DESIGN OF THE FUNDAMENTAL POWER COUPLER AND PHOTOCATHODE INSERTS FOR THE 112 MHZ SUPERCONDUCTING ELECTRON GUN*

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Abstract

A 112 MHz superconducting quarter-wave resonator electron gun will be used as the injector of the Coherent Electron Cooling (CEC) proof-of-principle experiment at BNL [1]. Furthermore, this electron gun can be the testing cavity for various photocathodes. In this paper, we present the design of the cathode stalks and a Fundamental Power Coupler (FPC) designated to the future experiments. Two types of cathode stalks are discussed. Special shape of the stalk is applied in order to minimize the RF power loss. The location of cathode plane is also optimized to enable the extraction of low emittance beam. The coaxial waveguide structure FPC has the properties of tunable coupling factor and small interference to the electron beam output. The optimization of the coupling factor and the location of the FPC are discussed in detail.

INTRODUCTION

A 112 MHz superconducting quarter-wave resonator electron gun had been built under cooperation between Brookhaven National Lab and Niowave Inc. This gun will be used as the injector of the Coherent Electron Cooling experiment in BNL. Besides that, this gun can also be used as the testing facility for various photocathode. However, two major modifications have to be done to make the gun suitable for the tasks mentioned above. First, the original cathode holder, which had also been used as a fundamental power coupler has to be replaced by a newly designed cathode stalk. The new stalk is specially designed for the test of Diamond Electron Amplifier which will multiply the primary electron current by a factor of nearly 200. Meanwhile, this stalk is compatible for the test of other photocathode such as the metal and multi-alkali cathode, one only have to change the insertion of it and the outer shield can be kept untouched. Secondly, the fundamental power coupler has been redesigned. Since the length of new cathode stalk has been made half wave length in order to optimize the field on cathode, it is not applicable as a power coupler any more. Therefore a new FPC which couples the RF power into cavity from the exit of cavity has been designed. Moreover, by adjusting the penetration of the Coupling Tube one can tune the frequency of cavity as well as adjust the coupling strength. The layout of the cavity including the cathode stalk and FPC is shown in Figure 1.

DESIGN OF CATHODE STALK

As mentioned above, for the future application of 112 MHz electron gun in CEC project as well as the testing experiments on different photocathodes the original stalk has to be replaced by a new one which can be used to mount a much larger cathode and also have enough space inside for the primary DC gun in the Diamond Amplifier experiment. The general considerations in the design of cathode stalk are discussed below.

Large Cathode Surface-half Wave Length Design

The cathode that is going to be tested in this gun has the diameter as large as 2 cm. This requirement leave only 4 mm gap between the stalk and nose cone at the entrance of the cavity. If we still use the original length of stalk which was selected as quarter wave length for the sake of power coupling, the voltage drop between the cavity and stalk will be more than 5.6 kV if a reasonable acceleration field is assumed. Therefore, we applied a half wave length design here to minimize the voltage drop between stalk and cavity.

According to the general equation of impedance of transmission line [2]:

$$Z_{in} = Z_0 \frac{Z_L + Z_0 \tanh(\gamma l)}{Z_0 + Z_L \tanh(\gamma l)} , \quad (1)$$

here $Z_0 = 60\, ln \frac{b}{a}$ where b and a and the radius of outer and inner conductor respectively.

$$\gamma = \alpha + j\beta , \quad (2)$$

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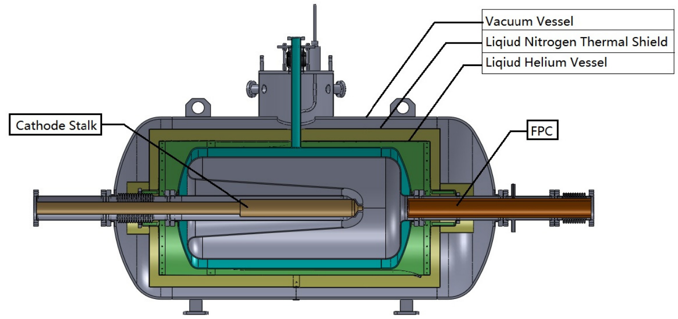

Figure 1: The layout of 112MHz electron gun with the new cathode stalk and fundamental power coupler.

in which

— ——— , (3)
–

where is the surface resistance of the conductor under specific frequency, is the impedance of free space, and is the propagation constant defined as —.

