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H^- SOURCE AND LOW ENERGY TRANSPORT FOR THE BNL RFQ PREINJECTOR*

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SUMMARY

An RFQ has replaced the 750 keV Cockcroft-Walton as the H^- preinjector for the AGS. A magnetron surface-plasma source with a circular aperture is used to produce 65 - 100 mA of H^- at 35 keV with a discharge current of less than 20 A. The circular symmetry of the beam is maintained in the 2 m transport to the RFQ via the use of magnetic solenoids for focusing. Currents of up to 60 mA have been obtained out of the RFQ.

I. INTRODUCTION

Since January 1, 1989, the H^- preinjector for the Brookhaven Alternating Gradient Synchrotron has been a 750 keV RFQ accelerator. The H^- source is a magnetron surface plasma source. There is a 2 meter transport line from the source to the RFQ, containing two focusing solenoids and a fast electrostatic beam chopper. The purpose of the chopper is to reduce beam losses during capture in the AGS by throwing away at 35 keV those particles which would be outside the rf bucket of the AGS. There is a 6 meter transport line from the RFQ to the linac, in order to leave a second H^- preinjector line and a polarized H^- line undisturbed.

To date, this new preinjector has approximately 5000 hours of operation, with only minimal downtime, and a very stable current of 25 mA out of the linac (200 MeV). Details of the RFQ (a 200 MHz, 4-vane type) and 750 keV transport line can be found in Ref. 1. In this paper, some features of the ion source and 35 keV beam transport will be discussed. This section is shown schematically in Fig. 1.

II. H^- SOURCE GEOMETRY

The magnetron surface plasma H^- source was chosen for the RFQ preinjector since we have 6 years of operational experience with this type source[2]. We have found it capable of operating up to 9 months continuously at a 5 Hz rep rate (0.25% duty factor). A similar source is used very successfully at FNAL.[3] Since the RFQ required a symmetric beam at the input, several years ago we began to study its operation with a circular aperture rather than the usual slit aperture. Initial studies included a 90°, n = 1/2 bending magnet after extraction.[4] In subsequent work this magnet was eliminated, and after extraction the beam was injected directly into the transport line, as shown in Fig. 1.

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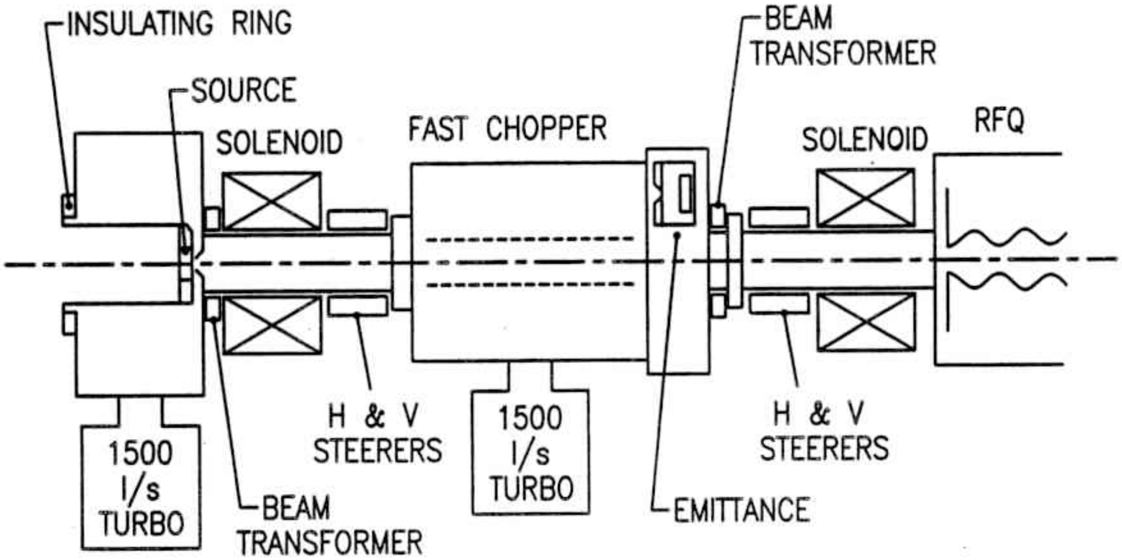

Fig. 1: Schematic of the source and 35 keV transport line.

The main parts of the source are the same as previously used.[2,3] The source operates at a 5 Hz repetition rate, and the gas, discharge, and extraction voltage are all pulsed. The discharge pulse is typically 700 μs, and the 35 kV extractor is pulsed for 500 μs, producing a 500 μs beam pulse. The source is mounted in a reentrant fashion in a vacuum box pumped by a 1500 l/s turbomolecular pump. The only opening between the source chamber and the transport line is the 2 mm diameter extractor aperture. During operation, the pressure in the source vacuum box is typically 4.5 x 10^{-6} T. The source transverse magnetic field is provided by SmCo magnets clamped above and below the source body. This provides a field of $\approx$ 1 kG in the discharge region. The source cathode has a spherical dimple ($r = 6.25$ mm) to geometrically focus the surface produced H^- ions from a large cathode area into the 2.8 mm diameter anode aperture. The extractor electrode has a 2 mm aperture and a 4 mm gap between the anode and extractor. The final geometry used is shown in Fig. 2. In tests, we obtained the best performance (smallest emittance, best match to the RFQ acceptance), with a 3.5 mm gap, but the decision was made to use the 4 mm gap for normal operation in order to reduce the frequency of extractor arcs. With the 4 mm gap, the calculations showed some beam loss on the extractor electrode.

