AN EXPERIMENTAL PROGRAM TO INVESTIGATE THE STRONG FOCUSSED, SPIRAL LINE RECIRCULATING INDUCTION ACCELERATOR*

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ABSTRACT

The spiral line recirculating induction accelerator (SLIA) is a new embodiment of an open-ended spiral line recirculator first studied by Wilson et al.[1] at NBS, and incorporates strong focussing in the bends for insensitivity to energy mismatch desirable with high gain per pass induction cavities. The accelerator involves recirculation of an electron beam several times in independent transport lines, which pass through common ferrite core accelerating sections. It is designed to produce effective accelerating gradients in the 100 MV/m range for compactness and yet be amenable to long pulse trains at high currents. Reduced weight is obtained by utilizing the high frequency (10-30 MHz) branched magnetic switching of Birx[2] to reset the induction cores during the recirculation period of the beam. An experimental and theoretical program is underway to investigate key physics issues regarding energy bandwidth, control of emittance growth, and electromagnetic instabilities. The progress of the Phase I program is discussed in this paper.

INTRODUCTION

The SLIA is a compact high current accelerator and is compared with other such accelerators in the paper by S.D. Putnam in these proceedings. Both the injection and extraction of the beam are facilitated by the open-ended nature of the SLIA. The magnetic fields throughout the transport system are static over the beam macropulse thus allowing for very low field errors. The strong focussing $\ell = 2$ stellarator field in the magnetic transport system improves tolerance of an energy mismatch at lower energies. This transport system is combined with ferromagnetic cores/cavities and branched magnetic drivers to allow excellent pulse shape control and pulse-to-pulse reproducibility required at high energy. The cores are reset while the beam is not in the accelerating section. The SLIA builds on the Linear Induction Accelerator (LIA) power technology developed at LLNL.

Each transport line contains its own individual magnetic field coils and is magnetically and electrostatically isolated from all other transport lines except in the common acceleration section. Shielded gaps are used to prevent low frequency beam deflection due to asymmetries in return currents.

The major physics issues for the SLIA are the control of emittance growth in the acceleration section and transport system; orbital dynamics and resonances; the beam breakup (BBU) instability; and the negative mass instability.

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PHASE I PROGRAM

The ongoing program is a 180° beam bending and transport experiment. It includes the design, fabrication, and testing of 1) a power supply (pulser) to drive the electron beam diode and induction cells; 2) a field immersed and field free diode for the injector; 3) the transport system including the magnetic field coils, shielding and coil terminations and 4) diagnostics including voltage and current monitors, beam bugs, and a beam emittance measurement device.

The objectives of the program are to 1) investigate and control the beam emittance growth due to magnetic field errors, beam envelope mismatching, and energy mismatching; 2) determine the energy bandwidth of the bending section; 3) determine if the Hughes-Godfrey instability is present in the experiment and 4) verify the existing theoretical models for beam transport or develop improved models if required.

PULSER/INJECTOR

The pulser is designed to drive both the electron beam diode and induction cells. The pulser/injector is composed of a Marx generator, Blumlein, glycol pulse forming line, vacuum insulator and diode. The electrical circuit for the pulser/injector is shown in Figure 1. The Marx generator is oil insulated and contains six stages. Each stage is composed of a 0.3 μF, 100 kV capacitor. The Marx generator stores 9 kJ of energy when charged to 100 kV.

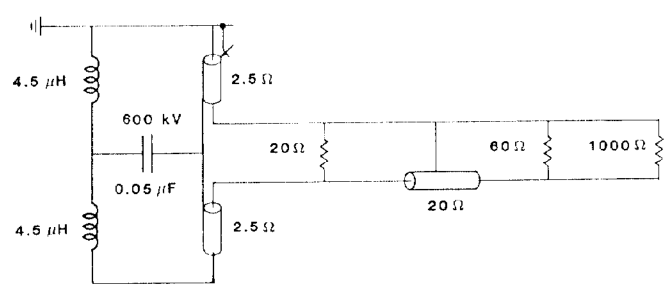

Figure 1. Electrical circuit for the pulser/injector.

The two transmission lines of the Blumlein pulse-forming lines are charged from the Marx through a symmetric or balanced circuit in order to minimize the voltage which appears across the diode during charging. The Blumlein pulse-forming line uses water as a dielectric medium, has a 5 Ω impedance and a 100 ns output pulse length.

There is a 20 Ω radial resistor at the output of the Blumlein for extracting power for the proposed induction cavities in the Phase II portion of the program. In the present program the 20 Ω radial resistor simulates the load represented by the induction cavities.

The 20 Ω radial resistor is in parallel with a 20 Ω glycol pulse-forming line/transformer. The primary purpose of the glycol line is to transform the voltage upward. The glycol line has an electrical transit time of 100 ns.

The 20 Ω glycol line is followed by a 60 Ω radial resistor. Since the radial resistor has an impedance which is small compared to the diode impedance the diode voltage is relatively independent of the diode current over the range of diode currents of interest (1-2 kA). The resistor also improves the electrostatic grading of the vacuum insulator.

