THE AGS H^- RFQ PREINJECTOR*

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Introduction

The development of a new preinjector line for the 200 MeV linac at BNL, which began in 1986, is nearing completion. The centerpiece of the new line is a high-current RFQ linac, which replaces one of two Cockcroft-Walton (C-W) generators in the pre-injector complex. Since several reports describing the status of the project have been published,[1] in this paper we shall give only a brief description of the line and then discuss the most recent work done on it before it was shut down in September, 1988, for installation in the LEBT area. Most of this work concerned the 35 keV beam extraction optics and the performance of the 753 keV line.

Description of the RFQ Preinjector Line

A layout of the line is shown in Fig. 1. The ion source is a magnetron surface plasma source which produces an axially symmetric H^- beam of more than 100 mA at 35 keV. Focusing of this beam into the RFQ is done with two pulsed solenoids. A chopper between the solenoids allows the beam to be better matched to the longitudinal bucket of the AGS.[2] This chopping can be easily done by electrostatic deflection in the low energy part of the beam line. Steering magnets, emittance measuring devices, and beam current transformers are also provided in the line as shown.

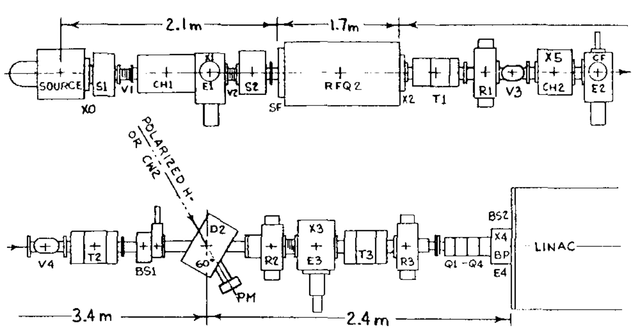

Fig. 1. Layout of the new RFQ preinjector beamline: BP-Beam phase probe; BS-Beam stop; CF-Coaxial Faraday cup; CH-Chopper; D2-Bending magnet; E-Emittance analyzer; Q-Quadrupole; R-RF cavity; S-Solenoid lens; SF-Segmented Faraday cup; T-Quadrupole triplet; V-Vernier steering magnet; X-Beam current transformer; PM-Profile monitor.

RFQ

The RFQ was designed and built at LBL.[3] The design input and output energies are 35 keV and 753 keV, respectively. At 50 mA input, the calculated normalized input and output emittances are 0.11 π cm-mrad and 0.12 π cm-mrad, respectively, and the theoretical transmission is 97%. The operating frequency is 201.25 MHz. Approximately 155 kW of rf power is required for an input current of 50 mA, and this is provided by a power amplifier using an RCA 4616 tetrode in its final stage. Similar units are used as the driver stage the linac tank rf systems.

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753 keV Test Line

For testing, the 753 keV line was assembled as shown in Fig. 1 up to the dipole, D2, after which was a viewing box at location R2. A current transformer, X3, and emittance devices, E3, were mounted in the viewing box. The dipole was reoriented to deflect the beam onto a profile monitor, PM, during studies of the beam energy spread.

Source Studies

The motivation for these studies was the observation that transverse emittances measured at E1 showed wings which indicated the presence of extraction optics aberrations--see Fig. 2a, resulting in a drop in transmission through the RFQ as the beam

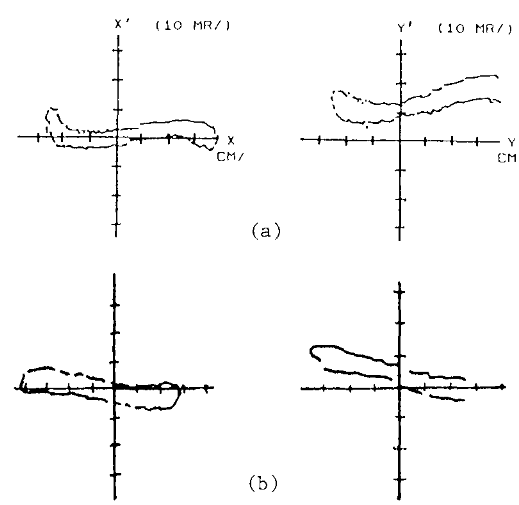

Fig. 2. Emittances measured at E1 in the 35 keV line for (a) ϕ_{anode} = 2 mm, electrode gap = 3 mm (CASE 1), E_n (90%) = 0.11 π cm-mrad; (b) ϕ = 2.8 mm, gap = 3.5 mm (CASE 2), E_n (90%) = 0.11 π cm-mrad (CASE 2); (c) ϕ = 2.8 mm, gap = 4 mm (CASE 3--not shown).

current increased, as shown by the dots in Fig. 3. With the aid of the program BEAM,[4] we were able to generate a transverse phase space plot of the extracted beam on the assumption that it was fully space charge neutralized at a distance of one extractor radius downstream of the extractor aperture. A typical plot is shown in Fig. 4a. Overlaying the plots for ion energies of 120 eV and 1 eV (the cathode potential being 120 V), should crudely account for the directed ion energy distribution. We readily make out aberrations in the phase space plots. The beam in the wings was not matched to the acceptance of the RFQ; hence the low transmission through it.

