ELECTRON BEAM TRANSPORT AND EMITTANCE MEASUREMENTS IN A LONG PERIODIC SOLENOID CHANNEL*

J. McAdoo, E. Chojnacki, P. Loschialpo, K. Low, M. Reiser and J. D. Lawson[a)]

Laboratory for Plasma and Fusion Energy Studies
University of Maryland
College Park, Maryland 20742

Abstract

An electron beam transport experiment utilizing 5 kV electrons in a 200 mA beam passing through 36 solenoid lenses is described. The fraction of the beam transmitted is a function of the lens strengths, the length of the channel, the beam size, and the precision of the alignment. Emittance measurements in the 36-lens channel showed no significant degradation compared to a 12-lens channel.

Introduction

The Electron Beam Transport Experiment at the University of Maryland was planned to study the causes of emittance growth and instabilities that limit beam current and beam quality in a periodic focusing beam transport system. Theoretical studies, design features, and experimental results from a periodic focusing channel consisting of 12 short solenoidal lenses are reported in References 1 and 2. The results of a single lens experiment are reported in References 3 and 4. In the 12-lens experiment, detailed measurements of beam transmission, beam matching, and emittance were made. In the single lens experiment, the effects of lens aberrations and space charge forces on the focusing of an electron beam were studied. These investigations comprised Stage 1 of our periodic focusing channel studies.

Preliminary results from the next stage using a 36-lens channel are reported here. The initial objective of this experiment is to compare beam transmission characteristics with those from the 12-lens experiment. These characteristics include fraction of current transmitted through the channel, dynamics of beam propagation, and emittance growth along the channel. The data presented below suggests that the increased channel length places greater constraints on the lens alignment specifications for 100% transmission of a given beam. Remarkably, in preliminary measurements, the length was found to have little effect on emittance growth for the fully transmitted beam.

Beam Transport Results in 36-Lens Channel

The experimental arrangement of the electron beam transport is shown schematically in Fig. 1. Two electron guns were used in these studies. The first, built at the Rutherford-Appleton Laboratory, has a cathode radius of 0.5 cm and produces a current of about 85 mA. The second, built by Hughes Aircraft, has a cathode radius of 1.27 cm and the current is typically 220 mA. Both guns were operated at 5 kV with 3 μs pulses repeated at 60 Hz. Downstream from the gun are two solenoids, M1 and M2, that are used for matching the beam into the channel of periodically spaced lenses, C1 to C36 (length of one period is 13.6 cm). Short diagnostic ports are provided between lenses C12 and C13 and between C24 and C25. The main diagnostic chamber with current monitor (Rogowski coil), flourescent screen and slit/Faraday cup system for emittance measurements is located at the end of the channel. The flourescent screen can be moved a short distance into the channel, and the beam spot on the screen can be viewed or videographed through a viewing port at the rear.

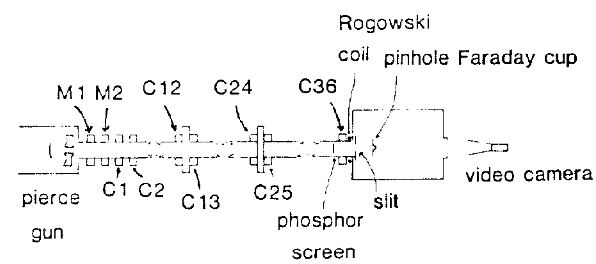

FIG. 1. Schematic of experimental arrangement of the electron beam transport system.

To obtain information on the beam transport through the channel, two measurements were made. First, the fraction of current transmitted through the channel was measured as a function of the strength of the lenses. Second, the emittance of the beam was measured.

The fraction of current transmitted is the ratio of the gun cathode current to the current exiting the 36-lens channel. For each measurement, the two matching lenses are adjusted to give maximum transmission. Since the 36 lenses are electrically connected in series, each has the same strength. The strength is reported as a value of σ_o, which is the phase advance of an electron oscillation in one lens period without space charge.[5] Higher values of field strength correspond to larger phase advance. Figure 2 shows the percent transmission as a function of σ_o with the Hughes gun for both the 12-lens channel and the 36-lens channel. Figure 3 shows the percent transmission for the Rutherford-Appleton gun in the 36-lens channel. Note the small range of σ_o near 70^0 over which the transmission for the Hughes gun in the 36-lens channel is substantially 100%. The Rutherford-Appleton gun transmits over a wider range of σ_o, because the beam is smaller as its radius scales with the cathode radius. The rapid decrease of tramsmission below $\sigma_o \approx 45^0$ is due to the fact that the beam radius becomes larger than the pipe radius. For σ_o above 90^0 we expect nonlinear effects and envelope instabilities to cause beam loss. We suspect that the narrow transmission region for the Hughes gun in the 36-lens channel is due to increased sensitivity of beam transport to alignment errors. That the alignment was not perfect can be seen in Fig. 5. Here the location of the beam-center, as viewed on a phosphor screen at the end of the channel, is plotted as a function of the channel lens strength. The beam

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[a)]Rutherford-Appleton Laboratory, U.K.

