# THE IUCF HIGH INTENSITY POLARIZED ION SOURCE PROJECT

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## Abstract

The IUCF high intensity polarized ion source has been completed and installed in the 600 kV terminal. 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 100 $\mu$ A 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<sup>10</sup> protons to be stored in the Electron Cooled Storage Ring in a few seconds. Results from source development and project status will be described.

# I. INTRODUCTION

To further enhance the unique opportunities in spin physics research using the Cooler ring, circulating beam intensities of  $10^{16}$  particles/sec are required because internal polarized target densities and/or reaction cross sections are very low.

In order to meet these experimental requirements, a high intensity source of polarized ions, coupled with a high efficiency bunching system and high transmission beam line<sup>1</sup> to the injector cyclotron, should allow  $10^{10}$  protons to be stored in the Cooler ring in a few seconds.

The design for the high intensity polarized ion source (HIPIOS) was based on the source at  $TUNL^2$ , developed by Tom Clegg and associates, which utilizes cold (30 K) atomic beam technology and an electron cyclotron ionizer (ECR).

HIPIOS deviates from the TUNL configuration in three significant ways: the first sextupole is 50% longer to provide stronger focussing, the cesium charge exchange canal is replaced by a gridded, single-gap RF buncher with a ramp waveform, and ion beam extraction from the source is achieved by raising the internal structure of the ECR ionizer to 20 kV potential. The latter was dictated by the necessity of operating the source assembly at local ground potential in the 600 kV terminal and has significantly complicated the design.

HIPIOS was initially built and tested off-line, the results of which are described in the 1992 Cyclotron Conference Proceedings<sup>3</sup>. The source has since been installed in the high voltage terminal with modifications based on the knowledge gained from initial testing. The improvements achieved with those modifications, and the current status of the entire project are described here.

# **II. HIPIOS OPERATION**

### A. Atomic Beam Development

During initial testing of the ECR it was noticed that the beam intensity from the dissociator drops by a factor of two during the first few hours of operation. The drop in atomic beam intensity with time is due to the coating of the cold nozzle with a white powdery substance analyzed to be  $SiO_2$ . Discussions with other groups that have had long-term operating experience with RF dissociators led us to conclude that the powder accumulation was directly correlated with the time integral of the RF discharge power, and therefore the temperature of the dissociator tube during dissociation.

Several design modifications were made to the dissociator in order to address this problem: a -20°C closed loop alcohol cooling system was installed in place of the water cooling system, the dissociator tube was modified to provide cooling within 1 cm of the accommodator, and the N<sub>2</sub> buffer gas which prevents recombination in the cold nozzle is mixed with the H<sub>2</sub> upstream of the dissociator, rather than being introduced directly into the accommodator. The dissociator now runs stably without any powder formation with the following operating conditions: 25 SCCM H<sub>2</sub>, .030 SCCM N<sub>2</sub>, 33.5 K nozzle temperature, -10° C alcohol return temperature and 100 W RF power (with 23 W reflected). We have consistently measured an atomic beam intensity of 2.0 x 10<sup>16</sup> atoms/sec with a density of 3.3 x 10<sup>11</sup> atoms/cm<sup>3</sup>. New development projects include mixing  $O_2$ with the hydrogen to further increase the beam intensity, and a modification to cool the downstream end of the dissociator tube to 100 K since the rate of recombination reaches a minimum at that temperature.

A collaboration between IUCF and Dr. Alexander Belov from the INR, Moscow has resulted in the construction of a time-of-flight mass spectrometer which will be installed immediately upstream of the ECR to measure the dissociated fraction of the beam. Dr. Belov also participated in the modifications to the ECR extraction system design.

#### B. ECR Ionizer Development

Operation of the ECR at ground potential while the permanent magnet sextupole was biased at 20 kV presented several problems - primarily one of radial and downstream ion extraction resulting in excessive current draw on the high voltage power supplies. Attempts to solve this problem by reverse biasing an entrance cone and screen around the permanent magnets was not entirely successful. Inspired by the ECR ionizer design at PSI, a quartz tube was installed as a liner for the permanent magnet sextupole to further reduce the radial extraction of beam from the ECR plasma.

Since the quartz tube restricts radial pumping of the plasma region, the extraction system has been redesigned to allow for improved axial pumping (Fig. 1). The first design, with an emittance limiting aperture of 1 cm, has been replaced by three molybdenum grids with 95% transmission in a diameter of 4.45 cm. The three grids are electrically isolated and attached to independent high voltage supplies to allow for testing of accel-accel and accel-decel extraction from the ECR.

Testing of the modifications has just begun, with encouraging results. With an atomic beam intensity of  $2.0 \times 10^{16}$  atoms/sec as measured in a compression tube 10 cm upstream of the ECR, a total beam current of 1.2 mA was extracted at 10 kV as measured on a beam stop 10 cm downstream of the ECR. With the atomic beam valve closed, the total beam current was measured to be 0.6 mA.



Figure 1. ECR and Buncher assembly with quartz tube and gridded extraction system.

## C. RF Transition Units

Since we do not yet have a way to measure beam polarization, the strong and weak field RF transition units for hydrogen were tested on the atomic beam source in Madison, WI. The cavities performed as expected, but a polarimeter will be essential for maximizing proton polarization out of the source. A design for a 5-10 keV metastable atom polarimeter was passed on to us by Anatoli Zelenski from the INR. We are anxious to build this polarimeter and install it in the HIPIOS diagnostics line as soon as funding and our work load allows.

