AXIAL RF POWER INPUT INTO PHOTOCATHODE ELECTRON GUNS*

D. Janssen#, FZR, Germany, V. Volkov, BINP, Novosibirsk, Russia, H. P. Bluem, A. M. M. Todd, AES, 27E Industrial Blvd, Medford, NY 11763, U.S.A.

Abstract

The RF power input into an accelerating cavity is usually performed with special couplers that deliver the power in an asymmetric manner. Further, for superconducting cavities, the delivery point is typically into the beam tube beyond the cavity cells. In photocathode electron guns, where the cathode is isolated from the surrounding cavity by a coaxial vacuum gap, another power coupling possibility exists, since the cathode gap forms a coaxial line which can be used for RF power input. In the present paper, we show the advantages of this input coupling method. We then discuss a particular coupler design and present numerical results for normal and superconducting cavities.

INTRODUCTION

The input of high RF power is one of the more difficult tasks in accelerator physics. Input couplers specifically designed for normal and superconducting cavities have been developed. At high input RF power, there should be little heat transfer into the cavity and the beam tube (especially in the superconducting case), the coupling structure should match the external quality factor and the resultant electric fields should not perturb the electron beam and induce emittance growth. The last requirement is generally satisfied by using two opposed input couplers in the beam tube [1] or an axial input coupler, where the beam tube is an intrinsic part of the coaxial transmission line [2]. In the present paper, we restrict the discussion to RF power input into the cavities of RF photocathode electron guns. The annular gap between the cathode and the gun cavity can be used for coaxial RF power input. This has the advantage that the RF field remains axially symmetric and no additional input couplers are needed on the output beam tube. The axial symmetry eliminates transverse kicks to the beam in the vicinity of the couplers that can lead to transverse emittance growth. Below, we give examples of concepts for axial power input into normal and superconducting RF gun cavities.

AXIAL POWER INPUT INTO A NORMAL CONDUCTING X-BAND RF GUN

Figure 1 shows a schematic view of a normal conducting X–band RF gun with a frequency of 11.424 GHz. This gun has been designed specifically for low emittance at large bunch charge [3]. It is presently in fabrication at Advanced Energy Systems.

* The described FZR work is supported by the German Government. The AES X-band work is supported by a US Department of Energy SBIR award. The AES SRF photoinjector and quarter wave choke joint work of Reference [7] is supported by the US Navy.

d.janssen@fz-rossendorf.de

The cavity has two cells which can be tuned separately. The photocathode is separated by a vacuum gap from the cavity and its surface is in front of the back wall of the

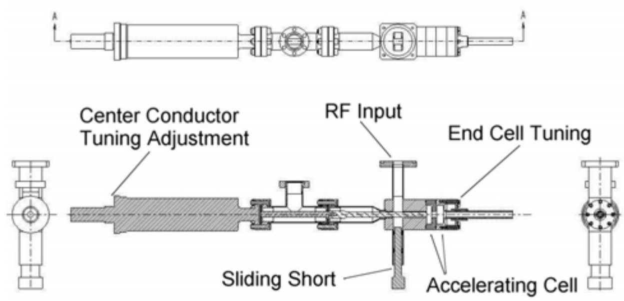

Figure 1: Schematic view of the two cell X-band gun.

first cell. The cathode can be moved in the axial direction by ~30 microns in order to tune the first cell. The RF power flows from a rectangular wave guide into a coaxial line which consists of the cathode stalk and the surrounding part of the cavity. In this way, the power input into the cavity cell is completely axially symmetric and does not contribute to transverse emittance growth.

A rectangular tube with a sliding short is placed in front of the waveguide. This allows the matching of the external quality factor to the required beam power. With no external transverse impediments, the bore of the emittance compensation solenoid can be minimized and near optimally located with respect to the gun and cathode, thereby minimizing the delivered transverse emittance [4]. The results of numerical simulations of this gun are given in Figure 2 and Table 1. It can be seen that for high bunch charge and short pulse length, a very low emittance is obtained.

Table 1: Analytic results

Parameter	Low Charge	High Charge (with short booster accelerator)	Units
Charge	0.10	1.0	nC
Beam Radius	0.28	0.34	mm rms
ε_{xn}	0.165	0.764	mm-mrad
Bunch Length	1.0	1.9	ps rms
Energy Spread	1.3	1.5	%
Energy	3.3	8.7	MeV

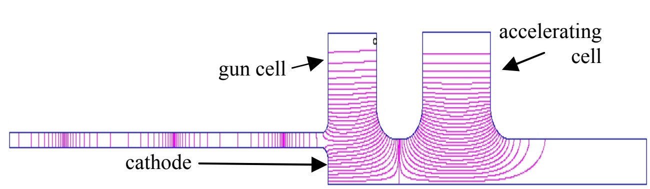

Figure 2: Field distribution in the cavity and coupler.

