DEVELOPMENT OF A NON-AXISYMMETRIC PERMANENT MAGNET FOCUSING SYSTEM FOR ELLIPTIC CHARGED-PARTICLE BEAMS

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Abstract

High-brightness space-charge-dominated elliptic electron or ion beams have wide applications in high-power rf sources, particle accelerators, and ion implantation. Building upon recent inventions and theoretical studies on the generation and transport of elliptic charged-particle beams, a basic research and development program is being carried out to experimentally demonstrate a high-brightness, space-charge-dominated elliptic electron beam using a non-axisymmetric permanent magnet focusing system and an elliptic electron gun. Results of the fabrication and initial test of an elliptic electron gun and the design of the elliptic electron beam system are presented.

INTRODUCTION

A high-brightness elliptic electron or positron beam is a novel device which has wide applications in high energy accelerators. Once developed, a large-aspect-ratio elliptic electron beam will enable the development of L-band elliptic-beam klystrons (EBKs) or sheet-beam klystrons (SBKs) [1] which are more efficient and lower voltage than multi-beam klystrons (MBKs) for the International Linear Collider (ILC) [2]. Elliptic electron and positron sources will be more suitable for beam injections, because sheet-like electron and positron bunches are brought to collision in the interaction section of the ILC.

In addition to the above high-energy accelerator applications, high-brightness elliptic charged-particle (electron, muon, proton, antiproton, and ion) beams have wide applications in other accelerators for nuclear physics research and high-energy density physics research because they are naturally matched into alternating-gradient focusing systems where the transverse section of the beam is a pulsating ellipse [3]. Furthermore, high-aspect-ratio elliptic beams will enable the research and development of advanced accelerators with planar structures [4,5].

This paper reports on the progress of the research on the demonstration of a high-intensity elliptic beam system that has been carried out at Beam Power Technology (BPT), Inc. In particular, results of the fabrication and initial testing of the elliptic electron gun and design of the elliptic electron system are discussed.

FABRICATION AND INITIAL TEST OF THE ELLIPTIC ELECTRON GUN

The BPT 6:1 elliptic electron guns were based on a concept design presented earlier [6,7]. The previous elliptic electron guns tested at BPT had kovar flanges that were brazed to the ceramic high voltage standoff. Further, pass thru openings were asymmetric. Because kovar is 50% iron, it introduces distortion which interferes with the elliptic matching field design. An improved all stainless steel design was built which eliminates these issues and simplifies the magnetic design. The non-magnetic elliptic electron gun used a round stainless steel vacuum seal, and a glass high voltage standoff. The fabricated non-magnetic elliptic electron gun is shown in Fig. 1.

The non-magnetic elliptic electron gun was tested. The measurements showed roll-off curves very close to expectations, and identical to those of the magnetic version as the filament current was increased. Figure 2 shows the measured cathode, collector and intercepted currents versus the heater filament current at a cathode voltage of -2.29 kV. Table 1 shows comparison between the design and experimental measurements at a heater filament current of 2.35A. At a filament current of 2.35 A, the cathode current was 0.121 A, the collector current was 0.115A, and the beam interception was 0.006 A, which was about 5% of the cathode current. Note that no

Table 1: Comparison between the design and experiment at a heater filament current of 2.35A

Parameters	Design	Measurement
Voltage	2.29 kV	2.29 kV
Cathode Current	0.105 A	0.121 A
Collector Current	0.105 A	0.115 A
Beam Interception	0.0%	5.0%

Figure 1: Fabricated non-magnetic elliptic electron gun.

