STATUS OF THE NEW HIGH INTENSITY H^- INJECTOR AT LAMPF

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Introduction

The requirement for higher intensity H^- ion beams for the proton storage ring now being constructed at LAMPF necessitated the development of a new H^- ion source and the rebuilding of the original H^- injector and its associated beam transport lines. The goal of the ion source development program was to produce an H^- beam with a peak intensity of 20 mA at 10% duty factor and with a beam emittance of less than 0.08 cm-mrad normalized at 95% beam fraction. The ion source concept which was best suited to our requirements was the multicusp, surface-production source developed for neutral beam injectors at Berkeley by Ehlers and Leung.[1] An accelerator version of this source has been subsequently developed at Los Alamos to meet these storage ring requirements. The use of these higher intensity H^- beams, together with the more stringent chopping and bunching requirements entailed in the operation of the storage ring, now requires rebuilding the entire H^- injector at LAMPF. This construction is in progress. It is anticipated that the new injector will be fully operational by the end of 1984 and that the required H^- beams will be available for the operation of the storage ring in early 1985.

Ion Source Development Program

The development program for the new H^- ion source was carried out on the high-voltage test stand in the injector complex at LAMPF.[2] This test stand permits production of high-voltage ion beams up to 100 kV from prototype ion sources and provides the capability of both intensity and emittance measurements for both unanalyzed and mass-analyzed beams. A series of prototype sources were built and tested; detailed studies of the dependence of the beam intensity and emittance on the source operating parameters were carried out.[3,4] The final design is shown in Fig. 1.

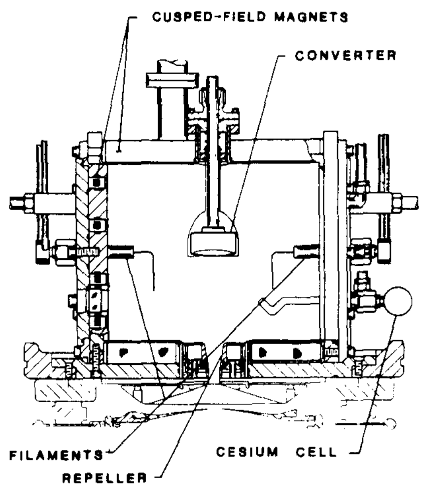

Fig. 1 The multicusp, surface-production source

The source employs a cylindrical, stainless steel housing with ten rows of magnets arranged on the outer cylindrical surface. Four rows of magnets are placed in each of the end plates to form a full-line cusp geometry with eight of the ten rows on the cylindrical surface. The source is sufficiently large (20 cm dia x 23 cm long) to accommodate converters up to 5 cm in diameter in a magnetic field-free region at the center of the source. Two tungsten filaments (.15 cm diameter x 17 cm long) mounted in the end plates provide the primary electrons to produce the arc discharge. Water cooling is provided to the filament holders, endplates, the repeller and converter electrodes, and the magnets. The source housing is cooled only indirectly by contact with the magnet holders; the source housing typically runs at 40°C.

The H^- ion beam is extracted through a break in the cusp field confinement geometry in the center of the cylindrical housing. A section of a line-cusp magnet has been removed and replaced with two similar magnets which are placed above and below the removed portion as shown in Fig. 2. This magnet arrangement essentially retains the plasma confinement geometry, but forms a dipole cusped field in the extraction region which rejects most of the secondary electrons formed on the converter while permitting extraction of the ion beam. These dipole cusped magnets are housed inside a cooled, insulated structure called the plasma repeller electrode. When this electrode is biased several volts positive with respect to the anode housing, significant reduction in the density of plasma electrons in the extraction region can be effected. The ion beam is sheared slightly in the horizontal plane as it traverses the dipole cusped field. However, since the beam is much larger than the extraction aperture, this shearing action does not affect the x-y symmetry of the extracted beam and only introduces a few percent emittance growth in the horizontal plane.

