DESIGN AND CONSTRUCTION OF A HIGH CHARGE AND HIGH CURRENT 1 – 1/2 CELL L-BAND RF PHOTOCATHODE GUN*

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Abstract

The Argonne Wakefield Accelerator has been successfully commissioned and used for conducting wakefield experiments in dielectric loaded structures and plasmas. Although the initial wakefield experiments were successful, higher drive beam quality would substantially improve the wakefield accelerating gradients. In this paper we present a new 1-1/2 cell L-band photocathode RF gun design. This gun will produce 10 - 100 nC beam with 2– 5 ps rms pulse length and normalized emittance less than 100 mm mrad. The final gun design and numerical simulations of the beam dynamics are presented.

1 INTRODUCTION

High current short electron beams have been a subject of intensive studies [1]. One of the particular uses for this type of beam is in wakefield acceleration applications. High current (kA) short electron beam generation and acceleration did not materialize until the advent of RF photoinjector technology[2]. Although most photocathode RF gun development has been concentrated on high brightness, low charge applications such as free electron laser injectors, there have been several relatively high charge rf photocathode based electron sources built and operated[3,4,5]. In general, there are two approaches to attaining high peak current. One approach is to generate an initially long electron bunch with a linear head-tail energy variation that is subsequently compressed using magnetic pulse compression. The advantage of magnetic compression is that it is a well-known technology and can produce sub-picosecond bunch lengths. However, due to strong longitudinal space charge effects, this technology is limited to relatively low charges (<10 nC).

Another approach is to directly generate short intense electron bunches at the photocathode and then accelerate them to relativistic energies rapidly using high axial electric fields in the gun [3]. The advantage of this approach is that it can deliver very high charges, for example, 100 nC if one uses an L-band gun. This would satisfy the requirements of most electron driven wakefield experiments for both plasma and dielectric structures, if the pulse length is short enough (< 10 ps FWHM). So far, the Argonne Wakefield Accelerator (AWA) has demonstrated the capability of producing 100 nC, 25 — 35 ps (FWHM) electron beams at 14 MeV. This unprecedented performance was obtained using a half cell photocathode gun cavity and two standing wave iris-loaded linac sections [6]. The AWA machine has reached its design goal and has been used for dielectric wakefield [7] and plasma [8] experiments. The initial results are encouraging [9]. Achieving higher gradients in wakefield experiments would require the drive electron pulse to be even shorter and have a lower emittance. In this paper, we discuss the design of a new RF photocathode gun with the capability of producing 10 - 100 nC with 2 - 5 ps (rms) pulse lengths.

2 DESIGN CONSIDERATIONS

In order to generate high charge and short bunch lengths from a photocathode RF gun, the electric field on the cathode surface has to be very intense. In this way the electrons leaving the cathode surface are quickly accelerated to relativistic velocities, minimizing the bunch lengthening and the emittance growth that the space charge forces produce [10,11]. There is also bunch lengthening and transverse emittance growth at the exit iris of the gun cavity due to the defocusing forces of the RF fields. Thus, this effect also calls for high accelerating gradient and high beam energy at the exit of the gun. It is therefore desirable to have a multicell gun with high accelerating gradient. Practical considerations (mainly a finite amount of RF power) limit the design to 1 – 1/2 cells. The choice for our new gun design is a Brookhaven type 1– 1/2 cell cavity [12] scaled up to L band operation. This gun will be followed by one of the present linac tanks that exist at the AWA facility.

A detailed numerical study [13, 14] of this gun was performed with the computer codes SUPERFISH and PARMELA [15]. Table 1 summarises the parameters used in the simulations. These extensive numerical simulations showed a strong dependence of bunch length and emittance with respect to the accelerating gradient in the gun cavity. Based on these studies, it was decided that an accelerating gradient of 80 MV/m on the cathode surface was a good operating point. This requires 10 MW of RF power to be coupled into the gun cavity, which still leaves enough power to run one of the linac tanks. This accelerating gradient yields good values of emittance and bunch length, while still not high enough to make the RF conditioning of the gun a challenging task. (In fact, we

