POLARIZED BEAM PERFORMANCE OF THE IUCF CIPIOS, CIS, AND COOLER RESEARCH ACCELERATOR FACILITIES

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Abstract

Indiana University (IUCF) recently commissioned a milli-Ampere polarized atomic beam source (CIPIOS)[1] and a 2.4 T-m Cooler Injector Synchrotron (CIS)[2] to inject high-intensity polarized protons and deuterons into our existing electron cooled storage ring (Cooler)[3] for nuclear physics research. CIPIOS produces both vector polarized and unpolarized H^- and D^- ions and tensor polarized D^- ions for CIS strip injection. The H^- beam vector polarization prior to CIS injection is ≥ 77%. A weak partial snake in CIS maintains polarization during acceleration through a $G\gamma=2$ imperfection resonance at 108.4-MeV so that the measured polarization of 202.8-MeV protons stored in the Cooler is also ≥ 77%. Recently, 90-MeV unpolarized deuterons from CIS were injected into the Cooler and ramped to 240 MeV for experiment. The CIPIOS/CIS/COOLER (CCC) facility can now routinely deliver over 10^{10} polarized and unpolarized p and d beams for scientific research. This contribution summarises the polarized beam manipulation and measurement tools available to users of the CCC accelerator facilities together with present demonstrated beam performance.

1 CIPIOS AND LINAC PERFORMANCE

A plan view of the CCC research accelerator facilities is shown in Fig. 1. CIPIOS is a pulsed, cold nozzle atomic beam polarized ion source with a plasma (H^-, D^-) charge exchange ionizer. It produces up to 1.2 mA (peak) of 25-keV polarized H^- or D^- beam with normalized emittances of 1.2 π mm-mrad. Using only the plasma charge exchange ionizer, CIPIOS can also produce over 12 mA (peak) of unpolarized H^- or D^- beam with normalized emittances of 1.6 π mm-mrad. For proton beam operation, the H^- beam from CIPIOS is matched to the acceptance of a commercial 3-MeV RFQ that is directly coupled to a 4-MeV DTL[4]. Over 0.6 mA (3 mA) of 7-MeV vertically polarized (unpolarized) H^- beam from the Linac are strip injected on thin carbon foils (≤4.5 $\mu g/cm^2$) into CIS. Over 0.5 x 10^{10} polarized and 1.5 x 10^{10} unpolarized protons are single-turn fast-extracted from CIS for Cooler injection at 0.8-Hz repetition rates. Measured proton beam polarizations in the Cooler range from 77% to 80%, and are nearly the same as measured from the source.

A 4-MeV D^- beam for strip injection into CIS is achieved by replacing the 3-MeV H^- vanes with 4-MeV D^- vanes in the RFQ section of the Linac pre-accelerator.

The DTL, which uses permanent magnet quadrupoles in the drift electrodes, serves only as a transmission beam line for this operating mode. Switching the source and Linac between 7-MeV H^- and 4-MeV D^- operation takes 5 working days, including conditioning the RFQ to maintain threshold voltage. In a demonstration run this spring, 0.5 mA (peak) of unpolarized 4-MeV D^- from the Linac was accelerated to 90 MeV in CIS, accumulated to 1.1 mA average (0.7 x 10^{10} deuterons) in the Cooler and ramped to 240-MeV. Experimental groups waiting for polarized D^- beams, which are scheduled to be available in September 2000, used both beams for background measurements.

2 THE CCC POLARIZED BEAM DELIVERY SYSTEM

2.1 Spin Manipulation

A variety of spin measurement and precession devices are available in the CCC accelerator facilities, as shown in red in Fig. 1. A superconducting spin precession solenoid located in BL9A rotates the proton spin into the transverse plane prior to Cooler injection. When used with the superconducting Snake solenoid in the Cooler S-region, this configuration delivers transverse and longitudinal polarization components in the S, T, A, and G-regions. A superconducting solenoid in the Cooler T-region works in conjunction with the room temperature electron cooling system solenoid in the C-region to produce polarized beam in the Cooler A-region with a

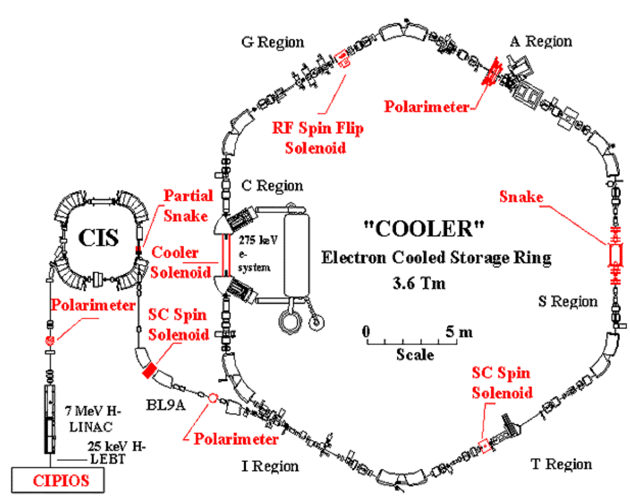

Figure 1. Plan view of the IUCF CCC polarized proton and deuteron beam accelerator facilities.

large longitudinal component. In addition to periodically reversing the sign of the polarization from the source, an rf solenoid in the G-region is used to periodically flip the spin of the Cooler stored proton beam to further minimize systematic errors during data acquisition. Consequently, CIPIOS, CIS and the Cooler are able to provide polarized protons with three stable spin orientations (normal or transverse in the S-region and longitudinal in the A-region) for experiment.

