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A CUSPED FIELD H^- ION SOURCE FOR LAMPF

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Introduction

The addition of the Proton storage Ring to LAMPF requires the development of a more intense H^- ion source. The goals of this development program are to produce a beam of sufficient quality to match the acceptance of the accelerator and sufficient intensity, quality, and duty factor to satisfy the operation of PSR as as well as existing LAMPF requirements. The ion source concept which is best suited to these requirements is the multi-cusp negative ion source being developed at LBL by Ehlers and Leung.[1] This source has been shown to produce high quality beams of moderate current density (20 mA/cm^2). However, to produce an accelerator quality H^- ion source, additional development is required in the area of high-voltage extraction of high-brightness beams.

Ion Source Test Stand

The H^- ion source development was carried out on the high-voltage test stand in the LAMPF injector complex.[2] This test stand was upgraded for this program with a larger high-voltage power supply (200 kV at 7.0 mA), a higher power isolation transformer (50 kVA), and more high-voltage racks. Modifications were also made to the accelerating column to accept the larger H^- ion source. Most of the beam tests have been carried out between 50 to 90 kV with only a few milliamperes DC current drain. The high-voltage limitation on the test stand is now approximately 90 kV due to external flashover from the larger ion source shroud to the test stand frame, but this is not a serious limitation since 80 kV operation has been found to be adequate to transport the required H^- beams. A layout of the general features of this test stand is shown in Fig 1.

The test stand basically provides both unanalyzed and mass-analyzed beams to appropriate emittance scanning stations. The beam transport line also has several beam diagnostic ports that permit visual observation of the beam spot on viewing screens in addition to emittance scanners. Beam currents are measured using both beam current toroids and biased Faraday cups in both the analyzed and unanalyzed sections of the transport line. The beam current monitors have been calibrated using the LAMPF H^+ duoplasmatron and the absolute accuracy of the beam current measurements is better than 3%. The 45° analyzing magnet and solenoid lens are capable of providing mass analysis up to mass 32 (for 20 keV beams). This capability has been used to measure the ion impurity spectrum of the H^- beam, which typically is only a few percent of the total extracted ion current. The principal impurities observed are O^-, OH^-, and O_2^- ions.

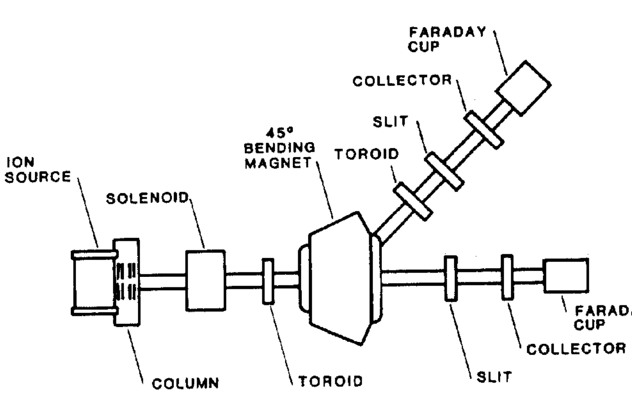

Fig. 1. Schematic Layout of Test Stand

Although the test stand is capable of supporting appreciable electron loading, the normal operation of this source entails electron currents of less than 20% of the H^- ion current. Some lead shielding on the transport line (45° analyzing magnet) together with lead glass viewing ports have been necessary to limit x-ray exposure dose when operating at higher voltages.

After the H^- ions are extracted from the accelerating column, the beam is focused with a large aperture solenoid lens, and subsequently transported to one of the two emittance stations. The emittance scanners are conventional slit and collector systems with spatial resolution of 0.2 mm and angular resolution of 1.5 mrad. The emittance data are processed by the SEL 840 control computer at LAMPF and on-line, reanalyzed emittance scans are provided to the test stand. There is still some uncertainty in the absolute accuracy of these measurements because of problems associated with bias voltages on the collectors. In order to operate on a plateau in collector sensitivity and to avoid hollow beam effects, the collectors have to be biased between -50 and -150 volts. There is then as much as a 50% increase in the observed emittance over the zero bias case.