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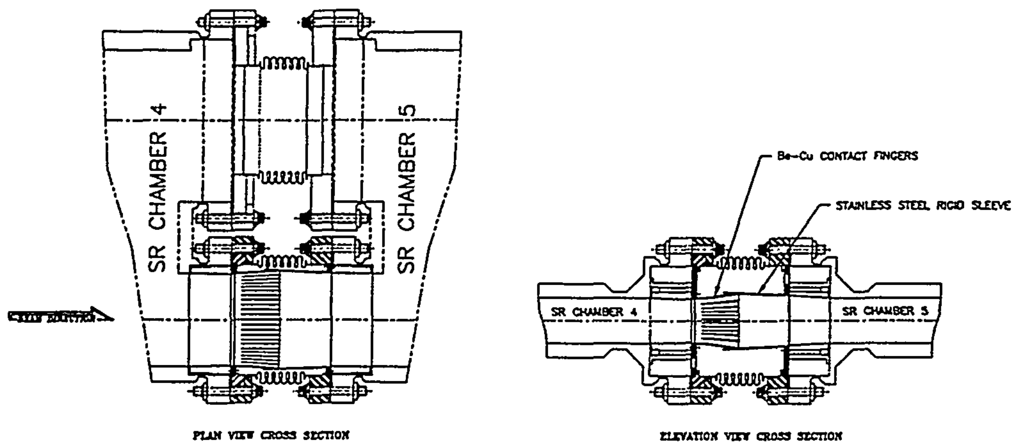

Figure 2: APS SR in-vacuum shield and bellows assembly

stock is then formed to the shape of the APS SR beam tube aperture. A similar aperture is machined into a copper disk that is used both to support the contact fingers and to capture a Be-Cu coil-spring gasket that ensures contact between the bellows shield assembly and the adjacent ring vacuum chamber component within the vacuum chamber flange enclosure. The two items are vacuum furnace brazed to form the typical flexible bellows shield assembly. After brazing, the Be-Cu contact fingers are fully solution hardened by heating at a temperature of 315° Celsius for two hours.

Specialized flexible shield assemblies employ 304 stainless steel mounting disks with the flexible shields attached by welding or screw fasteners. The mating rigid sleeve components are fabricated from Inconel® 625 or 316 stainless steel. The Inconel® rigid sleeves are an integral part of the ring bellows vacuum enclosure assemblies. As such, the exterior of the Inconel® rigid sleeves is in direct contact with air and is convection cooled. The stainless steel rigid sleeves are enclosed completely within the vacuum of the APS SR, and are primarily employed in the shortest bellows applications.

3 TEST AND MONITORING

The performance of both of the bellows shield designs has been monitored during SR beam operations. However, due to limited cooling, the vacuum-enclosed liner systems have been extensively tested and are continuously monitored during APS SR beam operations.

Testing included infrared radiometer camera imaging and thermocouple instrumentation of the rigid sleeve. The test set-up is shown in Figure 3. The infrared radiometer, an Inframetrics PM200, is capable of both thermal imaging of the contact fingers and rigid sleeve, and collecting and storing actual temperatures of the items in the image. A calcium fluoride, (CaF_2), infrared-transparent window is used to allow the imaging of the in-vacuum bellows shield components. The view into the window is shown in the inset of Figure 3. The Be-Cu fingers are coated with graphite to increase the emissivity of the metal surface to approximately 0.8. The radiometer is protected from radiation damage by a lead brick enclosure.

The optics include two front-silvered mirrors in a periscope arrangement in addition to the CaF_2 viewport. The thermocouples are type K, consisting of Chromel® and Alumel® wires. The thermocouple junctions are welded to the exterior of the rigid sleeve. Ten thermocouple junctions are evenly distributed across the lower perimeter of the rigid sleeve at the approximate location of the spring finger contacts. The individual thermocouple wires are insulated with binder-free fiberglass insulation. Two five-pair type-K thermocouple feedthroughs are employed to extract the thermocouple voltage, and an ion gauge is employed to measure local vacuum levels. The infrared radiometer set-up was used during one maximum peak current operation studies period, while the thermocouple instrumentation is a permanent installation.

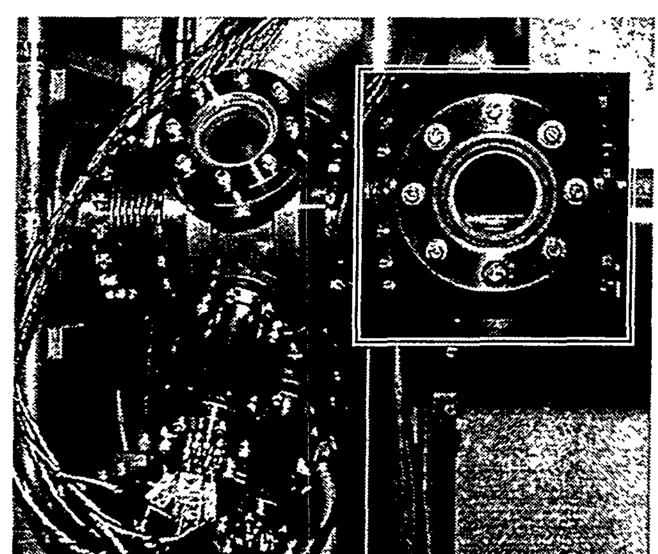

Figure 3: APS bellows shield test assembly

4 RESULTS

Results indicate that the liners perform well under all stored beam fill loadings through and including 100-mA, 8-bunch, 7-GeV operations. During the maximum peak current studies period, the operating mode was primarily high currents singlets fills. The highest observed temperatures were observed on the rigid sleeve components between the spring finger contacts location and the base of the sleeve. This was observed in the infrared imaging of the bellows shield assembly through the CaF_2 viewport. Also observed is the expected result that the peak heating occurs at the minor axis of the "elliptical" bellows shield assembly where the beam image currents are the largest.