2.2 Polarization Measurement

A beam polarimeter is located between the DTL and CIS to measure the polarization of the 7-MeV H^- and 4-MeV D^- beams from the source. This polarimeter observes elastic scattering from ^4He at 112° for protons[5]. For 4-MeV D^-, the $^3He(d,p)^4He$ reaction has the dual advantages of sizable analysing powers and a large positive Q-value. The vector and three tensor analysing powers have been measured several times in this energy range with good agreement[6][7][8][9]. We compare the left-right asymmetries at 67.5° and 135° to derive the vector (p_y) polarization and the average rates at the same two angles to derive the tensor (p_{yy}) polarization. The Helium gas is contained in a removable gas cell with Havar windows and the reaction products are observed using Silicon surface-barrier detectors.

Polarization is also measured in the Cooler using a carbon skimmer target that is inserted into the fringes of the circulating beam. Protons scattered from the carbon target are tracked through a set of wire chambers and scintillators down stream in the A-region. A third polarimeter is under development in BL9A between CIS and the Cooler ring. Measurements at that point must deal with the low duty factor (10^{-8}) and high particle flux (10^{10} p/p) from CIS. Upgrades to CIPIOS and all polarimeters are presently underway to produce and measure both the vector and tensor polarized of deuterons. The polarized deuteron beam performance will be the subject of a future report.

3 THE CIS Gγ= 2 IMPERFECTION DEPOLARIZING RESONANCE

In the first attempt to store polarized protons from CIS in the Cooler, the 7-MeV H^- beam polarization was measured to be 0.73 ± 0.03, yet the polarization of the 202.8-MeV proton beam accumulated and stored in the Cooler was less than 0.20[10]. Possible depolarising resonances are known to exist in both CIS (Gγ=2 imperfection resonance) and in the Cooler, but without the BL9A polarimeter, the source of the depolarization was not immediately known. An intrinsic resonance at 186-MeV is known to depolarize the 202.8-MeV proton beam accumulated in the Cooler, and is dependent on the ring vertical fractional betatron tune. The low Cooler stored beam polarization was insensitive to the ring tunes, hence the Gγ = 2 imperfection resonance at 108.4-MeV in the CIS ring was suspected of causing the depolarization. As a first test, we varied the ramp rate of the beam during acceleration through 108.4-MeV in CIS and found a weak correlation (~ 10%) between it and the Cooler beam polarization. To confirm the suspicion, a vertical bump was introduced into the CIS ramp to 202.8-MeV at 108.4-MeV. Fig. 2 shows the polarization measured in the Cooler as a function of the current in the vertical steerer that produced the bump during the ramp. The final polarization is in good agreement with the value obtained with the polarimeter ahead of CIS.

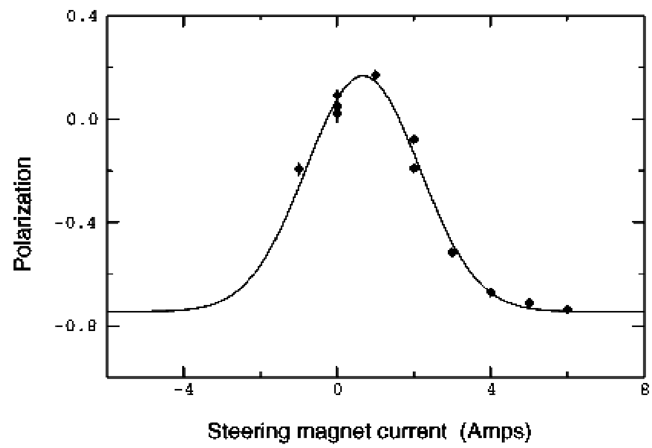

Figure 2. The polarization of 202.8 MeV protons stored in the Cooler vs the vertical bump amplitude in CIS.

The effect of the imperfection resonance on the polarization after acceleration through the resonance in CIS is dependent on both the acceleration rate and the resonance strength and is described in terms of the Froissart-Stora equation[11]. Obtaining a Cooler beam polarization near zero means there is a near balance between the size of the imperfection resonance and the acceleration rate in CIS. This situation is maximally unstable since any small change in the resonance strength generates large changes in the polarization. The vertical closed orbit bump increases the effective size of the imperfection resonance by moving the circulating beam out of the ring median plane where it encounters significant radial and longitudinal field components caused by the main ring dipole entrance and exit angles (12°) that determine the basic ring optics. The increased radial field components cause the full spin flip during acceleration through the resonance.