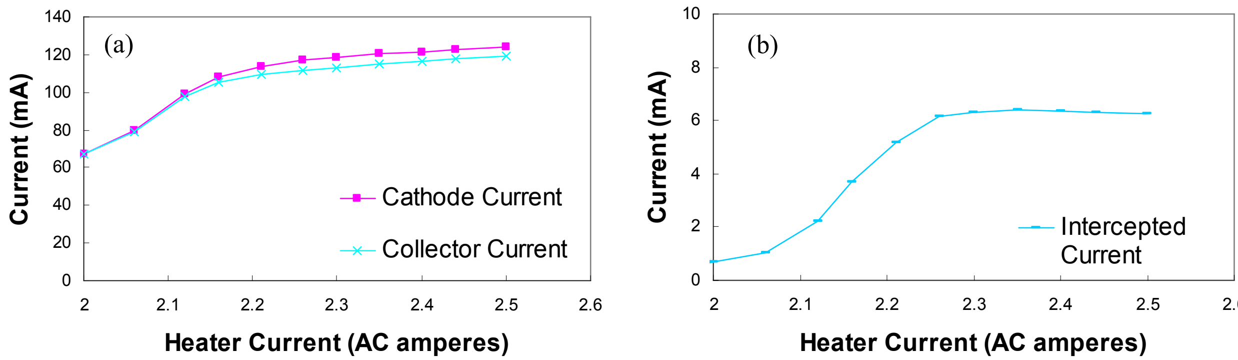

Figure 2: Plots of (a) measured cathode current and collector current and (b) measured intercepted current versus the heater filament current at a cathode voltage of -2.29 kV.

magnetic containment was used during this test. Variances against predictions were 15% in cathode current: 10% in collector current and 5% in beam interception.

BPT is analyzing the initial test results, in order to identify the causes for the discrepancies between the design and experiment as shown in Table 1.

An OMNITRAK electron beam analysis was performed to model the non-magnetic elliptic electron gun used in the bell jar tests. The parts of the tested non-magnetic elliptic electron gun are shown in Fig. 3, which includes a cathode, a cathode electrode, and an anode that is electrically connected to a rectangular drift tube. Not shown in Fig. 3 is a collector which is electrically isolated from the anode and associated drift tube. The distance from the cathode to the end of the rectangular drift tube was 14 mm.

For the design parameters, the OMNITRAK simulation for the elliptic electron gun is shown in Fig. 3, where the collector is the structure that is furthest way from the cathode, separated by 2 mm of white space. The end of the drift tube can be seen at z = 14 mm, and there is no interception at this point.

When effects of various movements of the cathode and the cathode electrode on the elliptic electron beam were simulated with OMNITRAK, it was found that the cathode current depends on the axial positions of the cathode and cathode electrode relative to the anode.

The results of the OMNITRAK simulations are plotted in Fig. 4. The curve with squares corresponds to movement of the cathode and cathode electrode together relative to the anode, whereas the curve with diamonds corresponds to the situation where only the cathode moves relative to the anode. The changes of the cathode current due to the joint movement of the cathode and the cathode electrode in the OMNITRAK simulations follow Child's law for emission, as expected. However, the changes to the cathode current due to cathode movements alone are more pronounced.

The OMNITRAK simulation results in Fig. 4 suggest that the discrepancy between the designed and measured cathode currents could be due to some combination of the movements of the cathode and the cathode electrode relative to the anode. BPT will verify this suggestion experimentally.

Finally, the OMNITRAK simulations with axial movement of the cathode and cathode electrode failed to offer any explanation for the 5% beam interception measured in the initial tests. BPT has postulated that this effect could be due to side emission from the cathode as a result of barium and various carbonates deposited around the side edges for 0.020" when this group of cathodes were prepared and fired at high temperatures. Any new cathode design generally has processing difficulties, and the slurry can end up wicking down the sides of the cathode and creating an emitting surface there. The electrons emitted from this side location are not correctly guided by the gun equipotentials and possibly end up intercepting the anode.

