ELECTRON TRANSPORT IN STELLARATOR FIELDS*

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In developing the Spiral Line Induction Accelerator, we have begun experiments on the transport of a beam drifting through straight and 180° curved beamline segments in the presence of a guide field, a continuously rotating quadrupole field (for strong focussing), and a bending field. Our goal is to accelerate an electron beam through multiple induction cavities several times while controlling the beam offset in the presence of energy spread, to minimize beam breakup interaction with the cavity. In our preliminary work, we have measured the charge and current transport of a 900 keV, 600 A electron beam around a 180° bend as a function of the quadrupole focussing gradient. The position of the beam centroid at the bend exit is in good agreement with the calculated position as the bending field is varied. For a guide field of 1870 gauss, the 90% beam transmission fractional tolerance to bending field mismatch is ±20% for zero quadrupole gradient, broadening to -50% and more than +130% for a gradient of 500 gauss/cm.

Introduction

A promising proposed concept for a compact, relatively lightweight accelerator for high-current, high-energy electron beams is the Spiral Line Induction Accelerator. The central feature of this approach is to recirculate a beam through an otherwise conventional induction cavity to accelerate high beam currents. The complications of injection and extraction of the beam, unavoidable in closed orbit devices patterned after the betatron, are sidestepped by carrying the beam on each transit of the cavity through an independent beamline. Each beamline bend will handle a single band of particle energy, and no variation of bending field will be necessary over the acceleration period. The general features of the concept are similar to suggestions made by M. Wilson [1]. The focussing proposed to enhance the energy tolerance of the bending regions is an adaptation of the Stellatron proposal [2], *i.e.*, the incorporation of a continuously rotating quadrupole field superimposed on a guide field (an $l = 2$ stellarator, in effect). We are in the process of testing the feasibility of this scheme by measuring the effects of stellarator field transport on a drifting beam prior to fabrication of an actual multi-pass induction accelerator.

Apparatus

The experimental apparatus consists of a Marx generator charging a water Blumlein pulse-forming line, the diode and vacuum chamber, beam compression magnets, the beamline and its magnets, and various diagnostics. A schematic of the beamline is shown in Fig. 1. The electron energy is monitored by capactive monitors near the diode, current is measured by Rogowski coils, single-turn B-dot loops, and a resistively monitored Faraday cup, and the beam emittance is measured by imaging the beam through a pinhole array. Imaging of the pinhole and of the entire beam is done via a fused silica Čerenkov convertor and an open-shutter camera, giving a time-integrated image. We have a gated microchannel plate camera in procurement, which will enable us to identify time variations within the beam.

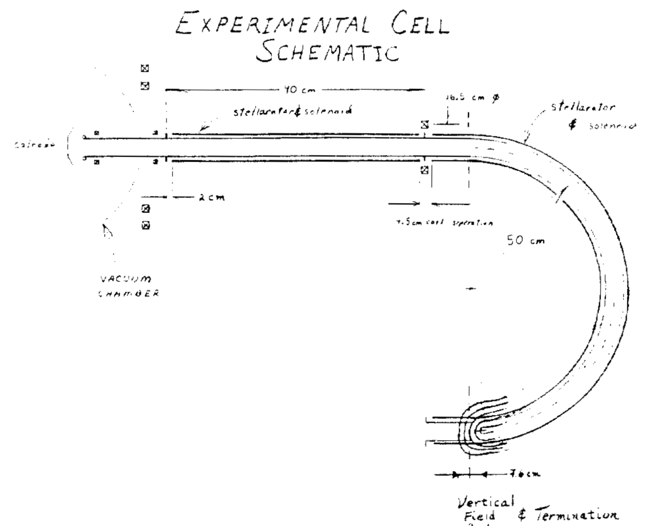

Figure 1: Beamline schematic, showing the injector, compression region, straight solenoid, and bend section.

Results

In Fig. 2 we show the voltage at the base of the cathode stalk and the voltage at the cathode field-shaper. While the source pulse is relatively flat, the inductance of the cathode stalk and the capacitance of the diode together cause large-amplitude ringing of the diode voltage. We plan to reduce this by loading the diode more heavily and changing the geometry as allowed by field emission limits. Fig. 3 shows the current at the exit of the 90-cm solenoid transport region between the anode pipe and the entrance to the bend. This segment was inserted to isolate any effects of the beam compression fields from those of the bend section. We had inserted a 1.2-inch diameter aperture at the mouth of the anode for these measurements, to try to minimize the beam emittance by clipping the outer boundary of the beam, which is most subject to focussing aberrations.

