CIS, A LOW ENERGY INJECTOR FOR THE IUCF COOLER

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Abstract

Construction has begun on a low energy booster synchrotron to replace the IUCF isochronous cyclotrons for the injection of polarized light ions into the existing 3.6 T-m electron-cooled storage ring (Cooler). CIS (Cooler Injector Synchrotron), with a circumference of 1/5th the Cooler ring, will provide $\geq 2.5 \cdot 10^{10}$ polarized protons (deuterons) per pulse at 1 Hz for Cooler injection. Bucket-to-bucket beam transfer from CIS to the Cooler operating on the 5th harmonic will fill the Cooler with 10^{11} protons in 5 sec. The higher intensity and improved duty cycle will enhance the range and quality of experimental nuclear physics research programs using Cooler beams.

I. INTRODUCTION

In August of 1994, NSF and Indiana University jointly funded the construction of a dedicated, low energy booster synchrotron to inject high intensity polarized proton and deuteron beams into the IUCF 3.6 T-m Cooler. The Cooler, which began operation in 1987[1], is presently filled with light ion beams from the IUCF cyclotrons. Strip injection of $^2H^+$ ions and cooling accumulation produces $\approx 10^{10}$ stored protons in a few seconds. A complex kick injection and cooling accumulation scheme for fully stripped polarized ions yields 10^9 stored particles in several minutes. Although both injection methods have demonstrated stacking factors of 10^3, stored Cooler beam intensities are limited by modest beam intensities available from the cyclotrons ($\approx$2 μA). Cooler intensities are is also limited ($\leq$2 mA) by coherent transverse instabilities aggravated by high peak currents and phase space densities caused by rf bunching and electron cooling[2], both of which provide beam qualities required by most experimental users.

CIS will fill the Cooler with a minimum of 10^{11} protons or deuterons in a few seconds without cooled accumulation techniques, while reducing the overhead and operating expense incurred by the precise cyclotron/Cooler matching requirements presently needed to obtain optimum Cooler performance. While 10^{10} stored polarized ions will enhance the developing spin physics program on the Cooler, 10^{11} stored polarized ions will open new avenues of research. High intensity Cooler beam is also needed to fill a proposed high energy ($\leq$ 20 GeV) Light Ion Spin Synchrotron (LISS), which is currently under design.

II. CIS PERFORMANCE GOALS

The layout of the CIS ring relative to the cyclotrons and Cooler is shown in Fig. 1, and the projected beam performance and ring lattice parameters are summarized in Table I. Details of the CIS ring lattice, strip injection performance and rf accelerator cavity design are provided in separate contributions to this conference.[3], [4], [5]

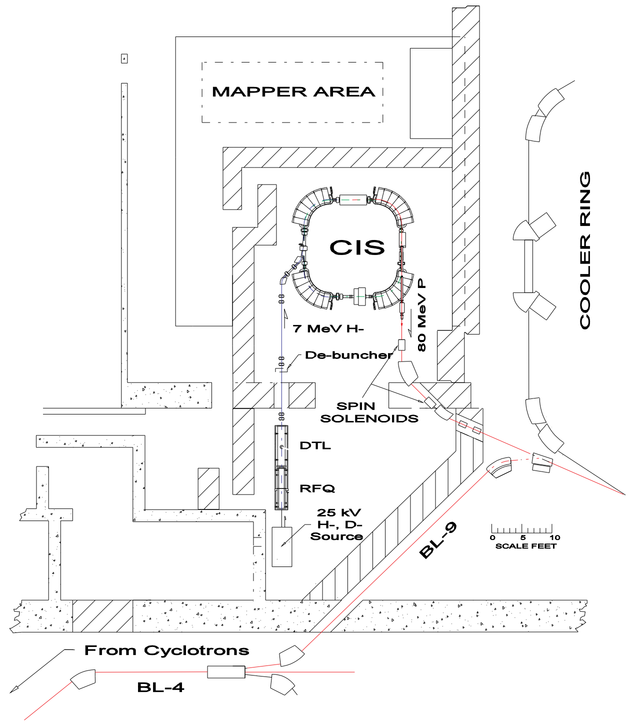

Figure. 1. Layout of CIS ring in IUCF accelerator vaults

A. Sources and Pre-accelerator

Ongoing development activities are rapidly increasing polarized H^- beam intensities towards the 1 mA level. Consequently, the CIS pre-accelerator, injection beam line and ring will be commissioned using a high intensity unpolarized H^- Cusp source to permit intensity development of the ring to its space charge limit. The existing IUCF High Intensity Polarized Ion Source (HIPIOS)[6] can then continue operation with the cyclotrons and Cooler during CIS construction. Installation of either an upgraded HIPIOS or a newer 1 mA polarized ion source will follow the initial CIS ring commissioning effort in 1997.