In order to minimize the voltage drop, one needs to minimize . By going through some calculation one can easily see that if we ignore the effect of , the minimum of can be acquired by choosing –.

The optimized result, which included the effect of finite conductivity of copper is shown in Table 1 in comparison with the original quarter wave length design. The field line near tip of stalk is calculated by SUPERFISH and shown in Figure 2. By integrating along the black solid line in Figure 2 we can get the voltage drop between the cathode and cavity.

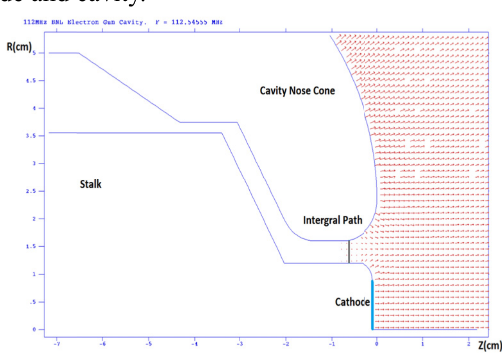

Figure 2: Field distribution near cathode surface and nose cone.

As we can see, there is a significant drop of the voltage.

Table 1: Compare between quarter wave and half wave stalk

Type	Length of stalk (cm)	Voltage Drop between cavity and stalk (KV)
Quarter wave length	66.7	5.61
Half Wave length	133.3	0.11

Furthermore, the transverse field distribution along the cathode surface had been optimized by the combination of carefully changing the position of the tip of stalk in the cavity and choosing the half wave length stalk. Figure 3 shows the original field distribution and the optimized result. We can see there is an order of magnitude improvement due to the fine tune of position of cathode surface.

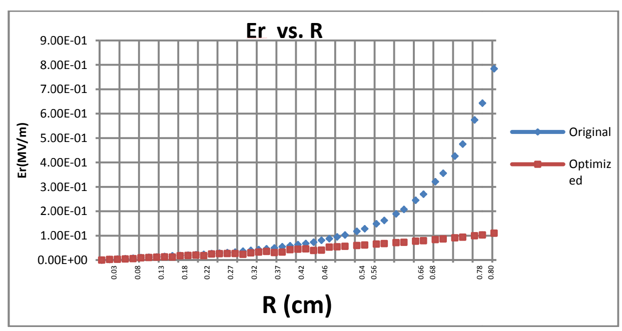

Figure 3: Transverse field distribution on cathode before(♦) and after(■) optimization.

Minimizing the RF Power Losses on Stalk and Outer Pipe

Another issue in the stalk design is the minimization of RF power losses on the surface of the stalk as well as the bellows and outer pipe. Here we adapted the design which involved a changing in the diameter of stalk [4]. This gives us varied impedance along the stalk and therefore provides a large reflection of RF power.

Theoretical RF power losses on a uniform cathode stalk can be calculated by equation:

– (4)

Where is the resistance of surface of copper under 112 MHz which is ; is the magnitude of H field on surface of stalk as a function of distance away from the shorted end; and is the radius of the uniformed stalk.

For the uniform half-wavelength stalk H field can be easily calculated as

$$H_{||}(l) = H_0 Cos(\frac{2\pi}{\lambda}\, l) \quad (5)$$

In our case, for 2 MV gap voltage, $H_0 = 410\ A/m$ on the surface of stalk. Therefore the power losses is given by plugging all the numbers into equation (4) and that gives us P = 34 W on the surface of stalk. This is in agreement with the result given by SUPERFISH, which is 36 W for the 2 MV gap voltage.

By introducing a step on the cathode stalk, namely stepping down the diameter of the left part of the stalk, we can decrease the RF power losses on the surface of stalk to 20 W without sacrificing too much space inside of the stalk.

More importantly, the RF power dissipated on the outer pipe, which essentially is an extra heat load to the existing cryomodule, can be brought down from 1.7 W to 0.4 W. And last but not least, the power loss on the bellows is decreased from 28 W to 7 W. The results for the variable diameter stalk in comparison to the uniform style are summarized in Table 2. The locations of interest locations are indicated in the layout of cathode stalk in Figure 4.

