Electron Flow in the SABRE Linear Induction Adder in Positive Polarity

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Abstract

In a positive polarity induction adder each of the induction cavities is a cathode, which emits electrons at a unique potential. These broad spectrum electrons strongly affect Magnetically Insulated Transmission Line (MITL) behavior. Electron flow decreases the cavity-to-MITL coupling efficiency, and reduces the power transport efficiency along the system. Also the operating impedance of the MITL is lowered, reducing the diode impedance required for good coupling and good total system power efficiency [1-4]. It is therefore imperative to understand the details of MITL electron flow. In previous work, measurement of MITL electron flow for a twenty-stage linear induction adder (Hermes III), operated in positive polarity, was compared with simulations [1]. There was qualitative agreement, but some differences were noted. For example, measured electron flow in the first cavities was greater than in the simulations. We have extended the work on this subject with detailed current measurements on a ten-stage linear induction adder (SABRE). Time resolved electron flow is determined from the difference between anode and cathode currents at several axial locations. A time-resolved mapping of electron flow versus adder length is constructed. Measurements of electron flow in the initial cavities agreed well with simulations. Electron flow for times near the current peak exhibits a monotonic increase with length, except at the adder end.

I. INTRODUCTION

The technologies of the inductive cavity and MITL have been combined as the basis of several high-voltage, high-current particle accelerators at SNL (Hermes III, Helia, SABRE). Voltage addition is achieved by stacking cavities. A coaxial, center conductor is stepped to smaller radius at each cavity gap to match the total drive impedance as voltages are added along the MITL. Insulation between the center conductor and cavity bore is obtained via high magnetic fields associated with the large cavity currents. Linear induction accelerators have been operated in both negative and positive polarity for x-ray simulation and ion fusion applications, respectively. In both cases electrons which are emitted from the cathode surfaces are insulated by the self-magnetic fields. In negative polarity operation, the cathode is one continuous conductor, the center conductor. However, in positive polarity, a separate cathode exists at each induction cavity. Electrons are emitted from the inner surface of each cavity, at a unique potential, and travel along parapotential lines toward the diode end of the adder. At any location inside the adder, the total electron flow is the sum of the flow from the upstream cavities. Therefore, in going from beginning to end of the adder, an increase in electron flow is expected.

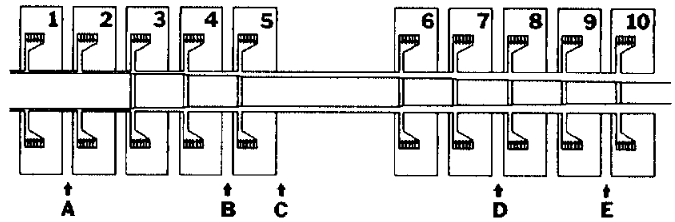

Figure 1. SABRE ten-stage adder. Arrows denote B-dot locations. Cavities are numbered 1-10.

In this paper we present measurements on electron flow in the SABRE adder section, as a function of time and space. SABRE was constructed to investigate light-ion inertial confinement fusion issues (e.g. accelerator physics, ion sources, beam transport).

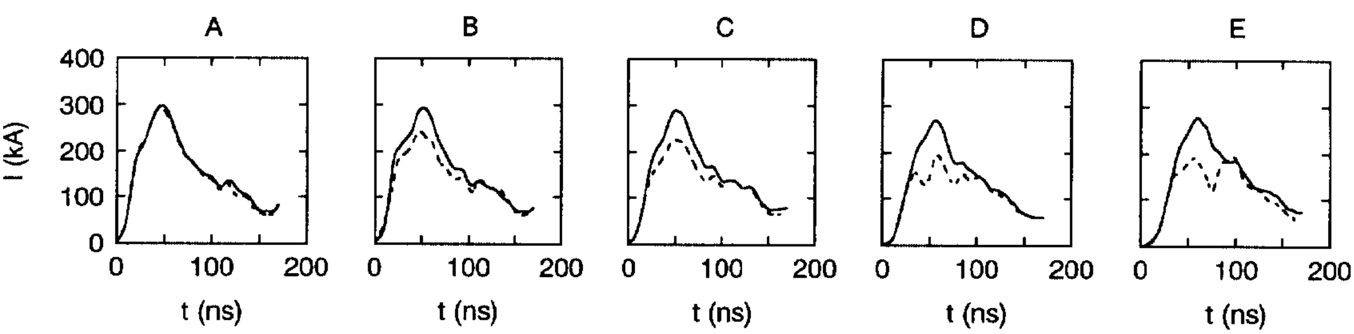

Figure 2. Adder B-dot signals at 5 axial locations. [——] Anode current. [– – –] Cathode current.

+Titan/Advanced Innovative Technologies
*Supported by the U.S. DOE, Contract AC04-76DP00789.

The SABRE MITL is terminated with an applied-B extraction ion diode 4-m downstream from the final cavity [4].

