# PERFORMANCE AND STATUS OF THE IUCF HIGH INTENSITY POLARIZED ION SOURCE

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## ABSTRACT

The IUCF High Intensity Polarized Ion Source has been completed and is being tested before its installation in a new terminal scheduled for September of this year. The design is based on the source in operation at TUNL, which employs cold (~30 K) atomic beam technology and an electron cyclotron resonance ionizer. It is expected to produce 100μA DC $\vec{H}^+$ and $\vec{D}^+$ ion beams with a polarization of 75% or greater. Coupled with a wideband and resonant bunching system and a high-transmission beam line into the injector cyclotron, the source should allow $10^{10}$ protons to be stored in the electron cooled storage ring in a few seconds. Results from operation of the source and studies of atomic beam properties will be described.

## 1. INTRODUCTION

A major fraction of the experimental program at the Indiana University Cyclotron Facility (IUCF) has always concentrated on studies of spin degrees of freedom. Most recently, the first data with low intensity polarized beam on an internal polarized $^3\vec{He}$ target has been taken with the IUCF Cooler ring[1]. To further enhance the unique opportunities in spin physics research using the Cooler ring, circulating beam intensities near the limit of ring operation, $10^{16}$ particles/sec, are required because target densities and/or reaction cross sections are very low.

In order to meet these experimental requirements a modern, high intensity source of polarized ions has been constructed. The source, which will be coupled by a high-

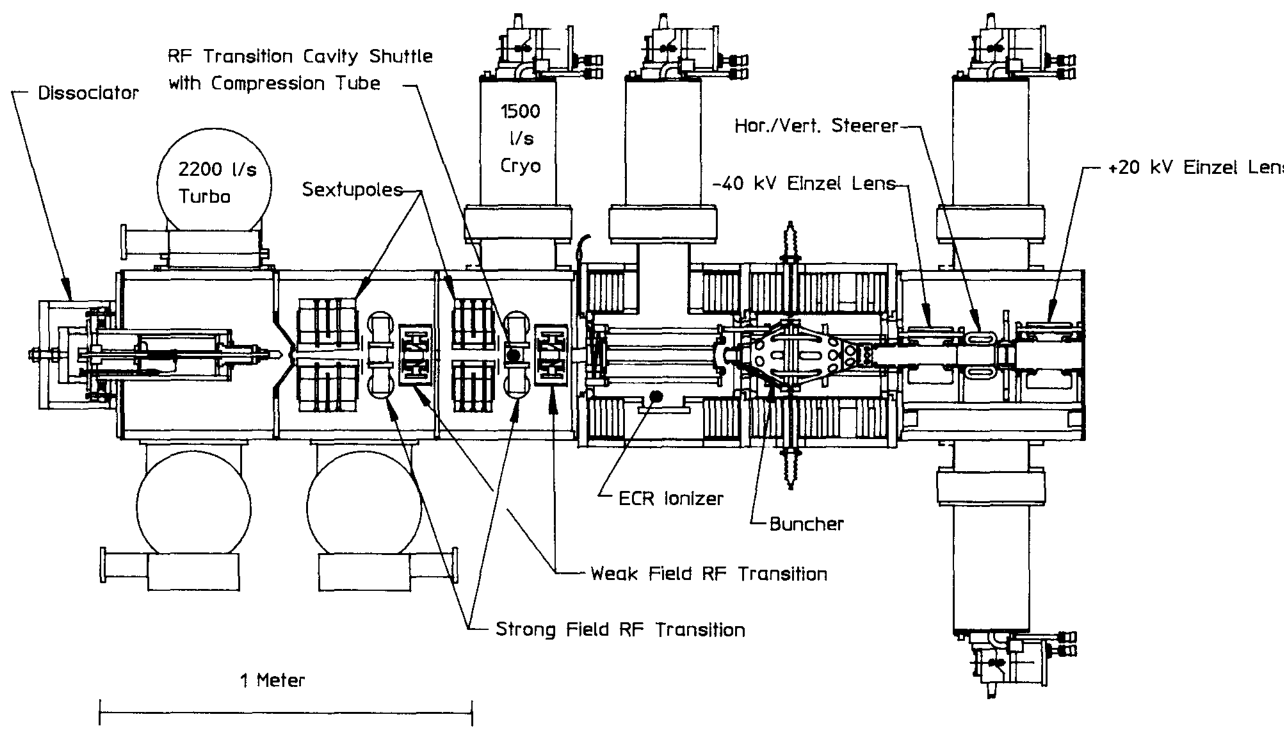


**Fig. 1** General layout of the IUCF High Intensity Polarized Ion Source showing the atomic beam section, ECR ionizer and the low energy, high efficiency bunching system. The source is now complete as shown and is being commissioned off line.

efficiency bunching system and a high-transmission beam line[2] to the first cyclotron, should allow $10^{10}$ protons to be stored in the Cooler ring in a few seconds.