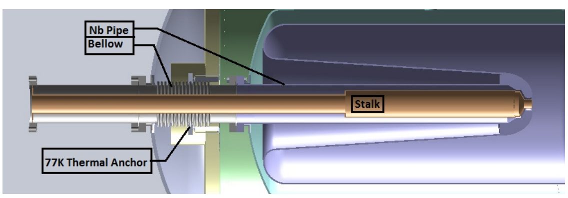

Figure 4: Important locations in RF power calculation.

Table 2: Compare between Uniform and Varies Diameter Design

Power losses	Uniform Type	Varies Diameter
On Stalk	36	20
On Bellows	28	7
On Outer Pipe	1.7	0.4

DESIGN OF FPC

Table 3 shows the designed parameters of the 112 MHz electron gun.

Table 3: Design Parameter of 112 MHz Electron Gun

Parameters	Value
Frequency	112 MHz
Charge per Pulse	1~3 nC
Repetition Rate	78 kHz
Accelerating Voltage	1~2 MV
Cavity Q_0	3e8
r/Q	122 Ω

The required Q external is calculated from the following equation [3]:

$$Q_{ext} = \frac{Q_0}{1+\frac{P_{beam}}{P_{heat}}} = \frac{Q_0}{1+\frac{f\times q\times V}{V^2/R}} \quad (6)$$

Where Q_0 is the cavity quality factor; f is repetition rate of beam bunch; q is charge per bunch; V is the accelerating gap voltage; and R can be easily calculated by multiplying R/Q with Q_0. To compensate the RF power due to heat losses and power extracted by beam, we will need a Q external ranged from 3e7 to 1.2e8.

We decided to use a coaxial style fundamental power coupler. In order to have a strong enough coupling, a coupling disk at the tip of the input antenna is included [5].

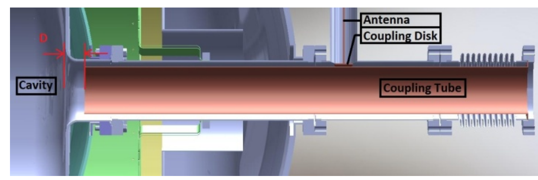

Figure 5: FPC including antenna, coupling disk and coupling tube.

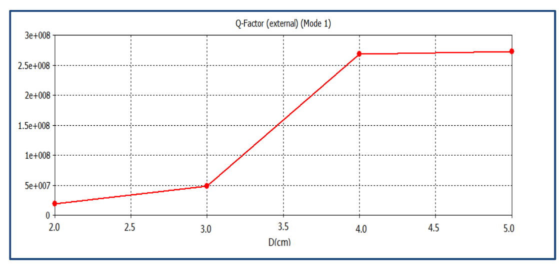

Figure 6: Q external versus relative position D of coupling tube, where D is defined in Figure 5.

As simulation results given by CST Microwave Studio in Figure 6 show, by adjusting the penetration of the coupling tube, we should be able to get a Q external range from 1.5e7 to 2.6e8. This range is larger than requirement given by design parameter above.

CONCLUSION

Based on the transmission line theory, we designed a half wavelength cathode stalk which significantly brings down the voltage drop between the cavity and the stalk from more than 5.6 kV to 0.1 kV. The transverse field distribution on cathode has been optimized by carefully choosing the position of cathode stalk inside the cavity. Moreover, in order to decrease the RF power loss, a variable diameter design of cathode stalk has been applied. Compared to the uniform shape of stalk, this design gives us much smaller power losses in important locations. Besides that, we also proposed a fundamental power coupler based on the designed beam parameters for the future proof-of-principle CEC experiment. This FPC should give a strong enough coupling which has the Q external range from 1.5e7 to 2.6e8.

REFERENCES

[1] V. N. Litvinenko, et al., "Proof-of-Principle Experiment for FEL-Based Coherent Electron Cooling," Proceedings of the 2011 Particle Accelerator Conference, New York, USA, March 28-April 1, 2011, THOBN3.

[2] I. Ben-Zvi, Quarter wave resonators for beta~1 accelerators, this conference, THIOA04.

[3] H. Padamsee, RF Superconductivity for Accelerators, ISBN 0-471-15432-6.

[4] J. R. Harris, et al., Design and operation of a superconducting quarter-wave electron gun, Physical Review Special Topics – Accelerators and Beams 14, 053501 (2011).

[5] S. Belomestnykh, et al., this conference, MOPO054.