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center behaves as a single electron which in general follows a helix-like path through the channel. In a cylindrical coordinate system whose axis coincides with the channel axis, the beam center advances through some angle as it passes through each lens. In a frame rotating with this angle the beam center follows a sinusoidal path along the axis. Both the period of the sinusoid and the rotation rate through the lenses are functions of the lens strength. Thus, for an aligned system of lenses into which the beam has been launched off axis, one would expect Fig. 5 to show a spiral of decreasing radius as the channel strength is increased. For a perfectly launched beam, of course, there would be no motion of the beam center at all as the lens strength is varied. The size of the spiral can be used as a quantitative measure of the misalignment. Unfortunately, this diagnostic had not been developed when the 12-lens experiments were completed. As a result, we cannot directly compare the quality of the alignment in those earlier experiments with the alignment in the 36-lens experiments. We believe that image charges induced by the misaligned beam in the drift tube as well as nonlinear focusing forces may be responsible for the increased sensitivity of the beam to alignment errors. Further experimental and theoretical studies are planned to obtain an understanding of this effect.

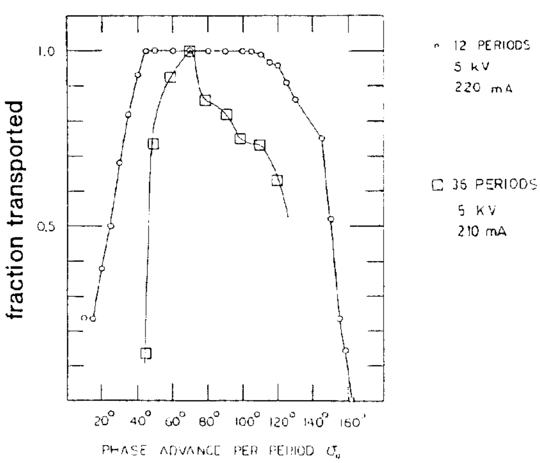

FIG. 2. Percent transmission as a function of σ_o with the Hughes gun for both the 12-lens channel and the 36-lens channel.

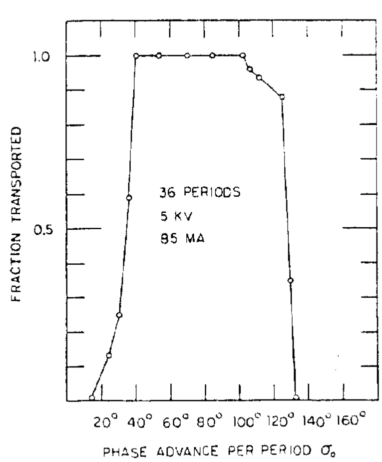

FIG. 3. Percent transmission for the Rutherford-Appleton gun in the 36-lens channel.

Emittance is measured by a computerized system whose basic set-up is shown in Fig. 6. A plate with a slit in it is placed in the beam path. A thin sheet of electrons passes through the slit. Downstream a Faraday cup scans transverse to the plane of the sheet. The resulting profile of the current density is stored for a complete set of slit positions which scan the entire beam. For the Hughes gun, the emittance for the 12-lens channel is 0.13 mm-rads measured at $\sigma_o = 70^0$. This is approximately 40% larger than the intrinsic emittance based on the cathode radius of $r_c = 1.27$ cm and temperature $kT \approx 0.13$ eV, where

$$\varepsilon_{intrinsic} = r_c(2kT/eV)^{1/2} = 0.092 \text{ mm-rads} .$$

Preliminary measurements of emittance have been made with the 36-lens system at $\sigma_o = 70^0$. These measurements do not indicate a significant degradation of beam quality from the 12-lens case. However, a more careful analysis of the data and additional measurements may be necessary to clarify this question.

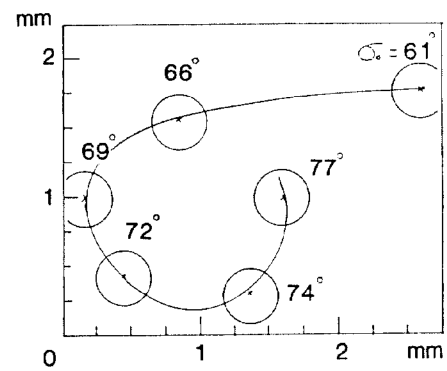

FIG. 4. Position of beam center in a plane transverse to the beam axis. Positions are plotted for various values of σ_o.

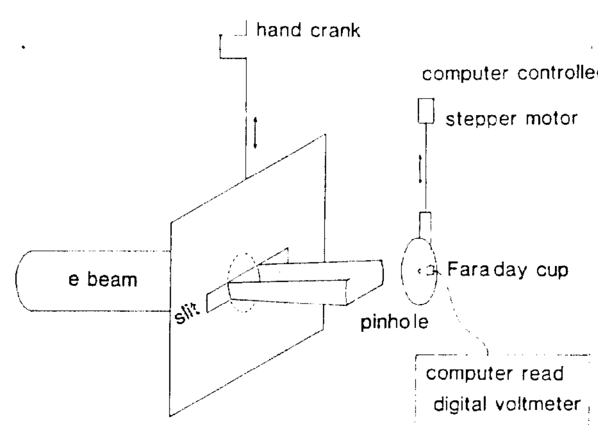

FIG. 5. Emittance measurement system.

Conclusion and Future Plans

The most significant result of these experiments is that the amount of current that can be transmitted down a periodic focusing channel of given size is a strong function of the channel's focusing strength (σ_o) and its length. The difference in the transmission curves for 12 lenses and 36 lenses (see Fig. 2) is not yet fully understood, but we suspect that alignment plays an important role. Future work is being planned to study the effect of alignment errors on the transmitted current and beam quality. An important part of this will include the investigation of the effect of image charges on the trajectory of the off-centered beam.

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