A MULTI-MILLIAMPERE POLARIZED AND UNPOLARIZED NEGATIVE ION SOURCE FOR IUCF*

V. P. Derenchuk†, IUCF, Bloomington, IN 47408, USA
A.S. Belov, INR, Troitsk, Moscow Region 117312, Russia

Abstract

The pulsed polarized negative ion source (CIPIOS) for the Indiana University Cooler synchrotron produces multi-milliampere beams for injection into the Cooler Injector Synchrotron (CIS). In normal operation, the unpolarized beam intensity at the source has exceeded 30mA peak and for polarized H^- and D^- beams over 1.5mA peak. The FWHM of the beam pulse is 150μs, the emittance for 90% of the beam is less than 1.5B-mm-mr normalized and the nominal polarization is 80% or greater for both beams. At these peak intensities, the source operates between 0.8Hz and 2Hz. At greater repetition rates, the peak polarized beam intensity decreases slowly.

1 INTRODUCTION

At Indiana University (IUCF) an atomic beam source (ABS) with a resonant charge-exchange ionizer produces polarized and unpolarized $H^-$and D^- ions[1] which are accelerated through an RFQ/DTL to an energy of 7MeV (4MeV for D^-). This beam fills the Cooler Injector Synchrotron (CIS)[2] using the strip injection technique and after acceleration to 202.8MeV is extracted and used to fill the Cooler synchrotron[6]. The ABS of this Cooler Injector Polarized Ion Source (CIPIOS) is equipped with a pulsed source of gas and RF power in order to take advantage of higher flow rates, similar to a source built by Belov at the Institute for Nuclear Research of the Russian Academy of Sciences (INR)[3]. For polarized ion beam production, permanent magnet sextupoles are used to focus the atomic beam into a resonant charge-exchange ionizer. The plasma injector and extraction system for the resonant charge-exchange ionizer was built at INR in Troitsk and is similar to their test bench ionizer[4]. The ionizer uses the large cross-section, $10^{-14}cm^2$ for resonant charge- exchange between low energy (10eV) $D^-(H^-)$ ions and polarized $H^o(D^o)$ atoms[5]. The ionizer consists of a plasma source with a Cs coated converter to produce the negative ions. This plasma is confined along the axis of the ionizer solenoid field. The large flux of negative ions from the plasma source is extracted and is used as an intense source of unpolarized beam for the accelerators with up to 25mA of unpolarized H^- and 30mA of D^- ion. Several weeks of maintenance free unpolarized and polarized operation has been demonstrated. Polarized H^- and D^- beam intensity is 1.5mA peak and with nominal polarizations of 80% and 85% respectively. The pulse FWHM is about 150μs (>200μs for unpolarized beam) and can operate at a repetition rate up to 4Hz with the existing pumping scheme. Failures during operation are rare and mean time between maintenance for unpolarized operation is in excess of 1000 hours or 41 days. Polarized operation requires maintenance every 12 days on the average to regenerate the cold nozzle and cryopumps.

Further development work by Belov on the test bench at INR has resulted in unpolarized beam currents that exceed 100mA (up to 150mA observed for H^-)[8] and polarized currents of 2.5mA[9] at repetition rates of 10Hz and a duty factor of $2x10^{-3}$. The high reliability proven at IUCF in combination with these high brightness unpolarized beams makes this source an ideal choice for a high energy accelerator facility.

2 OPERATION

2.1 ABS Operation

Hydrogen gas is dissociated in a Pyrex tube using an RF pulse coupled to the gas through a coil. An 80K He refrigerator cools the aluminum nozzle.

The dissociator in the ABS operates in a pulsed mode with the following characteristics:

- Pulsed RF supply: Two tube oscillator with pulsed anode voltage. 5kW max output for 1 ms duration at 4Hz. 2.0kW peak at 35MHz during normal operation.
- Pulsed gas valve: General Valve Corp. Series 9 with a 3.3Ω coil. Gas flow is $7.4x10^{17}$ molecules/pulse.
- Pulsed valve p.s.: A home built 300V switch, rise time <5μs, width variable to 1ms is used.

Atomic hydrogen or deuterium is ejected through the 2.2mm nozzle exit and is collimated by a 4mm skimmer just upstream of a permanent magnet sextupole triplet. A fourth sextupole is an electromagnet with a 31mm and permanent magnet loaded pole tips to achieve a pole tip field in excess of 1.1 Tesla. It focuses the atomic beam into the ionizer.