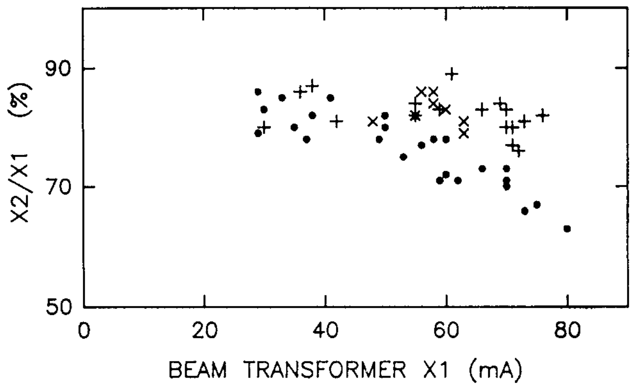

Fig. 3. Transmission through the RFQ vs beam current measured at X1: ● ≡ Case 1; + ≡ Case 2; x ≡ Case 3.

BEAM was then used to study other electrode geometries. The phase space plots for one of these are shown in Fig. 4b. New anode and extractor electrodes based on this design were machined and the magnetron was operated with the two values of electrode gap. Plots of beam current measured at X1 vs extractor voltage for the original structure and the new geometry are shown in Fig. 5. At 35 kV, the original geometry is starting to saturate, whereas emission from the new geometries is still space charge dominated. The measured emittances at E1 for

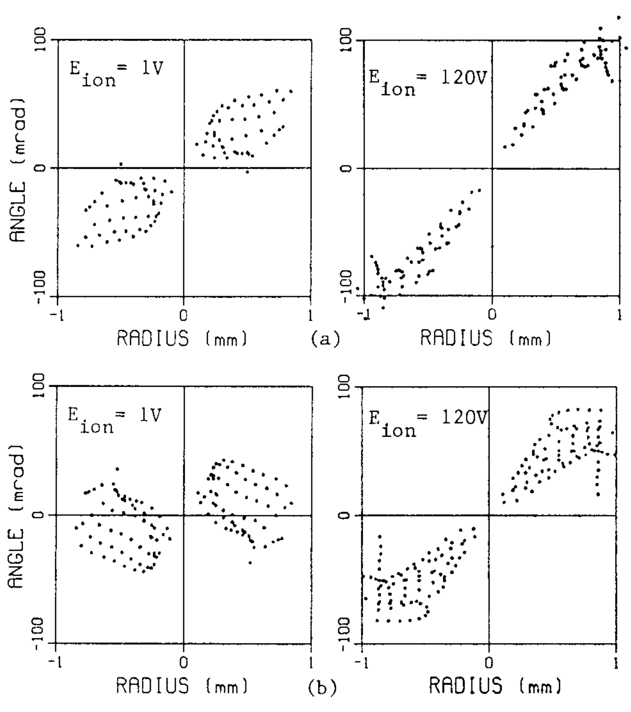

Fig. 4. Transverse phase space plots from BEAM for E_{ion} = 1 eV and 120 eV. (a) Case 1; (b) Case 2.

one of the new geometries are shown in Fig. 2b. The wings are clearly less pronounced for the new design. Transmission through the RFQ is also better with the new design, as shown by the x's and +'s in Fig. 3. Although the extracted beam current is lower with the new design, we obtained more beam out of the RFQ: 60 mA and 85% transmission through the RFQ.

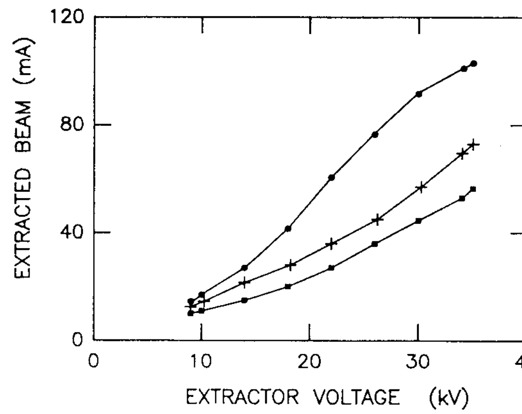

Fig. 5. Current extracted from magnetron, measured at X1, vs extractor voltage. ● = Case 1; + = Case 2; ■ = Case 3.