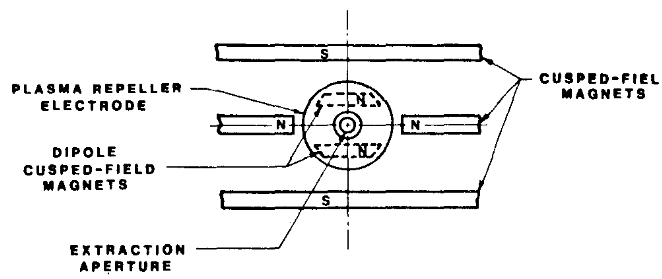

Fig. 2 The dipole, cusped-field magnet arrangement

Since the beam requirements at LAMPF entail relatively moderate peak currents (20 mA), the development effort centered on increasing beam brightness at a constant extracted beam current. It was quickly found that the emittance of the extracted beam was almost completely determined by the geometrical admittance of the ion source, i.e., the ion beam produced on the surface of the converter electrode has sufficiently large emittance to fill completely the phase space region determined by the aperture stops of the source. Thus, the desired beam emittance basically determines the geometry of the source. The final design of the source we have developed employs a 3.81 cm diameter converter which is located 12.62 cm from a 1.0 cm diameter plasma aperture at the first extraction gap. The geometrical admittance prediction for the beam emittance as a function of converter voltage is shown in Fig. 3 together with some experimental data for 20 mA beams. In our application, operation is generally carried out at as low a converter voltage as is consistent with obtaining the desired 20 mA beam current, since this results in the brightest beams.

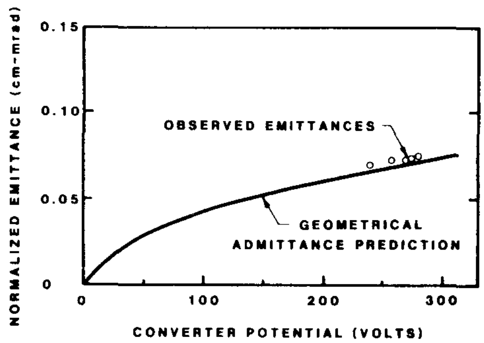

Fig. 3 Normalized emittance vs converter voltage

Ion Source Operation

The ion source is operated in a DC mode except for the arc, which is pulsed with a transistor modulator in series with a suitable high-voltage arc supply and a 4.3 ohm ballast resistor. This arrangement puts a large high-voltage spike on the arc initially and permits a rapid turnon (50 μsec) of the discharge. The arc voltage quickly relaxes to ~100 volts for 60A arc current. The extracted beam current exhibits some falloff (~5%) for long pulse (800 μ sec) operation which is presumed to be due primarily to depletion of Cs on the converter, but is not a serious problem in our application. This behavior is consistent with the hypothesis that the cesium loading of the converter occurs primarily while the arc is off. We find that 20 mA beams can be obtained at ~250 volts converter voltage with a cesium flow rate of 0.03 grams/hour and a hydrogen flow rate of 2 atm cc/min, and that the beam emittance is only slightly larger than the geometrical admittance prediction (0.07 cm-mrad). An emittance scan taken for a 94 keV beam is shown in Fig. 4. The emittance data were reanalyzed on line with the LAMPF control computer and the dependence of the emittance on the beam fraction for this 20 mA beam was determined (Fig. 4). This dependence of emittance with beam fraction is consistent with a Gaussian model for the emittance distribution function in phase space.[5] The ion beam temperature obtained from this model when referred to the plasma aperture is 2.6 eV. It should be noted that this temperature is not the sputter ion temperature at the converter surface, which has been measured to be over 5 eV at this converter voltage. The ion source acts as an emittance filter and only those H^- ions with sufficiently small transverse velocity components can in fact be extracted.