Atoms obtain nuclear polarization only after passing through transition units after electron spin is selected by the sextupoles. Two transition units for polarized H beam and three transition units for the production of polarized D can be rapidly switched on and off. The

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†laddie@iucf.Indiana.edu

nuclear polarized atoms reach a 1cm diameter focus inside the ionizer solenoid, about 5cm beyond the single grid extraction system.

Table 1: Sextupole Specifications. Position is measured from the beam exit at end of cold nozzle to the entrance of the magnet.

	PM Mag1	**PM Mag2**	**PM Mag3**	**PM Mag4**
Position	6.0 cm	9.5 cm	15.5 cm	100 cm
$\mathbf{R_{entrance}}$	4.78 mm	7.10 mm	9.30 mm	15.5 mm
$\mathbf{R_{exit}}$	6.42 mm	9.01 mm	9.72 mm	15.5 mm
Length	2.5 cm	5.0 cm	6.0 cm	22.7 cm
$\mathbf{B_{pole\ tip}}$	1.66 T	1.62 T	1.15 T	1.10 T

Two 1500 l/s turbo pumps backed by a roots blower and mechanical pump on the dissociator section and two 1500 l/s cryopumps on the sextupole section differentially pump the ABS. Only the 4 mm skimmer connects the two chambers.

2.2 Ionizer Operation

The charge exchange ionizer is comprised of a pulsed plasma source with a cesiated converter assembly that produces low energy plasma rich in D^- ions. The plasma source ejects H or D plasma through the converter into a 0.1Tesla solenoid where ionization takes place. Charge exchange takes place in the solenoid between the negative plasma ions and neutral polarized atoms. A polarized beam of negative H^- ions and a high intensity beam of unpolarized D^- ions are formed when the extraction potential is pulsed to 25kV. To produce polarized D^- and unpolarized H^-, the feed gas for the ABS and ionizer is switched.

Further improvements of the CIPIOS ionizer and extraction system should result in a doubling of the unpolarized beam currents. Up to 60mA of unpolarized D^- beam, 45mA of H^- and 2.5mA of polarized beam is expected within the same emittance.

The ionizer is pumped by one 2200 l/s turbo pump backed by a 500 l/s turbo-pump and mechanical pump in series and one 1500 l/s cryopumps.

The pulsed ionizer timing is adjusted to allow for the approximately 600μs drift time of the atoms from the ABS. Some characteristics of the ionizer are:

- Pulsed arc supply: IUCF built $300A_{peak}$, regulated to ±5A during the pulse. Max pulse length =1ms.
- Pulsed gas valve: Built at Institute for Nuclear Research, Troitsk, Russia. Inlet pressure is 40psia hydrogen or deuterium. Gas flow is 8.3×10^{17} molecules/pulse.
- Pulsed valve supply: IUCF built, 300 V_{peak} semiconductor switch.