Extraction Optics

The ion source testing on the high-voltage test stand has been carried out using the extraction optics originally developed for the LAMPF duoplasmatron. Since the H^- sources being tested have significantly lower extracted current density, there was a large perveance mismatch and appropriate modifications had to be made to the first extraction gap. These modifications were adequate to carry out the initial phase of the development program, but the ion optics now need to be optimized. These optics questions are being addressed by means of the plasma simulation code SNOW which was developed at Sandia.[3] The results obtained for circular beams in a self-focused geometry are similar to those found by Anderson for slot beams.[4] A typical SNOW simulation for our accelerating column is shown in Fig. 2. This simulation is really for an H^+ beam with an initial energy given by the converter potential. The validity of using this model to represent the H^- beams in our source has not yet been established, but the simulation is useful in guiding the design of the accelerating column. The model does predict the onset of beam impingement on the extractor electrode and, to the precision of experimental emittance measurements, predicts the proper beam envelope parameters of the 80 kV beam. The accelerating column design will seek to minimize the divergence of the extracted beam and the predictions from SNOW will be tested on the high voltage-test stand with actual H^- beams.

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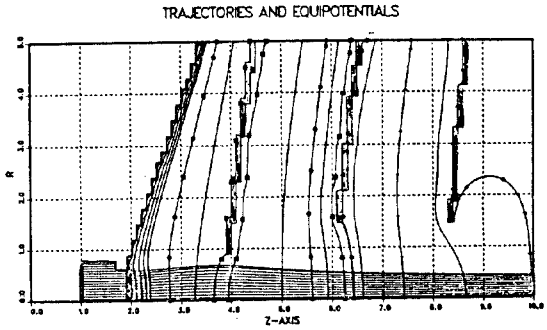

Fig. 2. SNOW Simulation for the 80 kV Column

Ion Source Development

The development program to date has been concentrated on two basic multi-cusp field designs. The first design was round multi-cusp geometry (17.8 cm diameter × 12.8 cm long) with twelve Alnico-8 bar magnets placed around the sides and back of the source housing. In this design the self-extracted H^- beam emerges from the end of the source rather than the side as in the Berkeley design. The source housing was made of copper, and the cusp-field magnets were inserted in cooling channels which were machined in the housing. The steady-state hydrogen plasma was generated by primary electrons (80 to 90 eV) emitted from two 0.15 cm diameter tungsten filaments, 20.5 cm in effective length, and wound in a configuration which minimizes the magnetic field at the converter. Several extraction geometries were tried using this source. In the original design a simple magnetic dipole (126-Gauss-cm strength) was used to suppress extraction of electrons. In the final design a front plate containing twelve magnets fanning out from the center of the source was employed in order to form a full-line cusp geometry with the magnets on the side of the source. This design did result in a substantial increase in arc current and plasma density, but only on a modest increase in extracted H^- ion current.

This source was operated with a DC arc but pulsed converter voltage to yield the desired duty factor. Under these conditions, the source produced reproducible 8 mA_p H^- beams with an emittance of 0.05 cm-mrad normalized.* These results were obtained with a 2.54 cm diameter spherical cap converter and a flight path of 8.25 cm to a 0.64 cm diameter extraction aperture in the plasma electrode. These parameters determine the geometrical admittance of the source which was chosen to limit the emittance of the extracted ion beam to the desired value. Tests were then conducted with a 5.08 cm diameter converter in order to increase the beam intensity. It was found, however, that the use of the such a large converter in this design severely limited the arc current and no further testing was done with this source.