II. ELECTRON FLOW

A. SABRE Adder

A line drawing of the SABRE voltage adder is given in Figure 1. There are two sets of five cavities. Each set is charged through an electrically triggered gas switch. Firing of the switch on the downstream set is delayed (6 - 17 ns) to compensate for the transit time between the two cavity sets. B-dot monitors were used to obtain the inner conductor (anode) current and outer conductor (cathode) current at five axial locations, between the following cavities: 1-2, 4-5, 5-6, 7-8, and 9-10. Each B-dot assembly consists of a B-dot pair configured for common mode noise rejection. At each location, a set of two anode B-dots and two cathode B-dots are positioned 180 degrees apart. The average anode and cathode currents measured at each axial location for a sample shot (with 13 ns switch delay) are given in Figure 2.

B. Measurements

In order to more easily visualize MITL electron flow along the length of the adder, the data of Fig. 2 are displayed as plots of current vs axial position (frames), at equally spaced time intervals (Fig. 3a). The difference between anode and cathode currents is the electron flow displayed in the corresponding frames of Fig. 3b.

We make the following observations from this data.

(1) The anode and cathode currents near the beginning of the adder are equal (within measurement error) for the entire pulse.

(2) *Frames during the pulse risetime (10-30 ns).* Electron flow initially appears in the first set of five cavities, which is energized before the second set of cavities.

(3) *Frames near the peak of the pulse (40-60 ns).* The anode current is roughly constant along the entire adder, which indicates no current losses to the anode. There is a general decrease in cathode current in the downstream direction, corresponding to an increase in electron flow with increasing cavity number. In two of these frames, there is a marked decrease in electron flow at the end of the adder.

C. Simulations

Simulations were performed using a 2½ - d particle code (TWO-QUICK) with parameters relevant to SABRE experiments. The results of a simulation with a 14 ns gas switch delay, similar to the delay of the shot in Fig. 3, are given in Fig. 4. Observations from this data are:

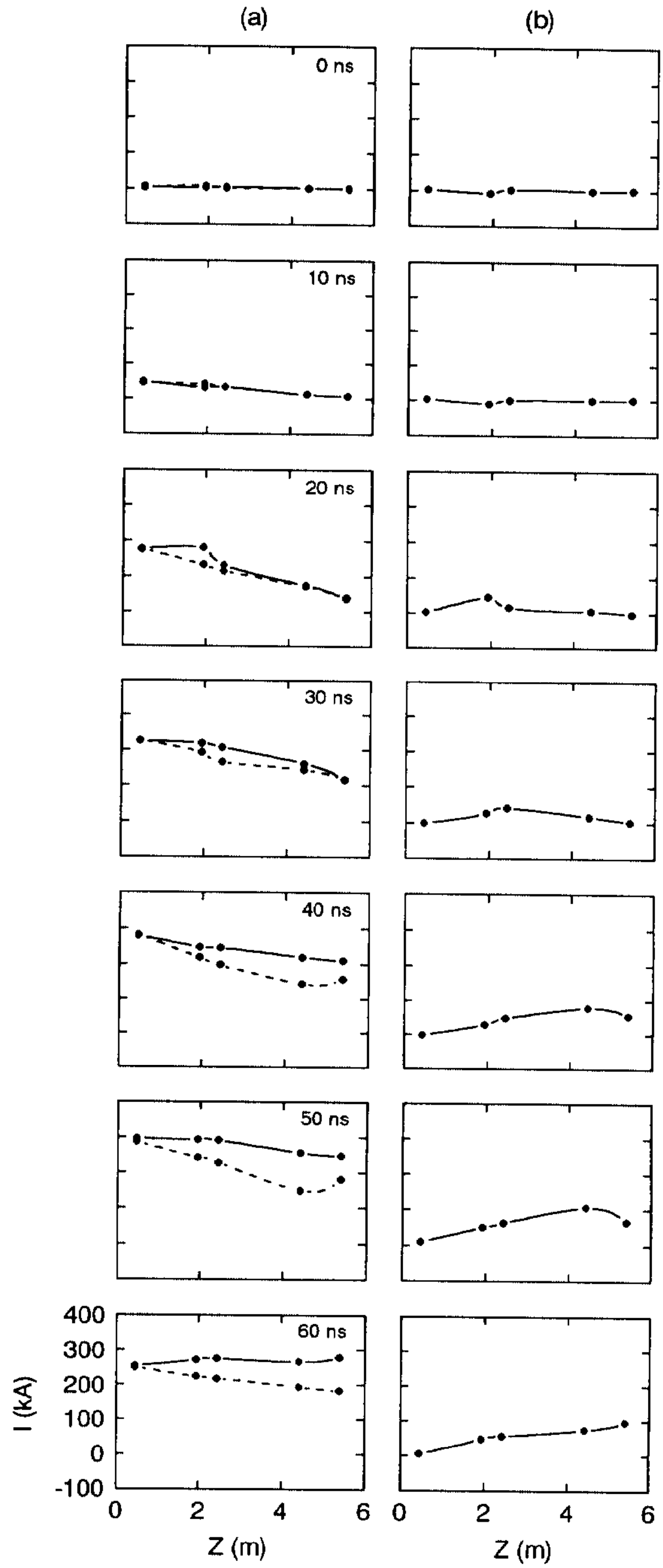

Figure 3. (a) Measured anode current [——] and cathode current [– – –] vs axial position.
(b) Difference in anode and cathode current = electron flow.