Maximum temperatures of the vacuum-enclosed bellows shield systems are typically 35-50° Celsius during standard 100-mA stored beam fills, and 50-70° Celsius during fills producing both maximum peak and total current simultaneously. Plots of the bellows shield thermocouple data for the typical APS SR singlets 100-mA fill operations are shown in Figures 4 and 5; the reference beam-off cold temperature for this data is 28° Celsius. This data shows that the thicker 0.036-inch-thick Type I contact fingers run approximately 15° Celsius cooler than the 0.020-inch-thick Type II contact fingers under the same operating conditions. The difference is a function of both the finger contact force and the finger heat conduction area. Previous thermocouple measurements of the temperature of the convection cooled Inconel® rigid sleeve showed no significant heating. Ion pump ring vacuum monitoring supports the temperature data.

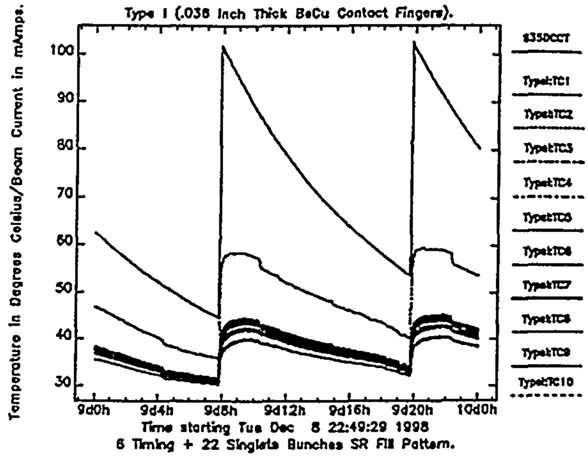

Figure 4: APS Type I bellows shield performance

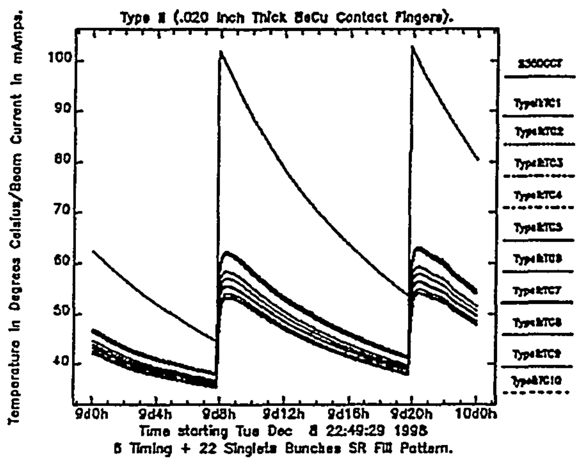

Figure 5: APS Type II bellows shield performance

5 CONCLUSIONS

First and foremost we conclude that the bellows shields are working very well under the present APS SR 100-mA current operations. The maximum operating temperature of 70° Celsius is well below the minimum annealing temperature of 176° Celsius of the Be-Cu alloy. At this temperature the contact fingers can be expected to provide positive contact force for an indefinite period of time. The indirect vacuum level monitoring and beam lifetime projections support this conclusion.

The future operating goals of the APS SR include continuous stored beam top-up and higher stored beam currents of up to 300 mA. As such, some improvements in the bellows shield design are being considered. The proposed rigid sleeve modification is to copper plate the stainless steel surface to reduce the electrical resistance. The thickness of the copper plating will be 0.0003-0.0005 inch, which is more than two times thicker than the 0.00014-inch copper skin depth of rf electrical currents generated by the fundamental frequency of the 352-MHz APS SR rf power system. All beam image current and rf resonant current resistive heating energy is expected to be deposited well within this skin depth.

The proposed modification to the flexible shield is to fabricate the spring contact fingers from Glidcop, which is alumina dispersion strengthened copper. Glidcop has nearly twice the electrical and thermal conductivity of Be-Cu and is much less susceptible to thermal aging and annealing. These improvements are being implemented in an ongoing machine development effort.

Finally, it must be stated that the convection-cooled bellows shield design is the preferred system but, due to SR real estate constraints, it is not always an option.

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