DESIGN AND FABRICATION OF A 10 MW, L-BAND, ANNULAR BEAM KLYSTRON*

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Abstract

Design improvements and fabrication of a 10 MW, 1.3 GHz Annular Beam Klystron are described. The principal improvement is the electron gun. Utilization of a Controlled Porosity Reservoir (CPR) cathode allows the use of a zero-compression gun, resulting in improved beam quality and reductions in the gun and solenoid diameters.

INTRODUCTION

Efforts to achieve a high efficiency 1.3 GHz, RF source for the International Linear Collider (ILC) and similar accelerators are centered on multiple beam klystrons (MBK) and, more recently, on a sheet beam klystron (SBK). CCR is developing an annular beam klystron (ABK) to fulfill the stringent requirements imposed by the ILC. That is, the minimum efficiency should be 65% at an RF output power of 10 MW, and the cathode current density should be less than 5 A/cm^2. The pulse width must be 1.5 milliseconds at a pulse frequency of 15 Hz.

Like the MBK, the ABK perveance can be much higher than in a traditional klystron. In contrast to the MBK, the ABK uses a single beam with simple transverse magnetic (TM) mode resonators. Thus, the tube is similar a traditional klystron and much simpler than an MBK. The ABK length, efficiency and gain are similar to those of an MBK with the same power, perveance and frequency.

The CCR ABK electron beam current is 140 A at 120 kV with inner and outer beam radii of 3.2 cm and 3.6 cm, respectively. The drift tube radius is 4 cm. The tube includes six cavities, and the solenoidal magnetic field is 1.5 kG. A schematic of the ABK electron gun and simulated beam is shown in Figure 1.

As previously reported [1], CCR created a design that met all requirements and was not significantly affected by the diocotron instability. However, the 2 kG magnetic field required more power than desired. With an ideal beam, calculations of the efficiency showed no degradation with fields down to at least 1.5 kG. However, lowering the field increased the beam ripple, which in turn decreased the efficiency. This ripple was due to gun optics.

Design of a gun using compression to create an annular beam is intrinsically difficult, due largely to the fact that there is no radial force on the inside surface of the beam. The original design with a 2 kG field used a complex interaction of the cyclotron motion with the radial fields of the anode to minimize the ripple. Unfortunately, it was not possible to maintain the balance of forces at lower magnetic fields.

Generating an annular beam without compression, i.e. with a uniform axial magnetic field, is much more straightforward. But, for this case, the beam density of 16 A/cm^2 is too high for conventional cathodes. This difficulty is avoided using a CCR Controlled Porosity Reservoir (CPR) cathode. Current densities to 50 A/cm^2 have been demonstrated with this type of cathode. At the required density of 16 A/cm^2, the predicted lifetime is 100,000 hours. This is more than adequate for most applications, including the ILC.