The SUPERFISH and 3D MAGIC calculations for this concept show that the coaxial portion has standing waves

0-7803-8859-3/05/$20.00

and is part of the resonant circuit. The input coupling occurs at the waveguide to coax transition. In Figure 3, we show the low power (cold) model of this gun which is being used to finalize the gun design and fabrication details.

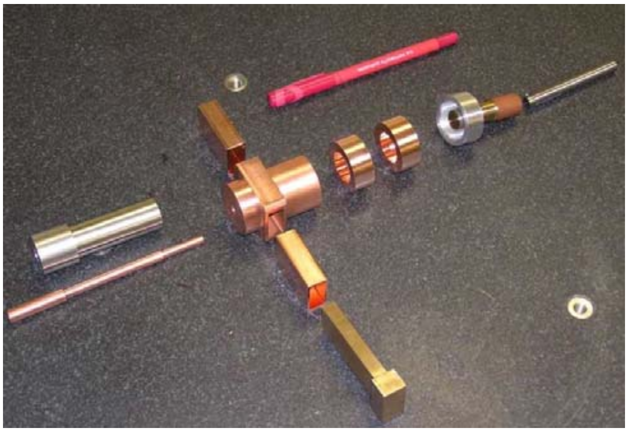

Figure 3: Low power model of the X-band normal conducting gun with the scale indicated by the red pen.

AXIAL POWER INPUT INTO A SUPERCONDUCTING RF GUN (SRF GUN)

For the 3½ cell superconducting RF gun, which is under development at FZR [5] and shown in Figure 4, an input coupler is used which is adapted from the ELBE project [6], as shown in Figure 5.

Figure 4: 3½ cell FZR SRF cavity.

This coupler has the disadvantage that the maximum power is limited to 10 kW and the external quality factor is not adjustable. Furthermore, the main coupler, the two HOM couplers and the RF pick up flange must be co-located in a single plane after the cavity cell, which is very difficult to accommodate in the mechanical design.

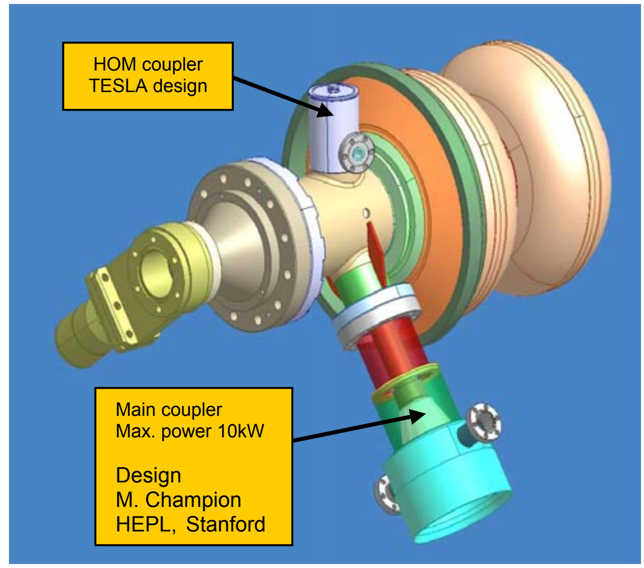

Figure 5: RF power coupler of the ELBE accelerator.

Because of this, we have developed a new coupler design where the power input is delivered through the gap between the cathode and the surrounding tube of the superconducting cavity. A schematic view of this axial power input into a superconducting RF gun is shown in Figure 6.

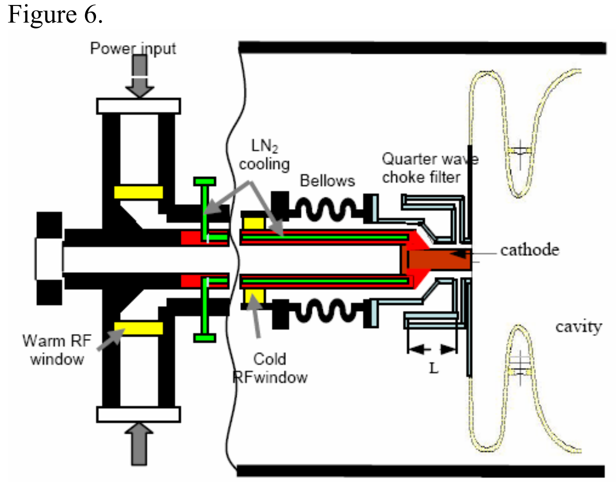

Figure 6: Schematic view of the axial RF power input into the gun half-cell of a superconducting cavity.

The RF power flows from outside the cryostat via a wave guide and a warm ceramics window into a coaxial line. The inside conductor of this line is the tube that serves as the cathode transfer channel and the cathode itself, which is cooled down to LN_2 temperature. The outer conductor contains a stainless steel bellows followed by a superconducting quarter wave choke filter. This filter not only prevents RF leakage from the cavity into the coaxial line but also permits adjustment of the external quality factor. A cold ceramic window in the cathode coaxial line is used for electrical isolation and for protection of the cavity vacuum. A slightly different quarter wave choke filter is being utilized in another SRF photocathode gun [7]. Recent tests of this form of choke joint have been successful up to 150% of the nominal field levels, provided appropriate steps are taken to suppress multipacting, which is the principle concern for this approach.