We shall use the new electrode design with the 3.5 mm gap in the final installation. An additional benefit is that, with the larger gap of 3.5 mm, the source is less prone to arcing.

753 keV Transport Studies

The transmission between the RFQ exit and the end of the line, X2/X3, was found to be in the range 75 ~ 80%, lower than expected. Emittances measured at E2 and E3 were in reasonable agreement with TRACE 3-D[5] calculations. However, the transport from the RFQ to E2 is still not understood. Using the measured beam emittance out of the RFQ (which was in very good agreement with the theoretical predictions), and the gradients of the triplet T1, we do not get a reasonable envelope, and the transverse emittances do not agree with those measured at E2.

To get a better picture of the transmission losses, a current transformer, X5, was installed in the chopper box, CH2. A typical measurement showed 21% loss between X2 and X5, and 9% loss between X5 and X3. The buncher, R1, was then temporarily removed since it was the limiting aperture in the line. The total loss in current between X2 and X3 dropped to 5%. Visual inspection of the input side of the buncher after it was removed from the line confirmed that the beam was hitting it. Indeed, the original TRACE 3-D design of the line shows a beam nearly cylindrical and almost filling the buncher aperture. This problem will be further investigated when the line is operating again.

Emittance Growth

As reported earlier,[1] the normalized emittance of a ~ 50 mA beam entering the RFQ is 0.11 π mm-mrad in both planes, and the emittances measured at the RFQ exit were 0.12 π mm-mrad, also in both planes. More recently, emittances measured at E2 and E3, after the buncher was removed, were also 0.12 π mm-mrad.

An analysis by Weiss[6] of the growth in transverse emittance of a bunched beam traversing an rf gap, which has been incorporated into TRACE 3-D, predicted a growth of more than 100% through R1 in the line. However, our buncher has high transparency grids at the ends of the rf gaps, which are not included in the analysis. After the buncher was tuned for maximum longitudinal focusing at the 50 Ω Faraday cup, CF, beam emittances were measured at E2. An increase of only 10% was observed when the buncher was turned on, leading us to conclude that the grids in the buncher are effectively flattening the electric field in the gaps.

Beam Energy Spread

The design calculations predict that a 50 mA beam exiting the RFQ has an energy spread of ± 14 keV, the full width at the baseline. However, because of the small bunch size at the RFQ exit - an ellipsoid with half-axes of 1.4 mm, 1.4 mm, and 5.5 mm - space charge quickly increases the energy spread. Calculations with TRACE 3-D show that the energy spread is ± 45 keV (and increasing slowly) after 230 cm of transport, coinciding with the center of CH2, where a 1 mm vertical slit was inserted. The triplet T1 was adjusted to produce a waist upstream of the slit so that only 4% of the beam was transmitted, thus reducing subsequent growth in the energy spread due to space charge. A beam profile monitor, PM, was installed at the location of the slit image, 45 cm from the dipole, D2. A calibration of the profile monitor, by measuring the displacement of the profile with a change in magnet current gave a value of 91 keV for the full width of the detector.

Figure 6 shows the energy spread in the beam to be somewhat greater than ± 45 keV, the full width of the profile monitor. The profile narrowed considerably, as expected, when the buncher was turned on.

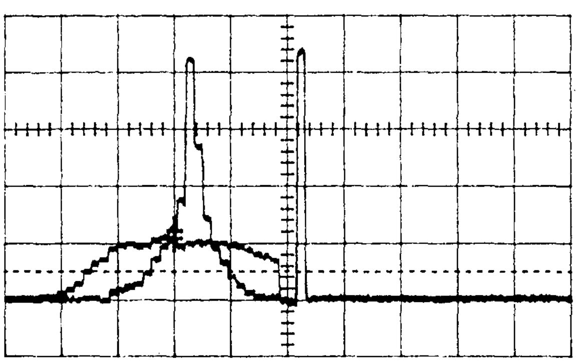

Fig. 6. Beam profile at PM for buncher R1 ON and OFF. 22.5 keV/horizontal division.

Status

Installation of the new LEBT line is now in progress and is expected to be completed around the middle of October. Several months of testing will then follow, and the new preinjector should be ready to provide beam to the AGS for the Physics program in January 1989.

References

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