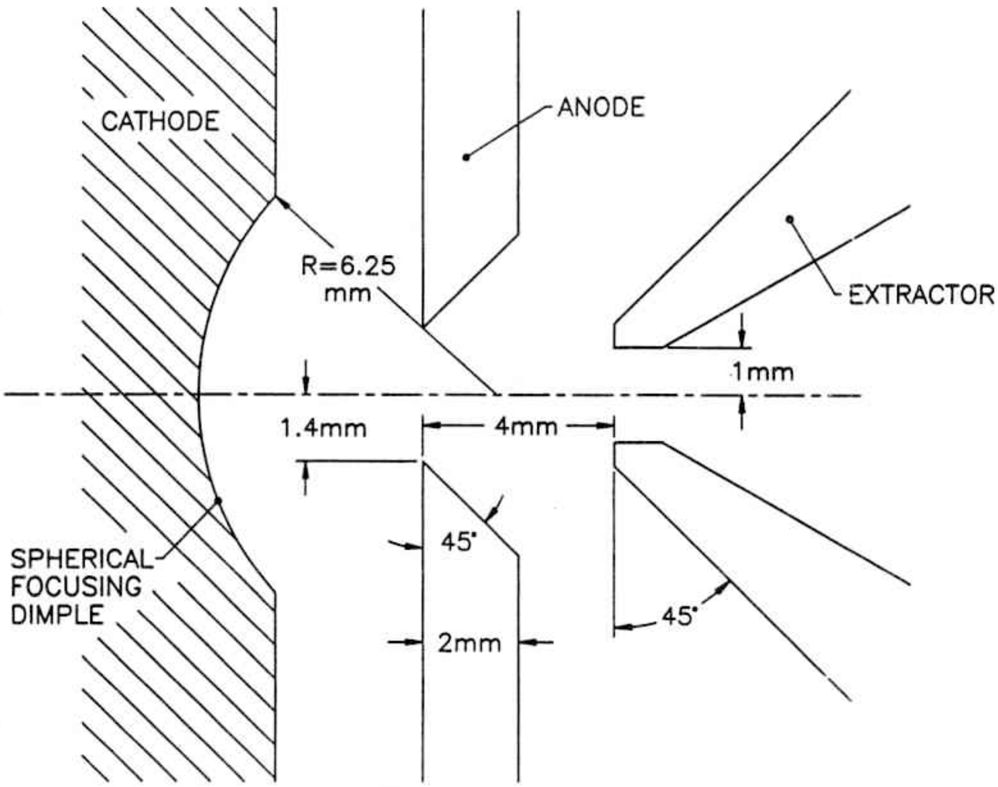

Fig. 2: Source and extractor geometry.

The source magnetic field causes the extracted electrons to be deflected and hit the extractor electrode on one side of the aperture. To reduce erosion, the tip of the extractor is made of tungsten (the bulk of the extractor electrode is made from aluminum). In spite of this, there is still significant erosion of the electrode (a narrow etched line begins to appear within days).

III. THE 35 keV BEAM TRANSPORT

The 35 keV beamline, to transport and match the beam to the RFQ, is shown in Fig. 1. Focusing in the line is provided by two 10 cm diameter, 25 cm long, pulsed magnetic solenoids. The solenoids typically operate at a current of approximately 400 A, where they produce a field of ≈ 3300 G over an effective length of 20 cm. The center of the first solenoid is 23 cm from the extractor, the two solenoids are separated by 150 cm, and the entrance of the RFQ (start of vanes) is 30 cm from the center of the second solenoid. Between the two solenoids there is a fast chopper (see Section V), and horizontal and vertical emittance heads of the slit and collector type.

IV. OPERATION OF THE SOURCE AND TRANSPORT LINE

With the extractor geometry given above, 65 mA of H^- was extracted, which is a current density of 1 A/cm^2. At 35 keV this beam is space charge limited at the extractor, and is very divergent, so not all the beam is captured by the first solenoid. Approximately 55 mA is transported to the middle of the 35 keV line. The emittance taken at this point shows a parallel beam of approximately 7 cm in diameter, which is symmetric in the horizontal and vertical planes. Therefore, the current density over most of the transport line is only 1.5 mA/cm^2. The normalized emittance for 90% beam fraction was approximately 0.12 π cm-mrad. The second solenoid then focuses this beam into the RFQ with a convergence angle of 130 mrad. The output of the RFQ was typically 45 - 50 mA. With a smaller extractor gap we were able to get better transmission through the transport line and RFQ, and currents of up to 60 mA out of the RFQ.