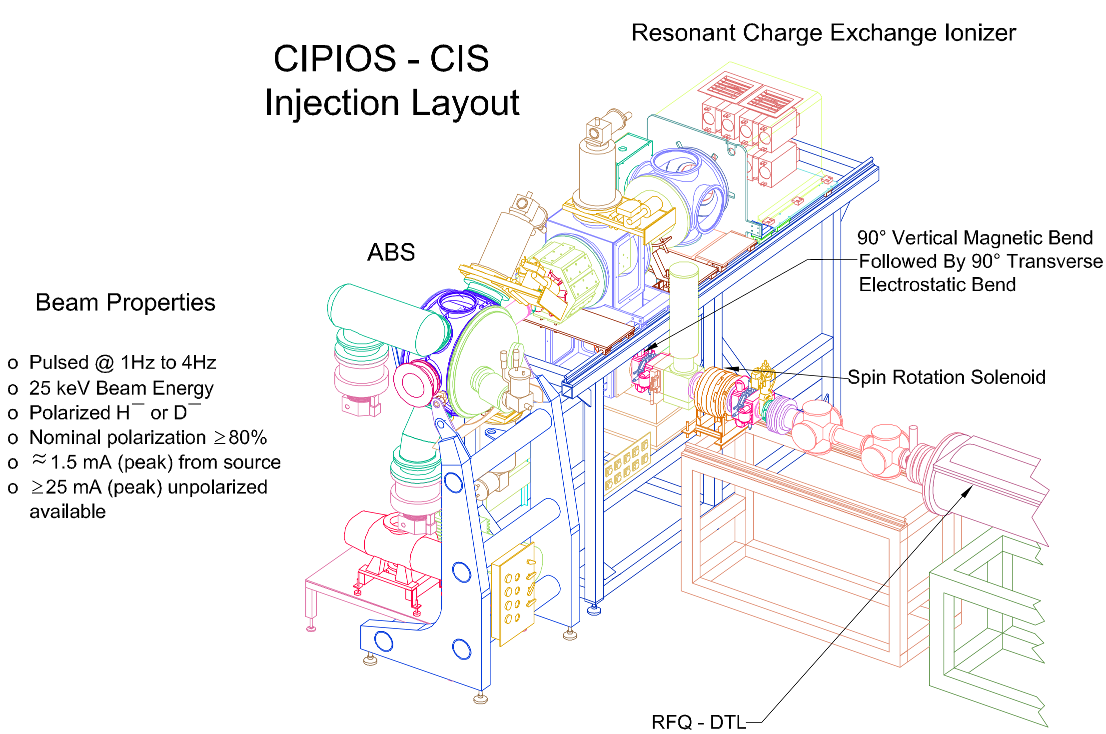

Figure 1 Schematic of ion source and LEBT showing the entrance to the RFQ. The beam is extracted from the ionizer toward the ABS and is then deflected downward with a magnetic bend and towards the RFQ with an electrostatic bend. This results in a nearly vertical polarization at the RFQ entrance.

- Converter: Molybdenum converter operates at
- 400C with a thin Cesium coating generated by Cesium Chromate in a matrix of Titanium powder.
- Ionizer Solenoid: Typical operation in ionization region is with a 0.1Tesla field strength.

3 BEAM PROPERTIES

Properties of the polarized and un-polarized beams from CIPIOS are listed below.

3.1 Polarized Beam Properties

For H^- beam:

- Beam Intensity: ≥ **1.5mA** peak after mass analysis sustainable for several days, 1.2mA average for long-term operation.
- Pulse shape: FWHM 150 µs.
- Emittance: 1.2π–mm-mrad normalized for 90% of the 25keV beam.
- Polarization: p_z=0.80±0.01 for two states.

For D^- beam:

- Beam Intensity: ≥ **1.5mA** peak after mass analysis sustainable for several days, 1.2mA average for long-term operation.
- Pulse shape: FWHM 175µs.
- Emittance: 1.25π–mm-mrad (estimated) normalized for 90% of the 25keV beam.
- Polarization, vector states:

p_z=+0.85±0.01, -0.70±0.01, p_{zz}=+0.89±0.01, 0.70±0.01 for two vector states.

p_{zz}=+0.88±0.01, -1.59±0.01, p_z=0.02±0.01, 0.01±0.01 for two pure tensor states.

3.3 Unpolarized Beam Properties

For H^- beam:

- Beam Intensity: ≥ **20mA** peak after mass analysis, sustainable for long-term operation.
- Pulse Shape: FWHM 250µs.
- Emittance: 1.55 π mm mrad normalized for 90% of the 25keV beam at the RFQ .

For D^- beam:

- Beam Intensity: ≥ **25mA** peak after mass analysis, sustainable for long-term operation.
- Pulse Shape: FWHM 250µs.
- Emittance: 1.60π–mm-mrad normalized for 90% of the 25keV beam at the RFQ

5 CONCLUSION

A increase of more than 50% for polarized and unpolarized beams is expected for CIPIOS by the fall of 2001. The result will be unpolarized beam currents of up to 60 mA peak in 1.60π–mm-mrad and polarized beam intensities of 2.4 mA with an emittance of 1.2π–mm-mrad normalized and 80% polarization. The test bench source at INR has produced unpolarized beam intensities in excess of 100 mA peak with FWHM of >200µs at 10Hz. With this expected increase in beam current and demonstrated 1500 hours of operation between required maintenance and failures, this type of source is a candidate for high-energy accelerators requiring both polarized and unpolarized beams.

6 REFERENCES

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[10]For additional information about CIPIOS browse to http://sauron.iucf.indiana.edu/CIPIOS/cipios_main .html.