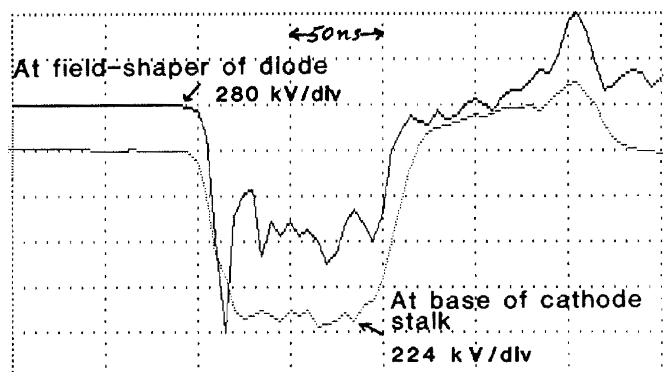

Figure 2: Voltage measured (a.) at cathode stalk base and (b.) at field shaper of diode. Large amplitude oscillations will be damped in later experiments.

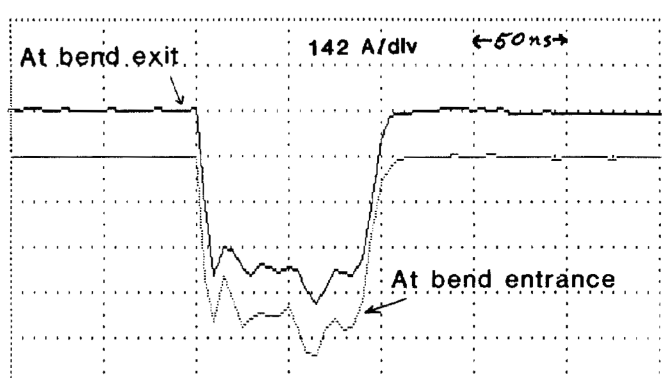

Figure 3: Current measured by resistive Faraday cup (a.) at exit of 90-cm straight solenoid just upstream from bend entrance and (b.) at exit of 180° bend section.

In this first stage of the experimentation, the compression region field design does not have a large energy bandwidth. This feature will be corrected in future experimental runs, but results at present in a large envelope oscillation of the beam, the initial amplitude and phase varying with energy. The time-integrated measurements we are presently capable of making show only the maximum excursion of the beam envelope. We designed

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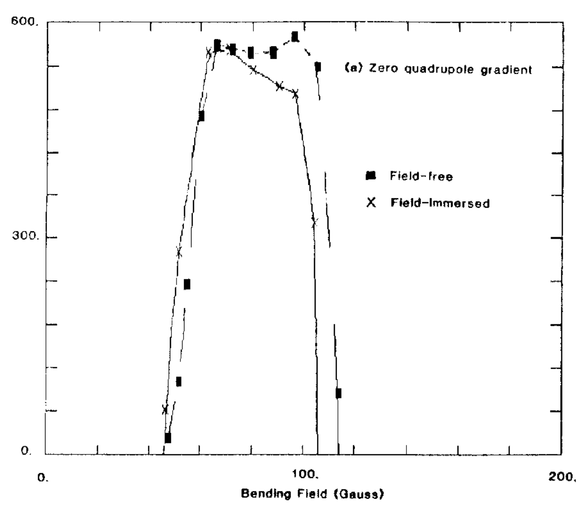
the compression fields for a beam energy of 800 keV, as an average over the flattest portion of the pulse. In the case of emittance data, only the measurements at the diode, in the absence of applied magnetic field, are easily interpreted. These measurements indicate that the initial normalized emittance of the beam is approximately 60–100 π cm milliradian. Measurements downstream, in the presence of external magnetic fields, show a much larger apparent emittance, in the range of 500 π cm milliradian both at the entrance to and exit from the bend. We attribute most of this apparent emittance to the broad energy spread of the beam. In a time-integrated measurement, this greatly overwhelms the improvement in the beam emittance from use of the anode aperture. We cannot yet determine whether the bend section adversely affects the beam emittance. Use of the gated camera mentioned above and flattening of the diode voltage will allow us to determine better whether the stellarator fields in the bend have any adverse effect on the beam emittance.