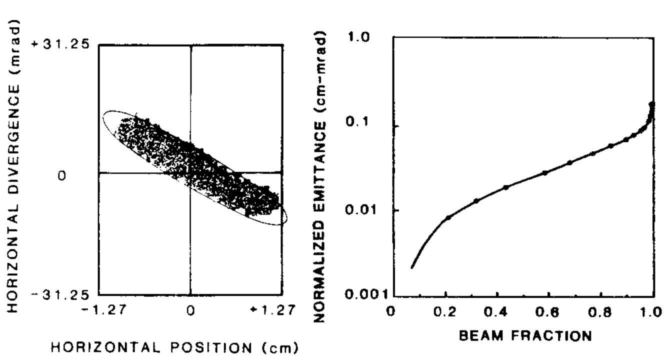

Fig. 4 Emittance Measurement for a 20 mA, 94 keV H^- Beam
(a) Emittance Scan
(b) Normalized Emittance vs Beam Fraction

The H^- yield from the converter will depend on Cs flow rate and higher beam currents can indeed be obtained at higher Cs flow rates and correspondingly higher converter voltages.[3] Unfortunately, the brightest operation occurs at lower converter voltages and thus lower extracted beam currents. Recent developments of volume-production sources are sufficiently promising to consider their use in this application in the future and thus eliminate the problems inherent in the use of cesium.[6]

Investigations have also been carried out to study the dependence of the H^- yield on other ion source parameters. It has been found that the yield is relatively insensitive to arc voltage at a given arc current over the range of arc voltages from 70 to 160 volts, i.e., we are running in an emission-limited mode. The surface roughness of the converter also has little effect on H^- yield. Different converter materials do appear to give different yields. The yield from a niobium converter was significantly higher than that from a molybdenum converter operated under the same conditions and at an extracted beam intensity of 20 mA, the beam produced from the niobium converter was 1.5 times as bright as that from a molybdenum converter.[3] The niobium converter, however, experienced significant spalling and general surface deterioration after several days of operation. For long-term operation, molybdenum still appears to be the best converter material because of its resistance to sputtering.

Several lifetime tests have been carried out on this source. The present lifetime is ~200 hours and is primarily limited by thermal evaporation of the tungsten filaments. In order to obtain operation with 60 amperes of arc current, the filaments are operated at ~2780°K. Burnout occurs at the center of the filaments shortly after a 6% reduction in filament diameter occurs. The time dependence of the change in resistance of the filaments appears to be larger than predictions based only on thermal evaporation and thus there is evidence of some plasma sputtering at our 10% duty factor. Work is currently in progress to determine the relative contributions of thermal evaporation and plasma sputtering to the filament lifetime. It is anticipated that the overall source lifetime will be in excess of two weeks for continuous operation.

Beam Transport and Injector Considerations

As indicated previously, the multicusp H^- ion source will produce large currents of electrons unless appropriate rejection measures are incorporated into its design. Our present source design produces an electron current which is 25% of the ion current. Although this electron loading is not a serious high voltage problem for the low voltage extraction of the H^- beam, it would be a potent source of x rays at our final operating voltage 750 kV. This consideration, together with our desire to retain the existing injector high-voltage column, led us to employ a two-stage acceleration system with an appropriate beam transport system between the two stages. In our present design, we will employ 100 kV in the first stage and 650 kV in the second stage to give the final beam energy of 750 keV. The use of such a beam transport line will not only permit mass analysis to reject the electrons, but will also provide the necessary diagnostics for tuning the system.

The ion source and its associated power supplies and control systems will be housed in a 3.4m x 4.6m x 3.4m Cockcroft-Walton high-voltage equipment dome. The details of the beam transport system together with the design beam profiles are shown in Fig. 5. The transport line is 3.3 m long and employs two solenoid focusing lenses, several steering magnets, and a 4.5° bending magnet to effect the desired mass analysis.

The use of solenoid lenses maintains the circular symmetry of the ion beam and permits a relatively simple two-knob tuning of the beam line. However, since solenoids are second order lenses, some care must be taken in the beam optics to insure that no significant phase space distortions are introduced into the beam. Computer simulations were carried out using a macro-particle transport code SCHAR[7] to determine the proper tune for this beam line. It was established that the emittance growth would be limited to a few percent of the present beam emittance for tunes which entailed beam sizes in the lenses of less than one-third the aperture of the lens. Simulations were also carried out to study the effect of position and angular misalignments of the beam axis with the lens axis. Tolerances of 0.5 mm and 2 mrad were found to be sufficient to preclude significant emittance growth.