The High Intensity Polarized Ion Source (HIPIOS)[3] built at IUCF is illustrated in Fig. 1. It is similar to the system recently built and brought into successful operation at TUNL by T.B. Clegg and associates.[4] Based on TUNL's experience, HIPIOS should produce in excess of 100 μA DC, $\vec{H}^+$ and $\vec{D}^+$ ion beams. The atomic beam section, which employs cold (~30 K) atomic beam technology, is a close copy of the TUNL design. The ionizer is an electron cyclotron resonance (ECR) device similar to those used at TUNL, PSI and Bonn for ionization of polarized atomic beam.

This paper describes the recent operating experience with the completed ion source and the status of the ion source installation in the new high voltage terminal.

## 2. OPERATION OF THE ATOMIC BEAM SECTION

### 2.1. Velocity Measurements

Measurements of atomic and molecular beam velocities with W. Gruebler's (ETH) atomic beam chopper allowed us to gain considerable experience during the initial operation of the dissociator. The beam velocity distribution was measured while operating the dissociator using different nozzle temperatures, flow rates, RF power levels and types of gas. This data[5] is consistent with the velocities measured by W. Gruebler et al. when different dissociator operating conditions are taken into account. Figure 2 shows plots for atomic hydrogen for different nozzle temperatures.

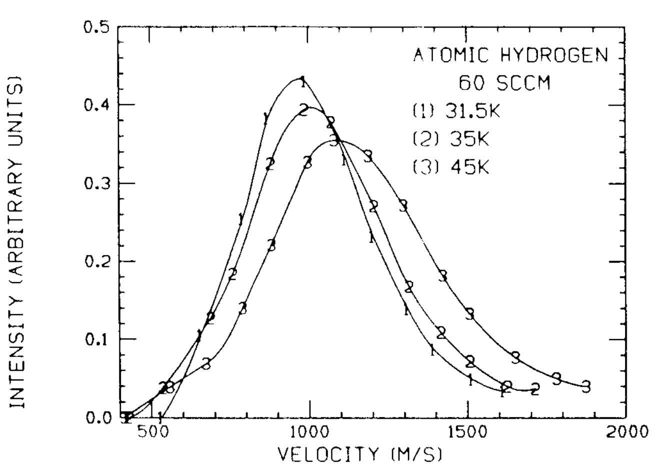


**Fig. 2** Velocity distributions for atomic hydrogen for different nozzle temperatures. Relative beam intensities between distributions is arbitrary and not a true comparison.

### 2.2. Flux Measurements

For measuring the atomic beam flux from the dissociator, the TUNL design for a compression tube was used with changes suggested by W. Haeberli et al. The Bayard-Alpert gauge previously used to measure pressure changes in the compression tube was replaced with a cold cathode gauge in order to eliminate systematic changes dependent on exposure to $H_2$.

Beam fluxes from $3x10^{14}$ to $1.5x10^{15}$ atoms/sec were measured at the end of the second sextupole chamber with both sextupole chambers empty. A range of flow rates and nozzle temperatures were investigated. These measurements when compared with those with the sextupoles installed, showed little evidence of beam attenuation due to their aperture. The peak intensity was observed with 210 Amps applied to sextupole #1, which corresponds to an integrated pole tip field of 108 kG-cm. The integrated pole tip field in sextupole #2 with 200 Amps applied is 60 kG-cm. Maximum beam intensity observed was on the order of $1.0x10^{16}$ $sec^{-1}$.

A smaller compression tube has been added to the sextupole #2 chamber RF transition shuttle in order to allow for atomic beam measurements with the source in operation. This tube has not been calibrated, but the relative pressure differential is extremely useful for optimizing the atomic beam flux density in the ECR ionizer. The maximum $\Delta P$ observed to date is $8.0x10^{-6}$ Torr, corresponding to a sextupole power of 12 for atomic beam measured with sextupoles on versus sextupoles off.

### 2.3. Operating Experience and Improvements

Temperature of the cold nozzle is regulated by a heater mounted on the clamp that holds the nozzle in place against the accomodator. A copper braid leads from this clamp to the He refrigerator cold head. Modifying the heater mount in order to more evenly heat the nozzle has improved temperature stability and reproducibility of atomic beam output.