(1) The anode and cathode currents near the beginning of the adder are equal for the entire pulse, just as they were for the measurements.

(2) *Frames during the pulse risetime (10-30 ns).* Electron flow initially appears in the first set of five cavities, similar to the measurements.

(3) *Frames near the peak of the pulse (40-60 ns).* Electron flow follows a general increasing trend with cavity number, as it did in the measurements. There is one exception, no decrease was observed at the adder end.

III. SUMMARY

Current efficiency may be defined as the ratio of cathode current/anode current at the adder end. Near the peak of the pulse, the current efficiency was approximately 65%. Accurate determination of energy loss associated with electron flow must take into account the broad electron energy spectrum. Future work will address this topic.

Measurements and simulations of electron flow in the SABRE adder are generally in good agreement. Agreement in the initial cavities was particularly good, unlike the Hermes-III case [1]. At the adder end, there was a decrease in electron flow in some frames (40-50 ns) which was not present in the simulations. This could be caused by electron particle loss or electron energy loss.

Analysis of electron flow in the format given here will be valuable in future work to gauge the success of attempts to decrease electron emission and therefore increase adder efficiency. Construction of the plots showing current vs position has been automated, so that analysis is readily available for each shot.

IV. REFERENCES

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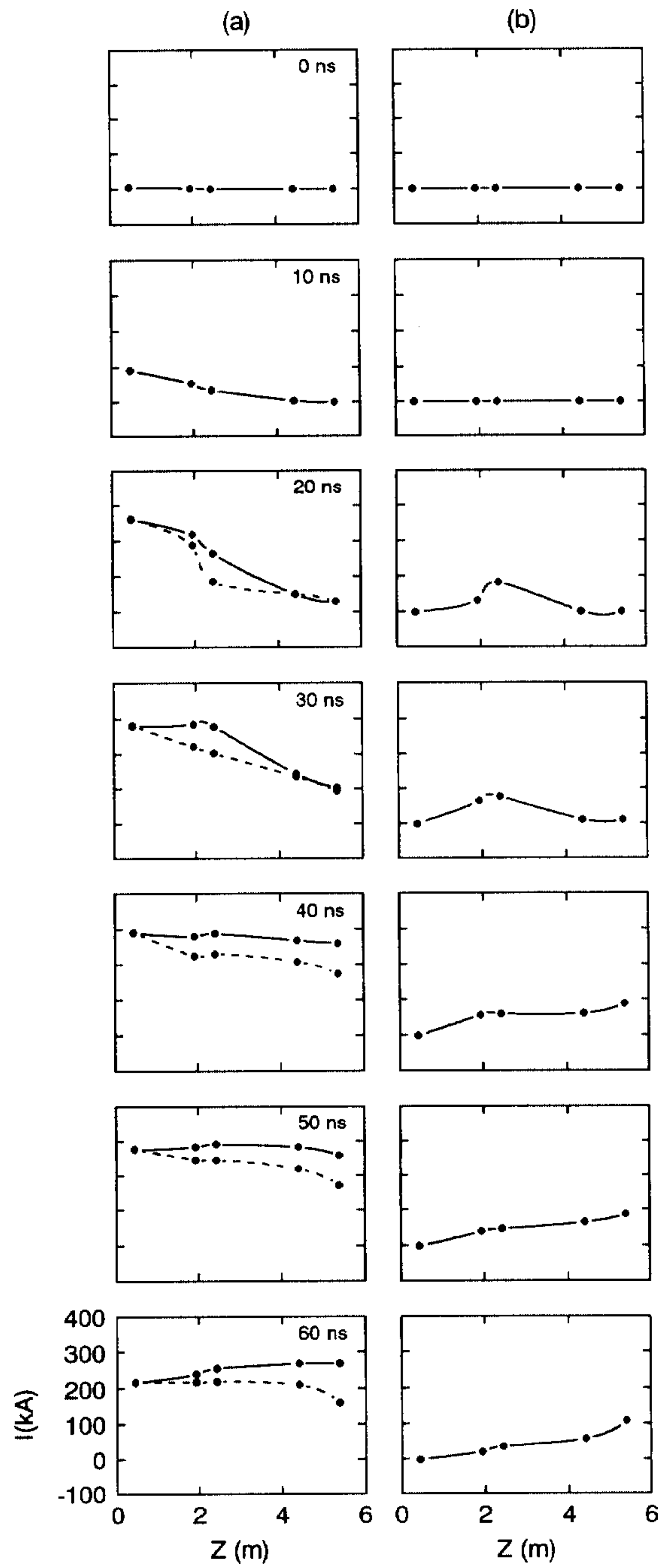

Figure 4. (a) Simulation of anode current [——] and cathode current [- - -] vs axial position.
(b) Difference in anode and cathode currents = electron flow.