Production of Tightly Focused E-Beams with High-Current Accelerators*

J. W. Poukey, M. G. Mazarakis,
C. A. Frost, and J. J. Ramirez
Sandia National Laboratories
Albuquerque, NM 87185

Abstract

Using numerical modeling we study several approaches to the problem of designing an injector to produce a 3-30 kA, 2-4 mm diameter electron beam in the energy range 10-20 MeV. The cathode may be small in diameter and immersed in a strong magnetic field, producing an equilibrium beam for transport to a target (the "immersed" case). This approach appears to be the most promising for applications such as radiography, and we shall emphasize it in this paper. The alternative is the conventional "non-immersed" cathode, in which the beam from a larger-radius, cold-beam cathode is focused with magnetic lenses to a small spot on the target. Because the non-immersed case has been extensively studied, and because it has disadvantages for our purposes, we shall only discuss a few of our non-immersed-cathode injector studies, primarily for purposes of comparison.

Either type of diode is to be powered by an inductive voltage adder based on the successful SABRE/Hermes III/RADLAC (SMILE) magnetically-insulated-transmission-line design concepts.[1,2] A possible variation uses a re-entrant geometry with low electric stresses so that only the cathode face emits. We discuss issues such as dumping excess current and voltage dependence of the focus.

I. INTRODUCTION

The problem of producing small-diameter electron beams at high voltages (10-20 MV) and currents (3-30 kA) is of interest for several applications, including radiography. There are two basic issues which we will consider, namely the method for accelerating the beam, and the design of the injector. The conventional method[3,4] uses a standard multi-gap linac with a non-immersed cathode in the injector diode. Code calculations for the FXR system, including the diode, the transport and acceleration through 48 gaps, and the final focus, have been described by Boyd.[4]

In our approach to beam acceleration, we propose an MITL (magnetically insulated transmission line) voltage adder of the Hermes III/SABRE type[1,5] to apply the entire voltage (e.g., 10 MV) across a single electron-diode gap d. The primary advantages of this approach, as compared to the conventional linac, are: (1) significant reduction in cost, (2) substantial reduction in complexity, and (3) avoidance of instabilities such as BBU (beam breakup).

In our approach to injector design, we propose the immersed diode. The primary advantage of this diode, as we shall show, is relative insensitivity to variations in applied voltage and B field. Another advantage for some applications is the production of a high-current, small-radius beam in equilibrium, as opposed to a beam focused at only one axial location.

II. IMMERSED DIODES

Using the 2-D electromagnetic PIC code MAGIC, we have simulated a number of immersed diodes (see Table I). An example (Run 13) at the SABRE voltage of 10 MV is shown in Fig. 1. The idea is to create a beam from a small-radius (r_k) tip inside a large B_z field. If B_z is large and uniform enough from cathode to target, the electrons will follow the B lines and the size of the beam at the target will be about r_k.

The motivations for this approach, as opposed to non-immersed systems with magnetic lenses,[6] are: (1) The successful

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IBEX experiments[7] (see run 0 in Table I). By "successful" is meant production of a small, low-emittance beam, and agreement between MAGIC and measurement. (2) The relative insensitivity of beam parameters at the target, namely r_b (beam radius) and $\beta_\perp$ (transverse velocity), to variations in voltage V and applied B_z (see Table I). We also varied drift tube radius r_t (compare runs 13 and 15), but found almost no change in results. There is some variation with B_z, as seen in runs 9,13 and 12,17; as expected, the higher B_z results in a higher quality beam.

For comparison, we did a series of quasistatic runs using a trajectory code for a non-immersed diode with a magnetic lens. We used a large-cathode, d = 70 cm (A-K gap) system which emits from a flat velvet region of radius 6 cm. We varied V and B_z by ±10% about values for a good focus (best result: beam diameter of 2 mm), and found that the focus moves in axial position z by enough to cause increases in r_b of up to 4 mm. This does not preclude using such a diode, but one must control V and B_z to much greater precision than for our immersed cases.

Table I
Immersed Diodes for Radiography. In all cases, except 0, A-K gap d = 15 cm, and the applied B_z is uniform. In case 0, the IBEX experiment,[7] the A-K gap was d = 7 cm. The last three columns are the output beam at the target. Code: MAGIC. Run 13 is shown in Fig. 1.