A drop in atomic beam intensity with time of 30% in the first 3 hours and 60% in 24 hours has been observed and is concluded to be due to the coating of the cold nozzle with a white powdery substance analyzed to be $SiO_2$. Several groups that have long term operating experience with RF dissociators with cold nozzles report varying degrees of accumulation of white powder correlated to the time integral of the RF discharge power.[6-8] It is clear that the $SiO_2$ is being eroded from the glass dissociator tube. We have tried a quartz tube and an alumina tube in place of the standard Pyrex one. The quartz showed little change in accumulation of white powder whereas the alumina tube would operate for less than an hour before the $H_2$ discharge became unstable. At the suggestion of T. Clegg

(TUNL), we also extended the Pyrex tube through the MACOR accomodator into the copper nozzle so that the atomic beam does not come into contact with the MACOR. We are continuing to determine optimum parameters for the most reliable long term operation of the dissociator.

## 3. ECR IONIZER

### 3.1. ECR Operation

The ECR ionizer (Fig. 3) was installed and ready for testing in early November of 1991 and beam was extracted shortly thereafter. The ECR sextupole magnet structure is biased at a high positive DC voltage for ion extraction. During initial operation of the ECR it was noted that the proton beam output increased as the plasma volume was increased. Current draw on the extraction supply also increased with plasma volume as did the pressure in the ECR. When the source was disassembled, there was evidence of ion beam incident on the RF transition units upstream of the ECR. Evidently, ions were being extracted from the plasma axially in the upstream direction, as well as radially through the gaps in the permanent magnet sextupole. In order to decrease the extraction current on the ECR, a cylindrical copper screen was installed around the permanent magnet sextupole and a cone inserted at the entrance to the ECR, both of which operate at a few hundred volts above the sextupole potential. This produces a potential barrier to eliminate extraction of the ion beam radially and axially upstream of the ECR. The original RF horn was substituted with a design using a microwave choke flange which can be floated at the sextupole potential and therefore come into contact with the magnets eliminating ion extraction through the horn. The choke flange horn design also is about twice as efficient in directing power into the plasma region of the ECR as measured by the temperature rise of a water sample in air.

Operation above 15 kV ECR bias has not yet been achieved due to current limitations of the power supplies. This problem is attributed to ions extracted from ECR onto the buncher electrodes through areas other than the extraction electrode. To eliminate this excess current draw, these areas will be covered. A quartz tube liner for the inside of the ECR sextupole also will be tested, which may eliminate the need for the screen and further reduce the current draw on the ECR, but at the cost of reduced radial pumping of the plasma region.

### 3.2. Ion Extraction

Beam has been successfully extracted from the ECR at the design energy of 2 keV which is intended to be accomplished by operating the ECR sextupole at 20 kV and the buncher electrodes at 18 kV. A second acceleration gap after the buncher provides the source output energy of 20 keV. To date, best beam extracted from the ECR was observed with the sextupole operating at 10 kV and an extraction potential of 3.5 kV.

The ECR was first operated with the atomic beam valve closed and gas injected directly into the ECR vacuum chamber. Introduction of hydrogen gas produced about 100 μA of proton current. With helium as an injection gas 25 μA of doubly charged and 200 μA of singly charged beam has been extracted and measured after mass analysis. The ECR ionizer will replace an arc source when doubly charged He beams are required.

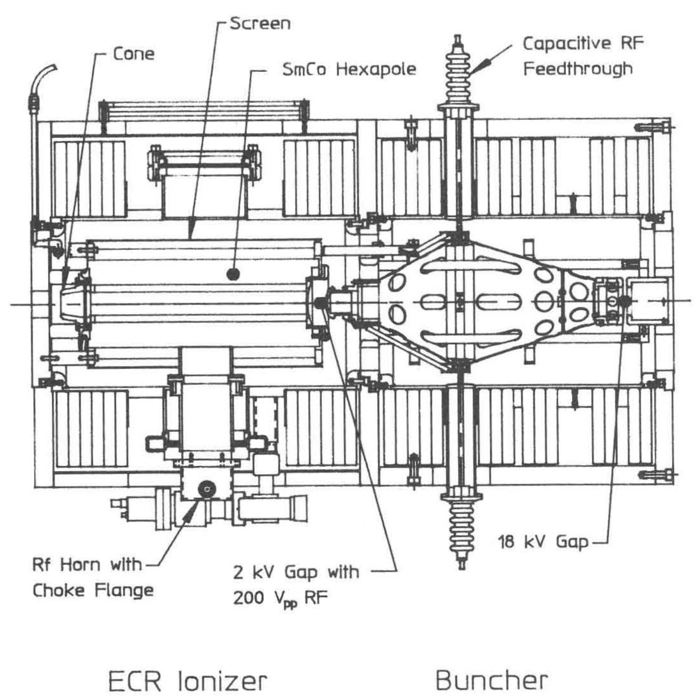


**Fig. 3** ECR Ionizer and buncher assembly showing RF horn with choke flange, biased screen, entrance electrode cone and low energy (2keV) buncher.