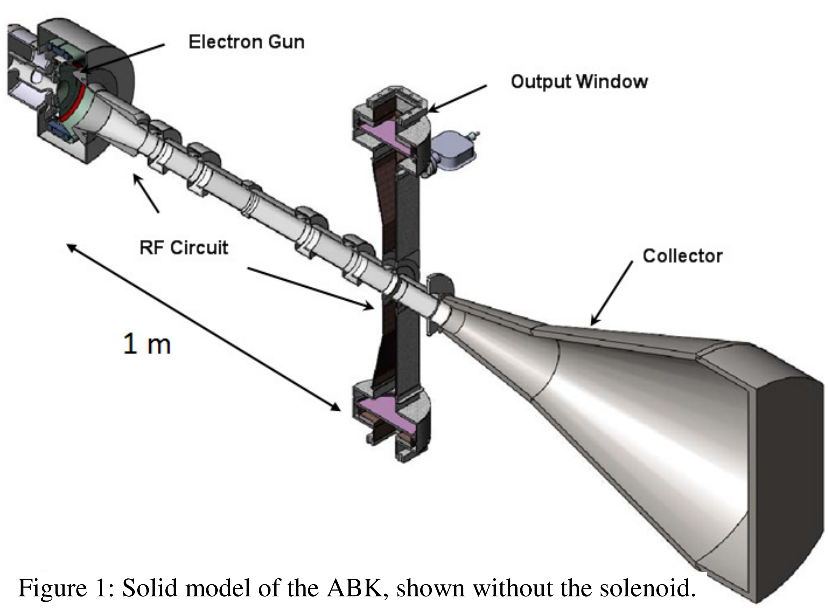

Figure 1: Solid model of the ABK, shown without the solenoid.

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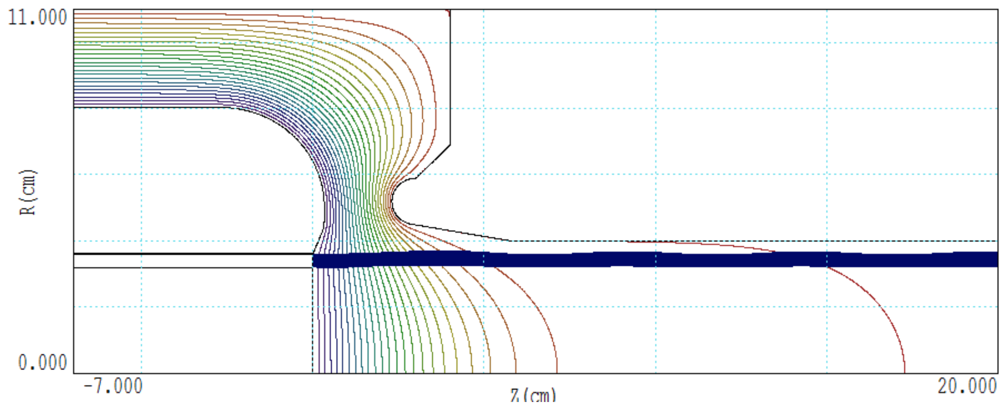

Figure 2: ABK gun with no compression of the beam.

ZERO COMPRESSION GUN

The new design for the gun is shown in Figure 2. There is still a modest ripple due to anode lensing, but, with a 1.5 kG magnetic field, the 4.7 mm peak-peak thickness is less than the original 5.1 mm with a 2 kG field. As with many guns with a high current density cathode, the electric field on the focus electrode was a concern. This, in fact, limited the shape of the focus electrode. In an ideal design, the focus electrode would extend further along an angle of roughly 67.5°, but this would have resulted in unacceptably high electric fields. As shown in Figure 3, the maximum field on the focus electrode is 63 kV/cm. This is under the engineering limit of 66 kV/cm for the design voltage and pulse width.

The average radius of the cathode is 3.4 cm, while the radius of the original cathode was 9 cm. The change in the cathode allowed reduction of the outer radius of the gun from 19 cm to 12 cm. This made it possible to decrease the radius of the solenoid, resulting in a 30% reduction in power required to produce the 1.5 kG field.

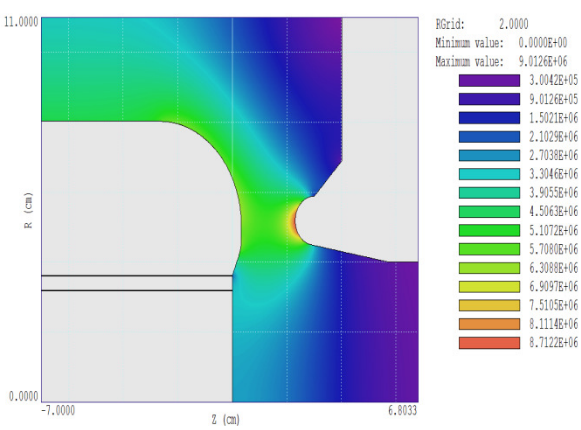

Figure 3: Electric field magnitude in the ABK gun.

