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Beam Control for Ion Induction Accelerators

Final Report on LDRD Project 99-ERD-052

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Abstract

Coordinated bending and acceleration of an intense space-charge-dominated ion beam has been achieved for the first time. This required the development of a variable waveform, precision, bi-polar high voltage pulser and a precision, high repetition rate induction core modulator. Waveforms applied to the induction cores accelerate the beam as the bi-polar high voltage pulser delivers a voltage ramp to electrostatic dipoles which bend the beam through a 90 degree permanent magnet quadrupole lattice. Further work on emittance minimization is also reported.

INTRODUCTION

Ion beam induction accelerators are the leading driver candidate for inertial fusion energy (IFE) production [1]. Intense ion beams are focussed onto a deuterium-tritium (DT) capsule to initiate a tiny thermonuclear burn; the fusion energy is captured for power generation by a flowing liquid metal wall. Much of the IFE target physics can be studied using the National Ignition Facility and most of the driver relevant ion beam dynamics can be studied with scaled beams at a modest cost. This project utilized an existing scaled beam facility (the Small Recirculator; developed primarily with LDRD funds) to study the effects of active beam control (steering, acceleration and bending) on a space-charge-dominated ion beam with dimensionless parameters (e.g., perveance) similar to an ion driver. The specific goals were to successfully coordinate the acceleration and bending of the ion beam while minimizing the emittance growth and to study in detail the effects of a beam phase space mismatch between the ion source and the transport lattice. These issues are critically important for the design of a full-scale ion beam driver. The beam emittance at the end of the driver will determine the final focus spot size on the DT capsule and this spot size determines, in large part, the final energy gain of the power plant or facility.

THE SMALL RECIRCULATOR

The experiments were conducted using an 80-keV, 2mA potassium beam in the Small Recirculator, a scaled circular ion induction accelerator [2, 3]. This machine has been under development for several years as

an alternate ion driver concept and as a long path length beam dynamics platform to study acceleration, bunch compression and emittance growth over driver relevant lattice spans (approximately 50 betatron periods). Table 1 lists some important specifications of the Small Recirculator. Each half lattice period (HLP) of the accelerator consists of a permanent magnetic quadrupole for focusing, an electrostatic dipole for bending (9 degrees), an induction core for acceleration (up to 1000-eV per core per lap) and longitudinal compression and a capacitive beam position monitor (100- μ m resolution).

Table 1: Small Recirculator Specifications

Circumference	14.4m	
Beam Species	K ⁺	
# of laps	15	
Max. Beam Radius	1.5 cm	
Beam Statistics	Lap 1	Lap 15
Beam Energy	80keV	320keV
Pulse Duration	4 μ s	1 μ s
Beam Current	2 mA	8 mA
Undepressed Phase Advance	78°	45°
Depressed Phase Advance	16°	12°

Figure 1 shows a schematic layout of the Small Recirculator configuration used for this project. The 90 degree bend transport lattice consists of ten HLP's with an induction core on every other HLP. A matching section with 9 electrostatic quadrupoles (7 for focusing and 2 for steering) transforms the beam envelope from a uniformly expanding beam at the source aperture to the strong focussing transport lattice of the bend section. Proper beam envelope matching is one of the most important aspects of an IFE driver. A mismatch between the source and the main accelerator section can cause substantial emittance growth that leads to beam instabilities and longitudinal velocity gradients further along the accelerator. These instabilities can cause significant beam loss and, in the worst case, leave the beam uncontrollable.

Several experiments were performed to study the sensitivity of the beam emittance after the 90 degree bend on the degree of mismatch in the electrostatic matching section. These experiments required precise control of the beam position through the matching section. The results have been reported in References 4 and 5 and indicate that the effects of even a slight beam envelope mismatch can be severe (up to 40% larger than the nominal matched

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Figure 3: The lower trace is the 500-volt pulse applied to the induction cores to accelerate the beam. The upper trace is the signal from the beam position monitor and shows the relative timing of the beam pulse through the induction core with respect to the accelerating voltage.

Figure 4: The signal from a Faraday cup located at the end of the 90 degree bend section showing the beam current profile of an accelerated beam. The dashed line shows the signal level for 100% current transport through the bend section.

FIGURE CAPTIONS

Figure 1: Schematic layout of the Small Recirculator configuration showing all of the important components and their relative locations. A picture of the bend section shows the 10 HLPs. The diagnostic tank at the end of the 90 degree bend is in the left hand foreground of the picture.

Figure 2: The upper panel shows the computer generated waveform used as input to the bi-polar dipole pulser. The beam pulse is timed to arrive at the first electrostatic dipole at approximately 475 microseconds from the beginning of the pulser waveform. The lower panel shows an oscilloscope trace of the identical positive and negative voltage pulses that are applied to the bending dipole plates as a result of the input waveform. The maximum output voltage is approximately 22-kV.

Figure 2 (available electronically)

Figure 4 (available electronically)