#### D. Buncher

Tests of the gridded single-gap buncher with the 600 W wideband RF power amplifier were very promising. Although the load is very reactive, a suitable coupling method was found which yielded the required waveform linearity at voltages even higher than anticipated. This higher voltage leads to a greater range of allowed beam energies in the bunching region. Further testing with beam will determine the optimal beam energy.

Initial bunching factor measurements were taken before the source was moved into the terminal using a gridded pickup. The minimum phase width observed was  $100^{\circ}$  and with the addition of a second molybdenum photo-etched grid we expect the system to operate as designed. We hope to compress all the beam into a  $30^{\circ}$  phase width, which would consequently lead to linear bunching in the following resonant (sinusoidal waveform) buncher.

## E. Control System

The Vista control system<sup>4</sup> has been almost completely implemented for HIPIOS and is working very reliably. We are now controlling the source elements with DACs and are developing a "combo" to run all of the extraction element high voltage supplies with one DAC.

# III. 20 keV BEAM TRANSPORT

The 20 keV ion beam emerging from the source is electrostatically focussed and magnetically steered through the 4 m long beam transfer line to the entrance of the acceleration column. This beam line 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 the 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. Assembly of the beam line is proceeding as manpower is available and is scheduled to be completed by the middle of August.

## IV. HIGH VOLTAGE TERMINAL

The 14' x 30' x 12' high stainless steel high voltage terminal (significantly larger than our existing terminals, but

getting smaller every day) houses HIPIOS and the 20 keV beam transport line with room for an additional ECR source. The space will initially be used for the polarimeter so that polarization studies can be done without having to accelerate beam from the terminal. The terminal operates at 600 kV and is supported on eleven insulating legs, each consisting of three ceramic insulators separated by two spun aluminum corona rings. Two of the legs have a conductive surface glaze to provide 900 Megohms voltage grading to ground, and the corona rings are cross-connected so that all surfaces at the same elevation have the same voltage. This design should require very little maintenance, unlike the water path grading system used on our existing terminals. AC power is delivered to the terminal by a 125 kVA alternator driven by a 200 hp motor connected to a G-10 filament-wound drive shaft - a design which we hope will require much less maintenance than the hydraulic system used to power the other terminals.

The terminal has been successfully tested at 600 kV without sparking or excessive leakage current. Fabrication of the AC drive system is now underway with installation scheduled for July. First beam extraction from the terminal is scheduled for mid-September.

# V. 600 kV BEAM LINE

The 30 m beam line (BL1C) will transport beam from Terminal C to the injector cyclotron. BL1C was designed with the goal of increasing the beam transmission efficiency from the source through the main stage cyclotron from the present 10% to over 30%. The beam line is composed of four  $180^{\circ}$ betatron phase advance sections between each  $45^{\circ}$  dipole which leads to alternating sections of high and vanishing dispersion, followed by a section to match beam phase space to the injector cyclotron acceptance. This symmetry also suggests a natural ordering for steering dipole and beam position monitor pairs (i.e. modula  $90^{\circ}$  in betatron phase advance).

Beam manipulation and diagnostic systems integrated into the beam line design will measure the beam transverse distribution at the beginning of the line, the beam envelope and dispersion throughout the line, and the cyclotron transverse acceptance. The diagnostic systems will also provide the operator with easy to use tools to match the beam properties to the measured acceptances. These tools will operate in an auto-tuning mode during routine operation after being tested in a "manual" mode. Longitudinal diagnostic systems will measure and provide hardware control of both the first and second moments of the beam longitudinal distribution.

The new diagnostics hardware required from Terminal C to the injector consists of 30 beam position monitors, two wire scanners, four beam stops, four slit systems, two phase pickups, four longitudinal profilometers and a 600 keV <sup>6</sup>Li (p,x) polarimeter.

The double-gap resonant waveform BL1C buncher, in conjunction with the terminal buncher, will reduce the energy spread caused by the bunching process by a factor of 4 from

the present system, while providing a sharper phase focus  $(\pm 3^{\circ})$ . This should enhance transmission through the injector cyclotron inflector system and actually eliminate the need for precise dispersion matching. The existing buncher will also be used to provide three stage bunching, allowing adjustment of the beam phase width at the longitudinal focus to optimize matching to the injector. A prototype buncher element has been fully tested, and the mechanical design for the tuneable elements is underway.

All the beam bunching systems will be phase-locked to the beam using hardware phase feedback loops, thus eliminating the otherwise-required precise regulation of power supplies and beam properties. The phase feedback loops will have bandwidths of 10 kHz or higher. The beam phase detectors require a dynamic range of over 40 dB for operation with beam currents in the range  $1 - 100 \mu A$ . An additional hardware feedback loop will modulate the buncher voltage in proportion to the square root of the beam current to compensate for space charge effects.

All of the elements for BL1C have been fabricated with the exception of the buncher and the slit assemblies. Installation of the beam line is underway, and the required modifications to the existing beam line upstream of the injector cyclotron will take place during the upcoming shutdown (May 24 - July 14). First beam into the injector from BL1C is scheduled for the end of September.

# VI. ACKNOWLEDGEMENTS

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