FABRICATION

The ABK is being fabricated. Most of the tube uses conventional methods, but the cathode is unusual. Because of the nature of the CPR cathode material [2], the ABK cathode must be made in segments. The arrangement is shown in Figure 4. The cathode will be made in 6 modules, each with 4 cathode segments. There was some concern that the asymmetries introduced by this fabrication method would degrade the beam optics. Simulations using the 3D trajectory code Beam Optics Analyzer (BOA) showed that this is not the case. In fact, even the removal of one of the segments has negligible impact on the beam trajectories. This is shown in Figures 5 and 6.

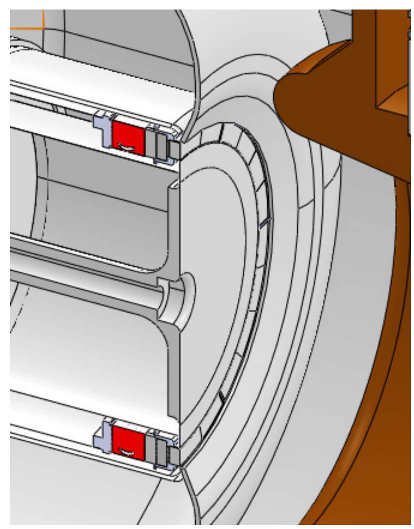

Figure 4: Cathode geometry.

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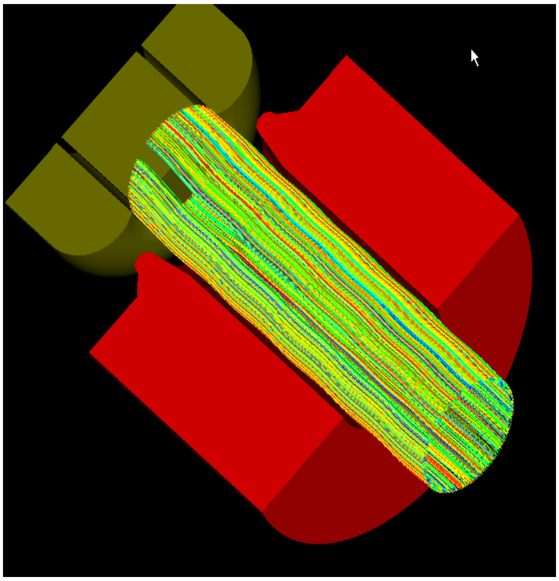

Figure 5: Trajectories generated by BOA, showing the effect of the deletion of a single segment of the cathode.

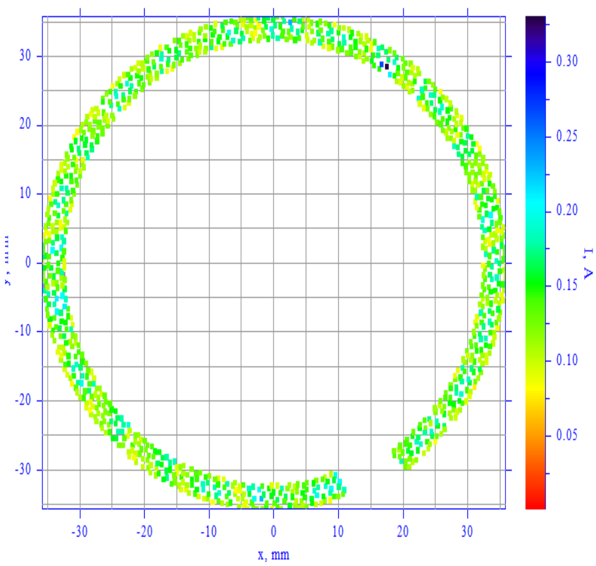

Figure 6: Cross section of the beam 70 cm downstream of the cathode. There is no visible distortion of the beam due to the missing cathode segment.

ACKNOWLEDGEMENT

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