A more practical way to introduce a well-defined spin perturbation without causing ring orbit distortions is to place a solenoid in one of the CIS straight sections[12]. A 135-turn air-core room temperature solenoid was mounted in the CIS ring extraction straight section. The solenoid is pulsed on and off during the ramp so that its full strength overlaps the point where γ =1.1155 (108.4-MeV). Complete spin flip in CIS occurs if the square of the imperfection error introduced by the solenoid is much larger than the rate of acceleration[13]. This was confirmed in CIS for all solenoid currents above 15 A, as shown in Fig. 3. The integral field strength at this current is 25 G-cm, corresponding to a spin precession angle of 0.26°, a modest partial snake strength. The source polarization was 0.70 ± 0.01 for this data. The CIS partial snake is now routinely pulsed on at 40 Amps while passing through the resonance for all polarized proton beam operations. This maintains a high polarization in the Cooler for experiments. There is no beam loss or orbit distortions observed in CIS when the partial snake is energized in this way.

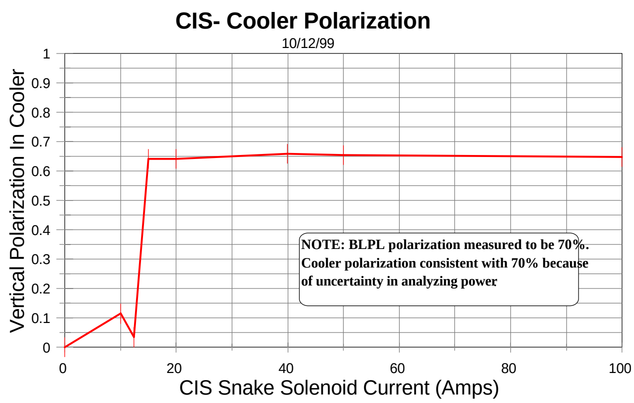

Figure3. Measured polarization of 202.8 MeV protons in the Cooler as a function of the partial snake current.

The Gγ=2 resonance is now considered to be a feature by polarized beam users who occasionally want unpolarized beam for normalization purposes. The combination of turning off the source rf transition units and the CIS partial snake results in a beam polarization very near zero in the Cooler.

4 DEUTERON BEAM PERFORMANCE

The CCC accelerator facilities were originally specified to deliver both polarized and unpolarized proton and deuteron beams for experiments in the Cooler. All specified proton beam goals were realized by the end of 1999 and are now available for experiment. A three-month shutdown beginning in January 2000 was used to develop CIPIOS and CIS deuteron beam performance. As described in section 1, a 0.5 mA, 4-MeV unpolarized deuteron beam was accelerated through the modified Linac pre-accelerator, strip injected, accumulated and accelerated to 90-MeV in CIS. As shown in Fig. 4, $6x10^9$ deuterons per pulse were extracted from CIS for Cooler injection, but the injection efficiency onto the Cooler stored orbit was significantly smaller that predicted for deuterons or observed for protons. This problem was later traced to a CIS extraction error that caused the beam to scatter off the side of the Lambertson extraction channel. Even so, over 7×10^9 deuterons were accumulated in the

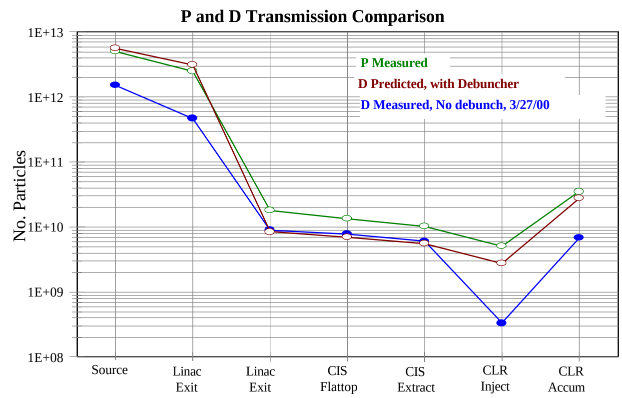

Figure 4. Comparison of measured proton and deuteron transmissions through the CCC accelerator system.

Cooler at 90-MeV and ramped to 240-MeV for the first development run on March 27, 2000. Polarized and unpolarized deuteron beam development is scheduled to continue in August 2000.

5 CONCLUSIONS

The predicted Gγ=2 imperfection resonance was observed to partially depolarize protons accelerated to energies greater than 108-MeV in CIS and was overcome by a weak partial snake solenoid. CIS now routinely delivers > 77% polarized protons to the Cooler with a variety of user selectable spin orientations for experiment. The ability to quickly switch the source and RFQ pre-accelerator between H^- and D^- operation was demonstrated. We plan to deliver polarized deuterons to the Cooler for experiments by late 2000, and periodically switch between protons and deuterons thereafter. Work supported by the National Science Foundation under grant NSF-PHY-9602872.

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