Polarized or unpolarized, 25 keV H^- ions are accelerated to 7 MeV via a coupled 3 MeV radio frequency quadrupole (RFQ) and 4 MeV drift tube linac (DTL) pre-accelerator operating at 425 MHz. The pre-accelerator will be fabricated and tested by AccSys Technologies, Inc.[7] and IUCF, working together as industrial partners. 25 keV D^- ions can be similarly accelerated using a separate RFQ/DTL pre-accelerator, which is not included in the initial construction program. Beam transmission from the source through the linac decreases with increasing source emittance. While the HIPIOS and Cusp source normalized emittances are less than 1.0π μm, the 1 mA polarized source emittances are reported to be somewhat larger.

Table I
CIS BOOSTER PARAMETERS

I. Proton Beam Properties	INJ	EXTR
Maximum Design Energy (MeV)	7	200
Initial Operating Energy (MeV)	7	80
Momentum (MeV/c)	114.8	498.2
Rigidity (Tm)	0.383	1.03
Accumulated Emittance (π μm)	34.0	10.0
Orbit Period, 7-80 MeV (μsec)	0.477	0.149
Tune Shift @ $2.5 \cdot 10^{10}$ Part.	0.03	0.006

II. Lattice Parameters		
Circumference (m)	17.364	
Straight Section Length (m)	2.341	
Dipole Magnet Radius (m)	1.273	
Dipole Length (m)	2.0	
Dipole Edge Angle	12°	
Magnet Field Maximum (T)	1.68	
Number of Quadrupoles	4	
Hz Tune (Q_x)	1.463	
Vt Tune (Q_y)	0.779	
β_x (m): Max (mid-bend)	4.373	
Min (mid-straight)	1.123	
β_y (m): Max	3.786	
Min (mid-straight)	3.342	
Dispersion (m): Max (mid-bend)	1.759	
Min	1.576	
Momentum Compaction Factor	0.655	
Chromaticity (x, y)	-0.53, -0.16	

For our performance estimates, a linac transmission of ≥85% was calculated for a 1 mA H^- beam with a normalized emittance of 1.2π μm. The RFQ/DTL will produce beam pulse widths of ≤360 μsec at up to 5 Hz.

A 9.7 m injection beam line is used to both de-bunch and phase space match the linac beam to the CIS ring Twiss parameters in the injection straight. The FWHM beam energy spread is ±0.5%, and will be further reduced by a factor of 3 to 5 by a de-buncher located 2.6 m from the linac exit. Space charge induced longitudinal emittance growth in this beam line is small for intensities below 1 mA.

B. Strip Injection Performance

The 7 MeV H^- (D^-) linac beam must be strip injected into the CIS ring to achieve the design goal of $2.5 \cdot 10^{10}$ particles/pulse at extraction. Beam is directed onto a carbon foil strip via a dc magnet chicane located symmetrically about the center of the injection straight section, as shown in Fig. 2. Two bumper magnets, located $\pm 90^o$ in phase advance from the foil in adjacent straight sections, move the closed orbit onto the foil during injection. A critical performance area for CIS is the intensity gain provided by strip injection of relatively low intensity polarized beams (≤200 μA), particularly since the CIS extracted beam emittance cannot exceed the Cooler acceptance of 10 π μm. Detailed ray trace computer simulations using a 7 MeV H^- beam with a normalized emittance of 1.2π μm and a 90% energy spread of 0.5%,

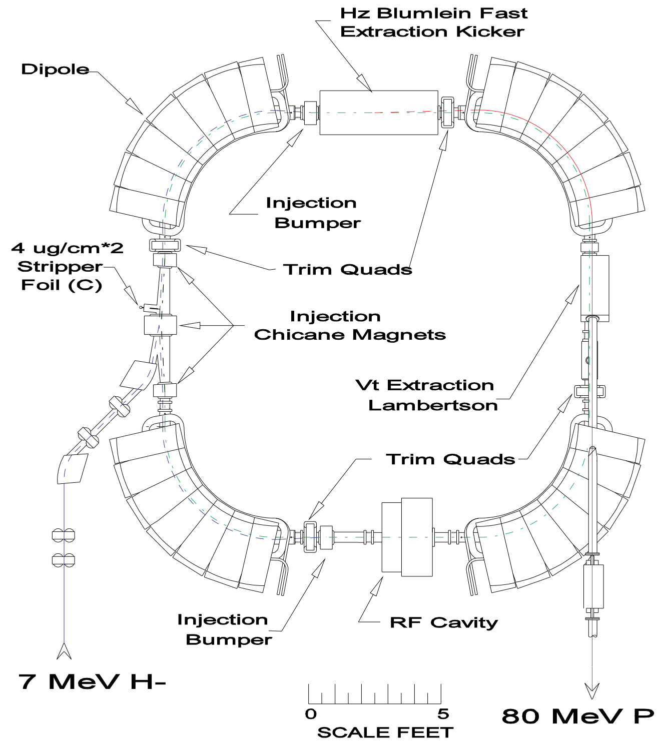

Figure. 2. CIS Ring Plan View

matched to the ring beta functions at a 4 μg/cm^2 Carbon foil strip, predict an intensity gain of 250 [4]. Consequently, a minimum H^- source intensity of 65 μA is required to achieve the design intensity goal, assuming 85% transmission through the linac and 60% transmission through CIS. Accumulation time for this intensity gain is 230 μsec, which matches well with typical beam pulse widths from pulsed polarized sources, and is within the range of the RFQ/DTL pulse structure.