For the Figure 6 design, we have calculated the external quality factor, Q_{ext}, the heat input into the cathode tube and the power of the electron beam using the complex field solver CLANS. In this calculation, the diameter of the cathode is 10 mm and the gap between the cathode and the cavity tube has been assumed to be 5 mm. The field energy in the cavity is normalized to 29.8 J, which corresponds to an accelerating gradient E_{acc} = 25 MV/m and an electron energy of 9.5 MeV.

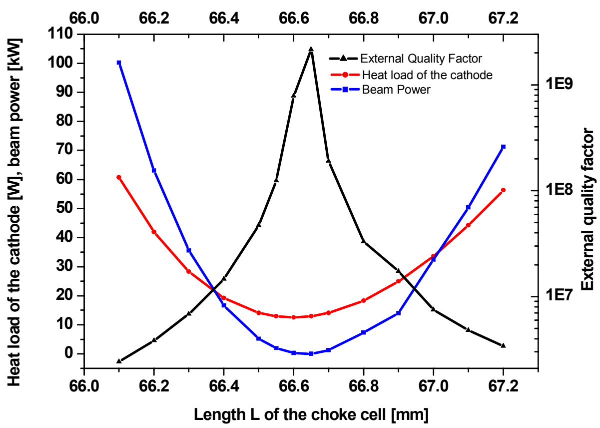

Figure 7: Dependence of beam power and heat load on the length of the choke filter.

The results of this calculation are shown in Figure 7. We have varied the length, L, of the choke filter and can distinguish two working regimes. In the first regime Q_{ext} has a maximum value of approximately $3x10^9$. The power flow through the filter is zero and we must use a "standard" input coupler on the beam tube side. (See Figure 5). In the second regime, we reduce the Q_{ext} value in order to deliver axial power input from the cathode side. For $Q_{ext} = 5x10^6$, the beam power is 50 kW and the heat input into the cathode is 34 W. By varying the bellows length, we can change the width Δz of the choke filter. Moving Δz 0.2 mm causes the value of Q_{ext} to change by approximately one order of magnitude.

For the required field normalization, the maximum surface electric and magnetic field strengths are 44 MV/m and 0.11 T respectively. This is within the known limits of TESLA cavities. The maximal RF voltage in the gap between the cathode and the cavity is 6.5 kV. Therefore, a DC voltage of the same order of magnitude between the isolated cathode and the cavity is sufficient to prevent multipacting effects.

CONCLUSION

In some normal and superconducting RF gun designs, the cathode is separated by a vacuum gap from the surrounding cavity. This gap can be used for coaxial input of RF power with many significant advantages, namely: additional RF couplers on the beam tube side of the gun are not necessary; the transverse emittance of the electron bunch is not increased by the dipole component of the axially asymmetric RF field; and there is no RF power leakage into the coaxial coupling line.

Additionally, in the case of the normal conducting X–band gun, the axial power input permits the near optimal placement of the solenoidal emittance compensation coils.

For the superconducting gun, where emittance compensation is effected by slightly different means, it is possible to change the external Q value over several orders of magnitude by adjusting the length of the quarter wave filter. The specific superconducting cavity described above has a cathode heat load of only 34 W to deliver a beam power of 50 kW. In this case, electric isolation of the cathode allows the use of a modest DC voltage for suppression of multipacting effects. In contrast, the Reference [7] quarter wave choke joint cannot easily be electrically isolated from the main cavity, principally because of the high average current specification (0.5 A) and the resultant high heat loads. In this case an alternate surface treatment solution has been demonstrated.

REFERENCES

[1] V. Veshcherevich et al., Cornell University, SRF Note # 03051208

[2] K. Abrahamyan et al., Nucl. Instr. and Meth. **A528** (2004) 360.

[3] H. P. Bluem et al., "Electron Injectors for Next Generation X-Ray Sources," *Proc. SPIE*, **5534** (2004) 132.

[4] B. E. Carlsten, "Photoelectric Injector Design Code," *Proc. PAC 1989 Chicago, Il, USA,* IEEE89CH2669-0 (1989) 313-315.

[5] D. Janssen, et al., "Status of the 3 ½ Cell Rossendorf Superconducting RF Gun," *Proc. FEL 2004 Conf.*, Trieste, Italy, (2004) 359.

[6] F. Gabriel, et al., Nucl. Instr. and Meth. B 161-163 (2000) 1143.

[7] A. M. M. Todd et al., "State-of-the-art Electron Guns and Injector Designs for Energy Recovery Linacs (ERL)", Paper WPAP033, *these Proceedings*.

0-7803-8859-3/05/$20.00 ©2005 IEEE