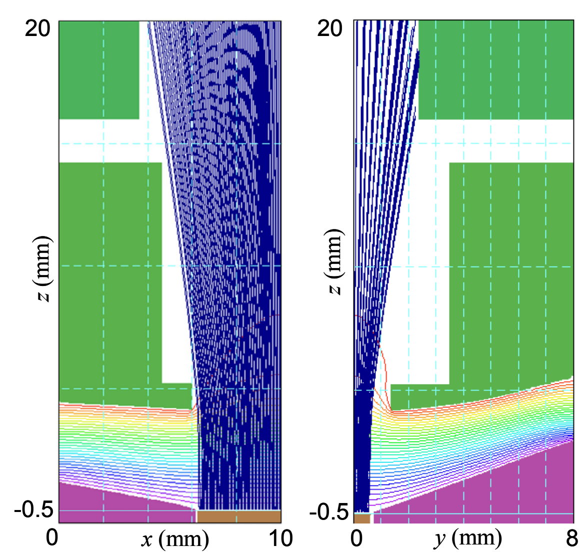

Figure 3: OMNITRAK simulation of the non-magnetic elliptic electron gun with the designed parameters in a bird-eye view (left) and a horizontal view (right), showing a beam current of 0.105 A and no beam interception.

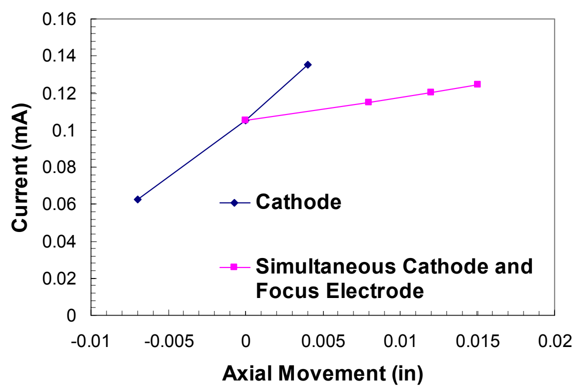

Figure 4: Plots of the cathode current versus axial movements: a) cathode movement (curve with diamond), and b) joint cathode- cathode electrode movement (curve with square).

BPT will work with its cathode vendor to eliminate these side emissions for the next build of the non-magnetic elliptic electron gun.

DESIGN OF THE ELLIPTIC ELECTRON SYSTEM

Using internal resources, BPT had developed a unique magnetic focusing and matching design achieving a non-twisting elliptic electron beam [9-11]. The technique allows BPT to compute the magnetic field profile required to make the non-twisting elliptic electron beam from the elliptic cathode match into the periodic permanent magnet stack.

Using this proprietary technique, BPT was able to obtain the OMINITRAK simulation results shown in Fig. 5. Figure 5 shows a straight, non-twisting elliptic beam as it propagates in the magnetic focusing system. In the simulation, a realistic magnetic focusing field, designed and modeled using OPERA3D, was applied to the system. As shown in Fig. 5, a straight, non-twisting elliptic beam transport was achieved.

CONCLUSION

Building upon recent inventions and theoretical studies in the generation and transport of elliptic charged-particle beams, a basic research and development program is being carried out to experimentally demonstrate such a beam using a non-axisymmetric permanent magnet focusing system and an elliptic electron gun. Results of the fabrication and initial test of the elliptic electron gun and the design of the elliptic electron beam system were discussed.

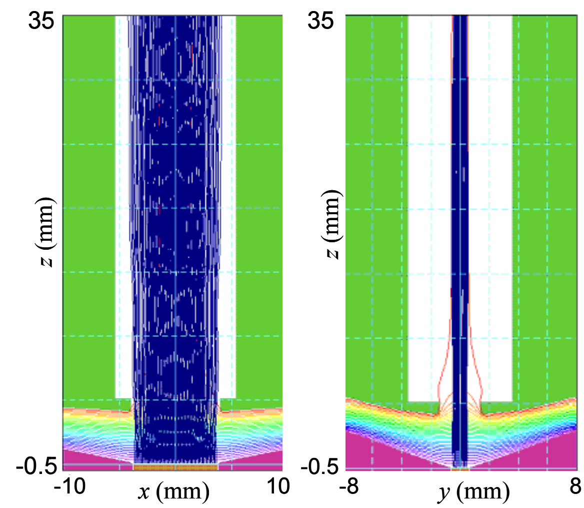

Figure 5: OMNITRAK simulation of the straight, non-twisting elliptic electron beam.

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