Q-measuremt.** We studied how the difference of the peak fields in the two cells affects the properties of the cavity.

$$Q = \frac{\mu}{\mu_0}\left(\frac{V}{\delta S}\right) \times (Geometrical Factor) \qquad (2)$$

where μ and μ_0 are permeabilities, δ is the skin depth, V is the cavity volume, and S is the surface area enclosing the volume. Eq. (2) shows that, since the ratio of surface area to the volume in the half cell is larger than that of the full cell, the higher field in the half cell will lower the Q of the whole cavity. Table 1 is the calculated results using SUPERFISH, where E_c is the field at cathode surface and E_2 is the peak field on axis of the full cell. It shows that field balancing can be measured by measuring the loaded Q(assuming the gun is at critical coupling).

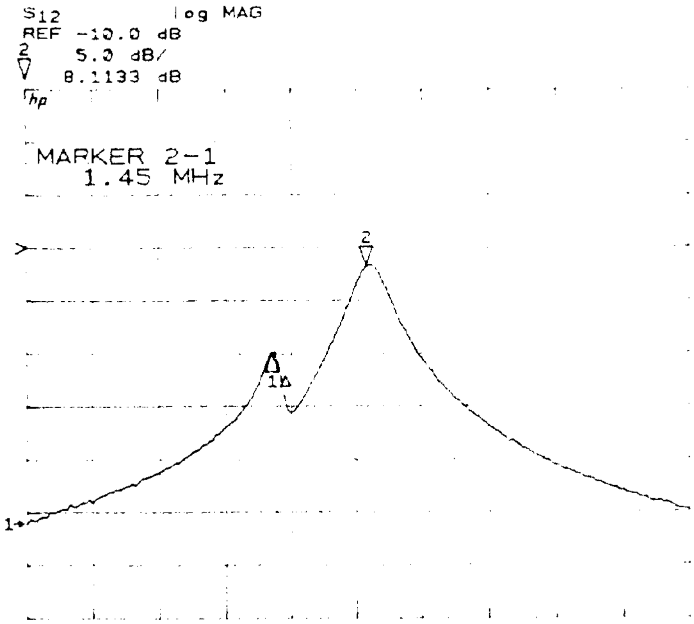

Figure 5: The mode separation for balanced fields.

Table 1: RF Cavity properties and Field relation

Q_0	R	E_c/E_2
11113	52.57	1.25
11887	56.76	1.02
11915	56.89	0.99
12387	58.83	0.86

- **Modes separation** The frequency difference of the π-mode and zero-modes can be expressed as,[7]

$$f_\pi - f_0 = kf. \tag{3}$$

where k is the coupling factor of the gun, and f is single cell resonant frequency. k is determined by the coupling factor of each cell, and hence determined by the field strength. Eq. (3) is usually used to calculate the coupling factor k, we can use perturbation method to calibrate the coupling factor, and use the mode separation to determine the field balance. Fig. 4 is the field distribution of the RF gun on axis obtained using the perturbation method. Fig. 5 is the corresponding mode separation for the balanced field.

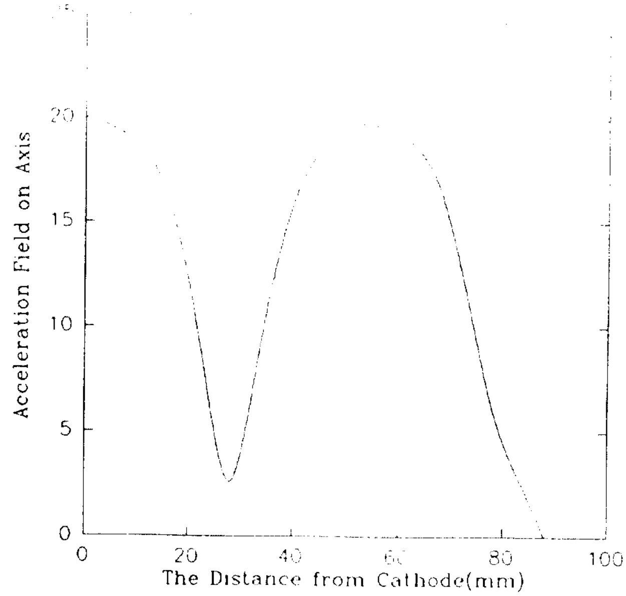

Figure 4: On-axis field distribution of the gun.

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