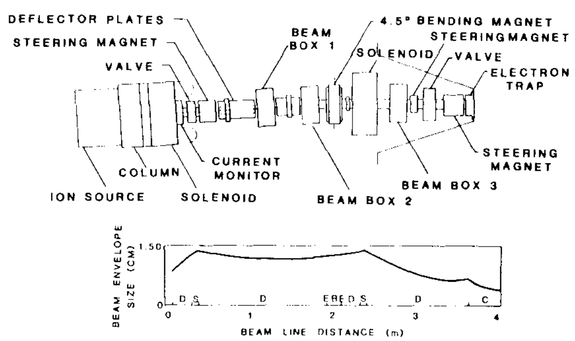

Fig. 5 Equipment Dome beam transport line

Beam emittance studies were then carried out on the high voltage test stand to investigate these questions with the actual H^- beams that would be used. For properly tuned beams, we obtain phase space distribution with the expected parallelogram shape, but when the beam size in the solenoid lens was increased to over one-half of the aperture, wing structures characteristic of spherical aberration appeared as shown in Fig. 6.

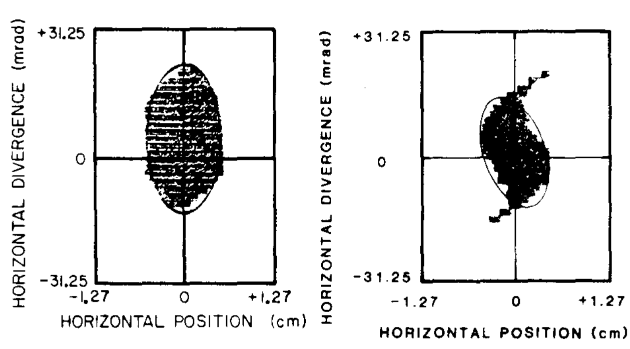

Fig. 6 Emittance Scans for 84 keV H^- Beams
(a) small beam in solenoid lens
(b) large beam in solenoid lens

The optics for the 750-keV beam transport system requires a small, slightly divergent beam at the exit of the main accelerating column. In order to achieve such a beam and still preserve a relatively small peak to-valley ratio in the equipment dome beam line, a beam energy of 100 keV has been employed in the first acceleration stage.

The tuning needed in the equipment dome beam line to achieve a given beam at the exit of the 650-kV accelerating column can best be displayed by plotting an α-β tuning diagram at the injector column exit for a given input beam, as shown in Fig. 7. Each line in this diagram is the locus of points in α-β space for a constant excitation of the first lens with variable excitation of the second lens, where α and β are the Courant-Snyder ellipse parameters. In this plot we see that, for the input beam assumed and the lens spacing employed, there is an inaccessible region in α-β space for positive α and an aberration limit determined by beam size in the second lens for negative α, but there is a region near α=0 where acceptable tunes can be achieved which will match the acceptance of the 750 keV beam line.

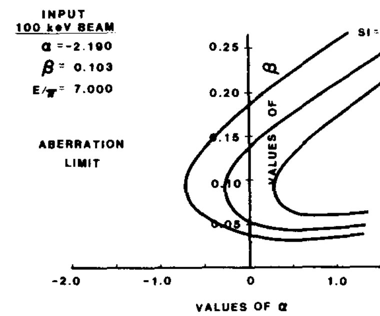

Fig. 7 The tuning diagram for the input beam to the 750-kV beam line

Conclusions

The multicusp surface-production H^- ion source is now capable of producing accelerator-quality beams with the reliability and lifetime needed for continuous accelerator operation. The source that has been developed at LAMPF is optimized for high brightness at relatively moderate beam currents; higher current operation can be obtained with some sacrifice in brightness. The use of such a source at a very high duty factor or in DC operation is presently somewhat impaired by the loss of cesium on the converter, but the present design is quite adequate for operation up to 10% duty factor.

References

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