The desired diode impedance is 500-1000 ohms at a 1 MV voltage. Ideally the diode should be capable of being operated in either a magnetized or non-magnetized mode with a final beam radius of 1 cm at entrance to the transport region. A low emittance diode is also desired. The design approach uses a non-emitting focussing electrode with the emission area defined by a velvet cathode. A re-entrant anode is used to obtain the desired current density at the emitting surface. An electrostatic field code was used to design a focussing electrode geometry which limited the electric field at the non-emitting portion of the cathode to 170 kV/cm or less. An estimate of the diode impedance was obtained by using the SLAC Electron Trajectory Code. Focussing electrode angles of 62.5° and 53.5° with an anode-cathode gap spacing of 6 cm were investigated by G. Caporaso for a non-magnetized diode. The predicted current was 993 A for the 62.5° case and 843 A for the 53.5° case. The predicted normalized emittance for the 62.5° case was 28.8 π cm - mrad and the brightness was 1.2 x 10^5 amp/cm^2/steradian.

MATCHING SECTION

In order to minimize opportunities for growth of the emittance of the beam, it is necessary to match the beam distribution to the transport channel. This is in principle a simple matter for continuous or interrupted solenoid focussing, but is less straightforward for a twisted quadrupole winding.

The matched envelope in a stellarator winding has an elliptical shape, rotating without distortion to follow the local quadrupole axes. In order to accomplish this, the local values of x' and y' at any location (x,y) (the two transverse dimensions, aligned with the local quadrupole axes) are related by[3,4] $x' = a\,y$ and $y' = b\,x$, where a and b depend on the focussing parameters. The values of a and b vary quite freely with the focussing, but the resulting motion may be decomposed into a solid-body rotation and a skew quadrupole distribution. We are designing a matching lens layout to use this decomposition to provide a beam with the required elliptical aspect ratio (1:1 to 1.4:1) and degree of skewness at the entrance to the stellarator field.

TRANSPORT SYSTEM

The transport system is made up of two 90-cm and one 180-cm straight sections and a 180° bend section. The inner radius of the beam pipe is 3 cm and the major radius of the 180° bend is 50 cm. The straight sections have stellarator and axial field coils and the bend section has stellarator, toroidal and vertical field coils.

The nominal magnetic field amplitudes are 5.0 kG for the axial/toroidal field and 100 G (Phase I) to 500 G (Phase II) for the vertical field. The nominal on-axis quadrupole gradient is 524 G/cm. We have the capability to independently control the currents in each of the magnetic field windings. The magnetic shield is a 7 inch ID aluminum pipe with a 3/4" thick wall.

The stellarator field winding is an $\ell = 2$ winding with a winding pitch length of 18 cm. The winding pitch length was chosen so that the ratio of the pitch length to the beam pipe wall radius was equal to six. In this region the Hughes-Godfrey instability occurs only at $k_\ell >> 0$ where the growth rate is low.

The capacitor banks can be configured to provide an ε[5] (ratio of stellarator field to toroidal field) as large as 0.5 for the nominal toroidal magnetic field. The predicted maximum energy mismatch allowed with the planned experimental parameters is 36% at 3.1 MeV and 13% at 9.7 MeV.

General purpose low voltage, modular capacitor banks consisting of twenty-four 1.4 mF, 450 V electrolytic capacitors were chosen as the energy source for the magnet coils. Low voltage banks avoid insulation problems with the small spacings required between the various coil windings. The capacitor banks can be connected in parallel or series to accommodate the widely varying inductances and resistances in the Phase I experiments.

DIAGNOSTICS

There are ten sets of beam bugs in the transport system to measure the motion of the center of the beam within the beam pipe. Since the magnet coils must be wound on top of the beam bugs, the LLNL design could not be used. Increasing the winding radius in the experiments from 3.5 cm to 4.2 cm while holding $\varepsilon = 0.3$ causes the current required in the windings to increase dramatically from 11.8 kA to 20.7 kA. The PSI beam bug design uses four B-dot loops inserted in the beam pipe wall and adds only 0.38 cm to the winding radii. Signals are brought out from under the coils with small 50 Ω semirigid coaxial cables.

The beam termination diagnostic package includes a segmented Faraday/charge collector array (CCA), an x-ray pinhole camera, total beam current Faraday cup, fully absorbing calorimeter, and a pepper-pot pinhole array. The CCA array will provide spatial and time resolved information on the beam current density. The x-ray pinhole camera will provide qualitative information on the beam uniformity with a better spatial resolution than the CCA. The fully absorbing calorimeter and total beam current Faraday cup can be used to infer a beam kinetic energy. The pepper-pot pinhole array measures the emittance of the beam.

EXPERIMENTAL PLAN

The initial experiments will characterize the beam (J(x, y, t), I(t) and emittance) from the injector as a function of pulser voltage, diode spacing, cathode shape, and magnetic field at the cathode. The matching region will then be added and the beam characterized at the exit from the matching region.

The effects of magnetic field errors will be investigated by characterizing the beam after transport through a) one 90 cm straight, b) two 90 cm straight sections and c) one 180 cm straight section. The beam bug output will be examined for evidence of instabilities. The beam displacement data will be Fourier transformed in order to examine the frequency spectrum. We plan to measure the energy bandwidth by adjusting the vertical, stellarator, and toroidal magnetic field. The final experiments will characterize the beam at the exit from the 180° bend section.

PROGRAM SCHEDULE

The electrical checkout of the injector is scheduled for April of 1987 with diode/beam extraction experiments beginning in May. Transport experiments are expected to begin in July after checkout of the transport magnets during June. No induction cavity acceleration experiments are scheduled since Phase II of the experiments has not yet been funded.

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