During FY'90 the preinjector ran continuously from January to June. After approximately one month of stable operation at 65 mA, the H^- current out of the source began to increase, and after 6 months was up by 62% to 105 mA. This increase in current occurred with no change in the source discharge, but was rather due to the erosion of the extractor electrode, allowing more beam to pass through the extractor. The divergence of the beam was increasing, however, so the current in the middle of the 35 keV line only increased by 36%, and the current out of the RFQ only increased by 22%. The emittance in the 35 keV line increased to approximately $\epsilon_n(90\%) = 0.14\ \pi$ cm-mrad. Therefore, in spite of the degradation in optics caused by the extractor erosion, we could continue to run and actually gain current as time went on.

The source typically operates at a discharge current of only 15 - 20 A at 150 V. The output is space charge limited, and the discharge current can drop to almost 10 A before the H^- current begins to drop (i.e. becomes emission limited). We operate at a discharge current higher than necessary in order to decrease the sensitivity to slow changes in the discharge, or to variations in the current during the pulse. It also helps keep the source temperature up at this low duty factor. The high efficiency of the source, with an extraction of 100 mA of H^- with only a 20 A, 150 V arc, is part of the reason that it is capable of operating stably for many months. The extracted electron current is generally less than the H^- current. There are approximately 0.5% missed pulses due to extractor arcs. The temperature of the cesium reservoir is typically $\lesssim$ 110° C.

V. FAST BEAM CHOPPER AND SPACE CHARGE EFFECTS

The purpose of the fast beam chopper in the 35 keV line is to dump at low energy those particles which would be lost during capture in the AGS. With this chopper 2.5 MHz beam bunches can be produced, with the width and phase of each bunch being individually programmable to match the moving rf buckets in the AGS during multiturn injection. Details of the use of this chopper have been given elsewhere[5], and in this section we will comment on its effect on the 35 keV beam.

The chopper is a pulsed electrostatic deflector, where voltages of ± 760 V are applied to plates above and below the beam to deflect the beam outside the opening of a 1.4 cm diameter aperture at the entrance to the RFQ. The chopper has a total length of 38 cm, and a separation between the upper and lower plates of 8 cm. At 35 keV, the flight time of the beam through the chopper is 150 ns. The chopper is therefore made up of 15 pairs of plates over the 38 cm length, which are connected as a slow-wave structure by coaxial cables, so that the voltage pulse travels plate-to-plate at the beam velocity. The chopper plates are powered by a pair of commercial high voltage pulse generators[6] having rise and fall times of less than 10 ns. They are driven by a digital delay generator.

Rise and fall times on the beam pulses of 10 ns are obtained. The minimum pulse width is approximately 80 ns, limited by the high voltage pulsers. Under normal operation (unchopped beam), the H^- beam is space charge neutralized in the transport line by ionization of residual gas. With the typical pressure in the transport line of 10^{-6} Torr, the neutralization time is approximately 50 μs. When the chopper voltage is applied for microseconds or longer, the neutralizing ions are swept out of the beam and the beam becomes very divergent due to space charge blowup. The result is that a much higher voltage than what one might at first expect is required to completely reject the beam before the RFQ. From studies of the beam current out of the RFQ as a function of dc voltage on the chopper, and comparisons with calculations of the beam optics in the 35 keV line under various space charge conditions, it appears that neutralization is lost only in the region between the chopper plates. This is supported by the fact that when biased grids were installed to create potential barriers at the entrance and exit of the chopper it had no effect on the performance.

A typical operation of the chopper for testing was a string of voltage pulses with 200 ns on time and 200 ns off time, for the 500 μs beam pulse. Beam is transported through the RFQ when the voltage is off, so there are no aberrations on the beam from imperfections in the electrostatic fields in the chopper region. In spite of this, emittances measured in the 35 keV line showed a distortion when the chopper was used. (The sample time of the emittance is greater than the 2.5 MHz chopping frequency, so one can observe both the deflected and undeflected beam emittances, separated in the y′ plane in the emittance plot). The explanation for the distortion seems to be the following. The 200 ns voltage on-time is not long enough to sweep away the neutralizing ions, but merely displaces them relative to the H^- beam. When the voltage goes off, the restoring force between the H^- beam and these displaced positive ions gives a kick to the H^- beam in a direction opposite to the direction that the chopper deflects the beam. In addition, due to the displacement of the neutralizing ions, a portion of the H^- beam is unneutralized, and therefore becomes divergent. Both these effects are observed on the emittance. This distortion of the emittance decreases/increases as the voltage-on time decreases/increases at the 2.5 MHz frequency. When operating with the chopper, the 35 keV line can be retuned to partially compensate for this distortion, but the full intensity out of the RFQ cannot be recovered. The net effect can be a loss of 25 - 50% of the beam current out of the RFQ. Because of this loss, we plan to install a fast chopper in the 750 keV line to replace the 35 keV chopper.

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