We find that within the approximately 5% pulse-to-pulse reproducibility, the current and charge are transported without loss through the straight solenoid and through the bend section for the bending field matched to the momentum of the electrons for the beamline bending radius. In Fig. 4(a.) we show plots of transmitted current to a Faraday cup at the exit of the bend section versus the strength of the bending field, with zero quadrupole gradient, for field-free and field-immersed cathode conditions. The fractional tolerance to changes in the bending field for 90% transmission of current is ±20%. There is no significant difference between the two initial conditions. Because of the spread in energy of the particles, some time slices of the beam are lost before others as the field is changed. For this reason, we have chosen to show current transmission plots at a particular energy (the peak of current and voltage, approximately 600 A at 900 keV), rather than average over a large energy spread.

Photos of the beam at the bend exit show that for the zero quadrupole case with the bending field set at the matched value, the beam is well-centered in the beampipe, while for a value of the field too low (high) the beam has drifted up (down). The bending field points into the earth and the guide field is parallel to the electron directed velocity. The corresponding pictures for a quadrupole gradient of 200 gauss/cm show that the drift has been changed from a primarily vertical motion to one primarily in the horizontal plane, although the bandwidth for current transmission (not shown) is unchanged. In Fig. 4(b.) we show another plot of current to the Faraday cup as a function of bending field strength for a quadrupole gradient of 300 gauss/cm. The tolerance to field mismatch has grown to about ±42%. Data for a quadrupole gradient of 500 gauss/cm suffered from a failing trim coil in the compression region, but the initial results are that the bending field tolerance for 90% transmission is over the range from -50% to more than +130%. We are investigating focussing designs to minimize chromatic effects in the bend region.



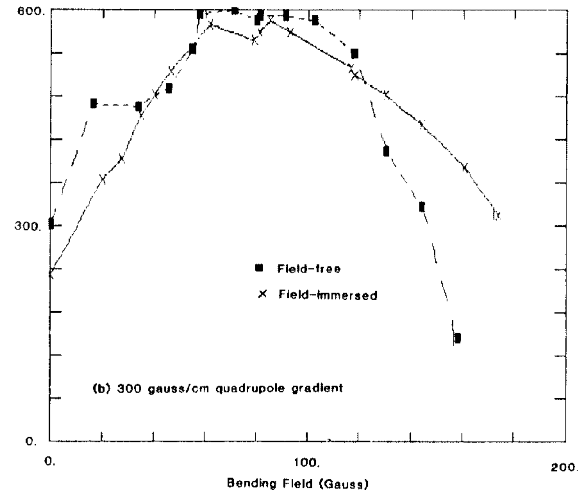


Figure 4: Bandwidth measurements for current transport as a function of bending field strength for (a.) zero quadrupole gradient for field-free and field-immersed injection, and (b.) a quadrupole gradient of 300 gauss/cm for field-free and field-immersed injection. There is no significant difference between field-free and field-immersed injection, although the tolerance to field mismatch is doubled between the two quadrupole gradients, rising from ±20% to ±42%. Data for a gradient of 500 gauss/cm are incomplete, but indicate that the 90% passband extends from 50% below the matched field to over 2.3 times the matched field.

We noted in the 300 gauss/cm runs that at the bend exit, the 0.006-inch titanium foil we were using to help reject low-energy electrons (those still above the Čerenkov threshold) from the imaging film, had been dimpled by local heating from the electron beam. The dimple required only one shot to form, and was about 0.170 inch in diameter. We placed a 0.035-inch thick titanium sheet at the image plate location, with a 0.188-inch diameter aperture within approximately 0.04 inch of the position of the dimpled area, and with the Faraday cup downstream to measure the transmitted current as a function of time. We found that a current equal to half of the current of the unattenuated beam was transmitted by this aperture at a time corresponding to a beam energy of about 800 keV. At the time corresponding to the peak energy and total current, less than 10% of the beam was transmitted through the aperture. The calculated equilibrium diameter of the beam for the emittance measured at the diode is 0.18 inch. This is supporting evidence that for this particular energy, the beam quality may be comparable to that at the diode.

With the anticipated improvements in the compression field design and in the diode voltage pulse shape, and with the gated camera for beam size and emittance measurements, we expect to be able to complete the drifting beam experiments and have all the data necessary to design a new beamline for the first multipass acceleration experiment.

<u>References</u>

[1] Mark A. D. Wilson, IEEE Trans. on Nuc. Sci., **NS-28** (3), 3375-3377.

[2] C. Roberson, *et al.*, Phys. Rev. Lett. <u>50</u>, 507 (1983); also Part. Accel., <u>17</u>, 79 (1985).