					Output Beam Quality		
Run	V (MV)	r_k (mm)	r_t (mm)	B_z (kG)	I_b (kA)	$\beta_\perp$	r_b (mm)
0	3.5	1.6	30	22	12	0.17	2.1
9	10	2	40	25	39	0.15	3.1
10	12	2	40	25	51	0.16	3.5
11	13	2	40	40	49	0.14	2.0
12	10	1	20	60	37	0.14	1.1
13	10	2	10	40	35	0.07	1.7
15	10	2	40	40	35	0.07	1.8
17	10	1	10	40	42	0.10	1.7
18	12	1	10	60	47	0.07	1.4

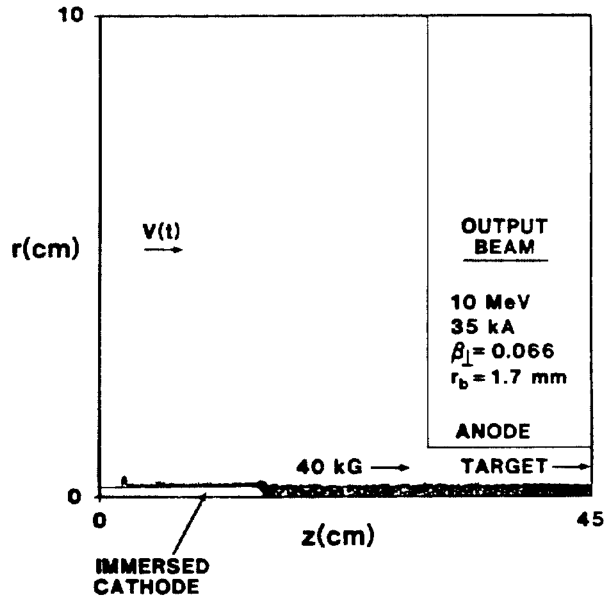

Figure 1. MAGIC simulation of immersed diode at 10 MV, 35 kA, (see run 13 of Table I). The entire diode and target (rhs) are immersed in 40 kG, yielding a high quality, small-diameter beam.

III. TRANSITION TO VOLTAGE ADDER

The input "voltage pulse" in Fig. 1 is generated by an MITL voltage-adder system such as SABRE.[5] Some simulations of the entire MITL and ten feeds have been attempted, but here we just discuss the transition from the adder to the diode. A sample run is given in Fig. 2, which includes the large outer conductor from the coaxial feed, and a truncated small-radius cathode. The coils produce 60 kG for the immersed diode, and allow over half the total of 84 kA to be "dumped" radially.

The main problem here is that the configuration inevitably yields some "halo" electrons, originating back on the cathode shank. In Fig. 2, these lead to an rms beam radius r_b on target of 2.8 mm; this is somewhat larger than desirable. Using a more gentle taper reduces this radius somewhat, but the problems of MITL sheath and shank electrons persist. Possible solutions include current-dump projections in the MITL, aperturing, and contouring the cathode to follow a flux surface.

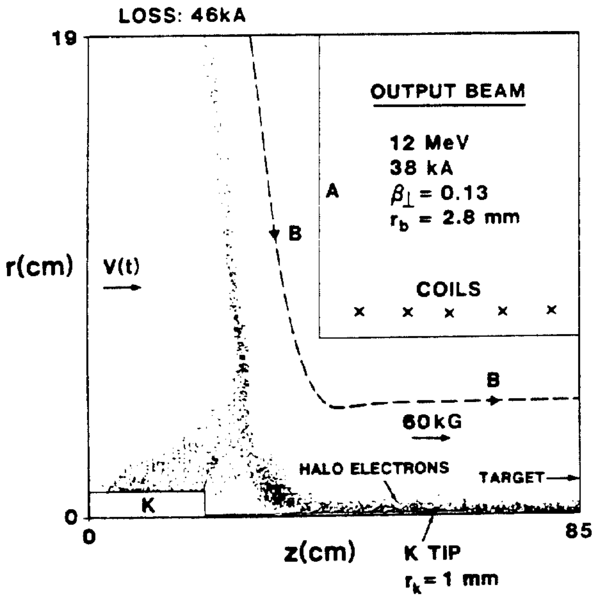

Figure 2. MAGIC run of immersed diode plus transition to voltage adder. The adder gives input voltage V(t) (modeled as TEM wave; max 12 MV). Note loss along fringing B lines.

IV. OTHER SYSTEMS

We have also studied non-immersed diodes with magnetic lenses in some detail. As discussed above, we find that such diodes are not as good as immersed ones for our purposes (e.g., radiography), due to the difficulty in maintaining a very small focal spot size over realistic voltage pulses.

An interesting variation here is a non-MITL voltage adder of the Recirculating Linear Accelerator type,[8] with a carefully designed, low-stress, non-immersed cathode and a re-entrant anode containing magnetic-field coils. Both MAGIC and trajectory-code runs show some good properties of this system, although voltage sensitivity may still be a problem. Further studies would be needed to investigate this point, and certainly to achieve a practical design.

V. SUMMARY

For the production of small-diameter electron beams in the range 10-20 MeV, we propose an inductive-voltage-adder, single (diode)-gap approach, e.g., SABRE instead of the conventional multi-gap linac. For the injector, we propose to use a small-diameter cathode immersed in a field of 40-60 kG. Our calculations predict that very high current densities can be expected, with relative insensitivity to parameter variations.

VI. REFERENCES

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