Another prototype ion source, similar to the Berkeley source, was then designed in order to accommodate larger converters and still achieve high plasma densities. This design employs a cylindrical geometry with ten Alnico-8 magnets mounted around the cylinder and in the endplates as shown in Fig. 3. Langmuir probe studies of the two source designs show that the

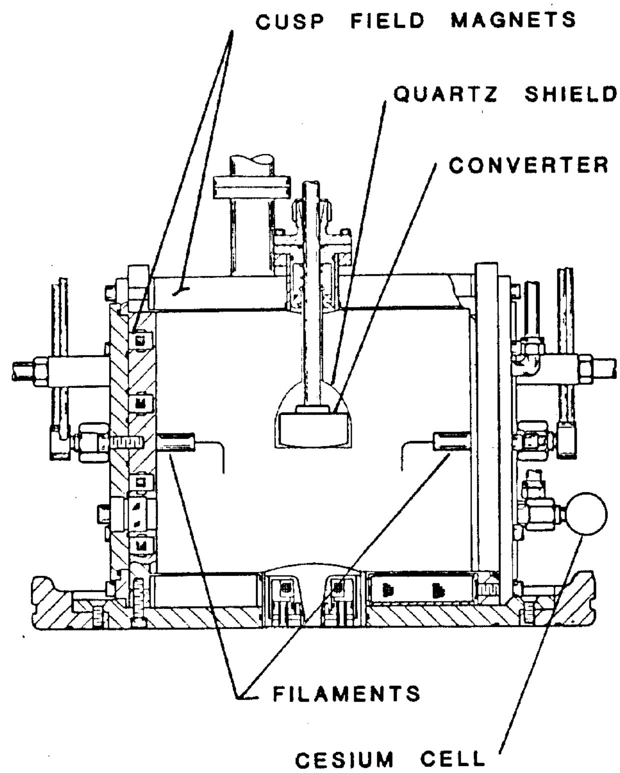

Fig. 3. Cylindrical Protype Source

new prototype has slightly larger plasma density than the first prototype (3 instead of 2×10^{12} cm^{-3}). The ion beam in the new prototype is extracted through a break in cusp-field geometry; magnets are positioned above and below the extraction aperture in a symmetric manner to minimize plasma loss area and to provide an essentially field-free region for beam extraction. Using this extraction system, this prototype source has produced up to 20 mA_p H^- beams at 10% duty factor of sufficient quality that they could be mass analyzed and transported a distance of 2 meters to an emittance scanner with no transmission loss. An emittance scan of this beam is shown in Fig. 4.

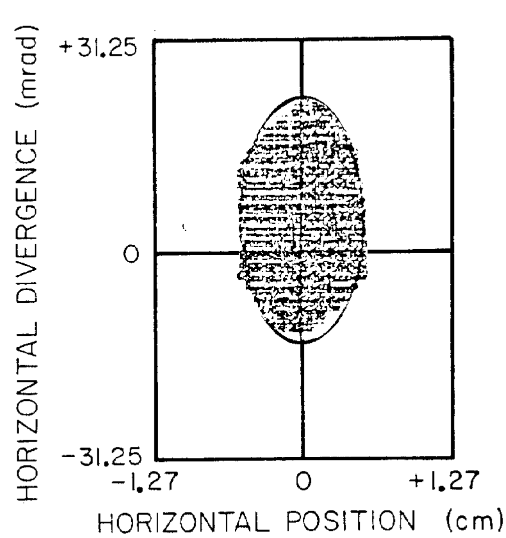

Fig. 4. Emittance Scan for a 88 kV, 20 mA_p, H^- Beam

*Normalized Emittance = $\frac{\text{Phase Space Area}}{\pi}\beta\gamma$

The measured emittance values for this source are somewhat higher than those estimated from consideration of the geometrical admittance of the source (154 π cm-mrad) as shown in Fig. 5. This source has been operated under both pulsed and DC arc conditions; similar beams were obtained in both modes.

Emittance Studies

During the initial tests with these sources, the emittance distributions exhibited significant filamention. A typical example of the early data is shown in Fig. 6 where large wing structures are present at the edge of the beam. These structures were also observed for low-current beams and hence are attributed to optical aberrations rather than space change effects. The beams produced with the cylindrical prototype source exhibited less aberrations at the same beam current. In Fig. 7. an emittance scan of a 12 mA_p, 68 kV H^- beam is presented which has smaller filamention than the previous 13 mAp beam (Fig. 6). However, as the beam current was raised, the filamention again increased.