### 3.3. Performance with Atomic Beam

With atomic beam injected into the ECR, over 90 μA of proton current was measured downstream of a 90° mass analysis magnet. The best 'real' beam to background ratio was observed with 68 μA of total proton current and 6 μA of background current measured by turning the focussing sextupoles off. After 18 hours of operation the total current drops to 35 μA with 8 μA of background. The drop in intensity is due to a deterioration of the performance of the dissociator while the increase in background is from loading of the sextupole #2 chamber and ECR cryopumps with hydrogen.

## 4. IN-TERMINAL BEAM TRANSPORT

### 4.1. Beam Bunching and Acceleration

The energy of the beam extracted from the ECR is relatively low (2 keV) to permit efficient prebunching before leaving the ion source. The ECR solenoidal magnetic field is continued through the buncher section following the ECR (Fig. 3) to avoid the large emittance increase that would be associated with passage of such a low-energy ion beam through a termination of the ECR solenoidal field. Immediately after extraction from the ECR, the beam passes through the short, gridded RF gap of the buncher. RF power from a 500 W wide-band amplifier, fed through a 20 kV DC capacitive RF feed-through, provides the 200 Vpp linear sawtooth bunching waveform. The conical geometry of the buncher electrode effectively results in a single gap nonresonant buncher. The energy modulated beam drifts in the uniform solenoid field of the buncher section for ~35 cm to achieve bunch formation at an acceleration gap where the beam energy is raised to 20 keV just prior to exiting the solenoid field. The strength of the solenoid field is chosen to provide focussing of the proton beam at this acceleration gap while unfocussed nitrogen ions from the $N_2$ plasma buffer gas are intercepted, allowing for early rejection of much of the sizeable nitrogen component extracted from the ECR.

### 4.2. Beam Transport System

The 20 keV ion beam emerging from the buncher section is focussed and steered in the source exit section into the 4 m long beam transfer line to the 600 kV terminal acceleration column entrance. Aside from the usual electrostatic focussing, magnetic steering, and beam diagnostic elements, this beam transport line (Fig. 4)

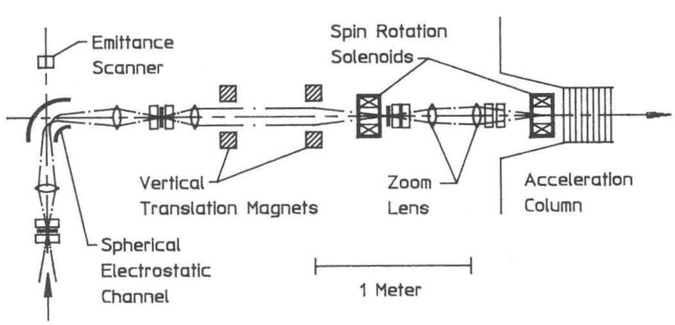


**Fig. 4** In-terminal beam transport line showing the features described in the text.

incorporates three principal systems of note. A combination of a 90° bend, spherical electrostatic channel and a pair of spin-rotation solenoids placed at beam waists, is used to change the spin alignment axis of the polarized beam from axial orientation at the source exit to vertical at the end of the transfer line. A doubly focussing, doubly achromatic magnetic beam translation system produces a 0.5 m vertical parallel drop of the ion beam in the terminal to match source beam height to the acceleration column. A unit magnification electrostatic zoom lens system matches the fixed transfer line optics to the variable acceleration column optics to provide controlled ground potential beam line injection over a wide range of terminal voltages.

## 5. PROJECT STATUS

The ion source is complete up to the transfer beam line and is now in the testing stages. The controls system using HP workstations and X-windows software, interfaced to a VME and a PLC, is partially implemented.[9] The buncher hardware and RF drive system is ready to be tested with beam. Fabrication of all transfer beam line elements is nearly complete. Installation of the source in the new terminal will take place in September of 1992. The 600 keV beam transport line[2] will begin to be installed during a 6 week shutdown and first beam transported to the Injector Cyclotron is expected to take place in late spring of 1993.

## 6. ACKNOWLEDGMENTS

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