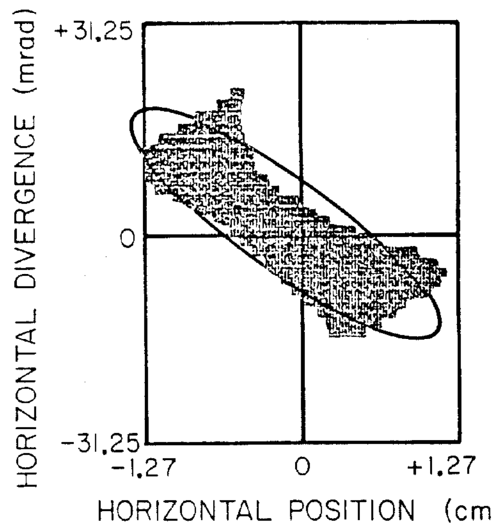

Fig. 7. Emittance Scan for a 12 mA_p, 68 kV H^- Beam

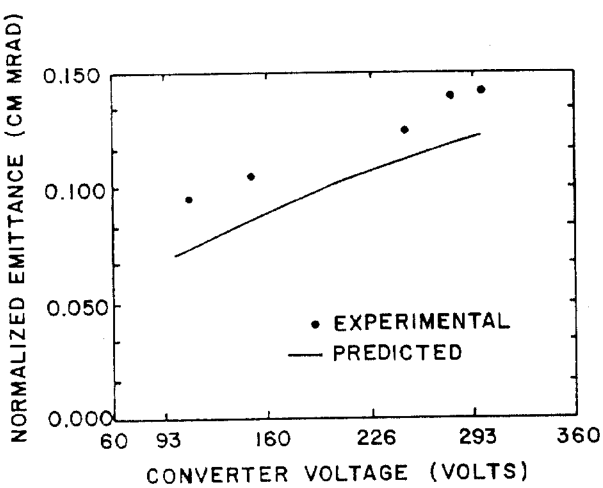

Fig. 5. Normalized Emittance vs Converter Voltage

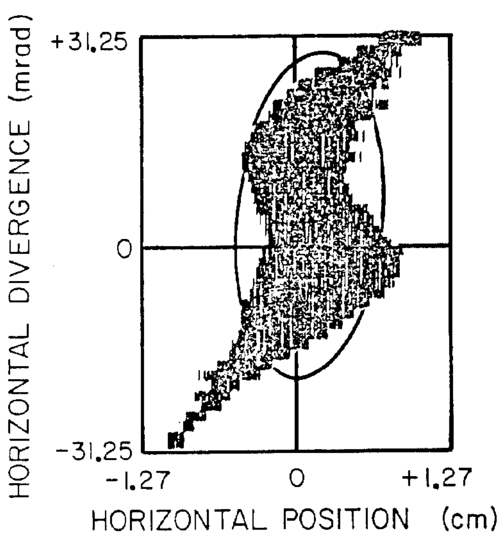

Fig. 6. Emittance Scan for a 13 mA_p, 50 kV H^- Beam

Modifications were made both in the ion source and in the accelerating column to improve the extraction optics and subsequent tests produced 20 mA_p beams with much less filamention. In Fig. 4 an emittance scan of a 20 mA_p, 88 kV, H^- beam is presented with the expected parallelogram shape in phase space. The normalized emittance of this beam is 0.13 cm mrad while the expected emittance under these conditions is 0.12 cm mrad. Thus, beam aberrations are not expected to be a serious problem for these beams.

Conclusions

A self focused, cusped-field H^- ion source has been developed which produces up to 20 mA_p H^- current at 10% duty factor with a normalized emittance of 0.13 cm mrad. This source produces quiet beams with only a few percent impurity ion current and less than 20% electron loading. Further development work is still needed to meet the design requirements for the proton storage ring application.

References

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