IUCF has recently fabricated several 4.5 μg/cm^2 Carbon stripper foils with one and two unsupported edges of 22 mm. These will soon be tested in the Cooler to determine performance and survivability. Work is continuing to develop thinner foils, although 50% thinner foils may require accumulation times longer than the 360 μsec linac pulse width.

III. Ring Design

CIS is a weak focussing synchrotron with a superperiod of 4 and operates below transition. Primary beam focussing is determined by the C-shaped corner dipole edge angles. Dipole back leg windings and vertical steerers in each straight section are used for orbit centering. Four trim quads are available for small tune adjustments during routine operations, and can also be used to vary ring tunes and the transition energy for accelerator physics studies. The ring dipole magnet design allows acceleration of protons (deuterons) up to 200 MeV (100 MeV) at 5 Hz. However, proton energies will initially be limited to 80 MeV at 1 Hz for budgetary reasons. Future power supply and extraction element upgrades will be required to achieve the maximum design capability of the ring.

The injected beam is adiabatically captured using a VCO controlled, ferrite biased rf cavity similar in design to the IUCF Cooler MPI rf cavity[8]. The cavity operates on the first harmonic of the orbit frequency, which varies from 2.09 to 9.78 MHz for protons from injection to 200 MeV. VCO control is relinquished to beam position monitors (two radial position monitors 180^o apart in phase advance) and phase feedback systems (wall gap monitor) during acceleration.

Single turn beam extraction is accomplished via a fast rise time (50 nsec) horizontal counter traveling wave (Blumlein) kicker,[9] which jumps the beam accross a 7 mm wide septum of a vertical extraction Lambertson magnet in the following straight section. An injection bumper and dipole backleg windings move the closed orbit close to the septum prior to firing the kicker.

IV. MAGNET DESIGN

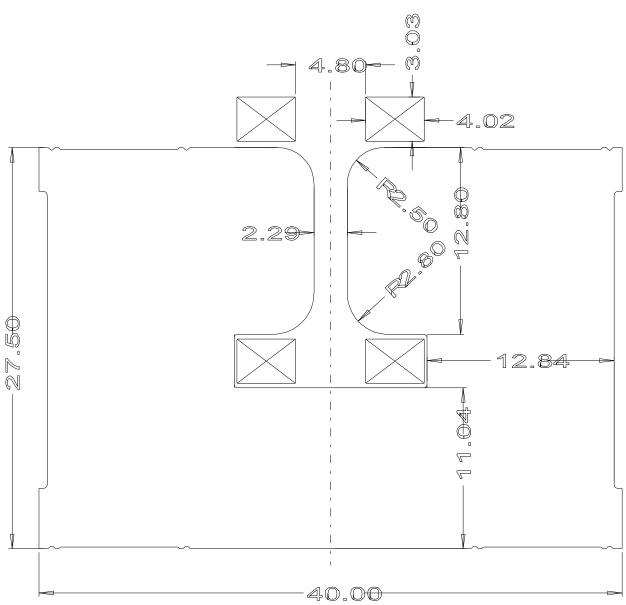

Figure. 3. Dipole Magnet Lamination (inches)

The high energy and small bending radius of CIS (see Table I) requires 90° dipole magnets with a high field (1.68 T) and large sagitta (37 cm), presenting several laminated magnet design challenges. Axially symmetric field calculations (computer code *MagNet*) were used to optimize the radial cross section of the magnet lamination shape, shown in fig. 3. A large pole width to gap ratio was chosen to keep the sextupole component below -0.6 T/m^2 at 1.68 T. No other multipoles are significant in the region $\pm$4.5 cm either side of field center. Since the beam is affected by multipoles in the field integral, 3-d *MagNet* calculations are in progress to optimize the magnet end shape. Also, eddy current effects in the 0.06 inch thick magnet laminations and metallic vacuum chamber in the gap will also be modeled using the time transient solver in *MagNet*.

A practical magnet design was achieved with the aid of magnet experts at the FNAL, ANL-APS, and BNL magnet factories. The magnets will consist of laminated wedge shaped modules, as shown in figure 2. The blocks are fabricated from low carbon steel laminations coated with B-stage epoxy. A stacking fixture is used to assemble and compress the laminations and cured them in a hot air furnace. Strengthening plates are then welded onto the blocks prior to their being machined into wedge shapes. Five wedge shaped blocks and two parallel endpacks are then assembled on a prefabricated base plate to complete the dipole magnet.

V. PROJECT STATUS AND SCHEDULE

An intense CIS design effort beginning in August 1994 culminated in an external design review in February, 1995. Presently, the CIS dipole magnet magnet steel and lamination stamping vendor selection is underway. Detailed magnet and coil fabrication bid packages are nearly complete, with expected vendor selection before June. Field mapping and endpack fine adjustment of the first dipole is planned for January of 1996. In a paralel effort, design of the AccSys Technology RFQ/DTL Linac is complete, fabrication will begin in late May and delivery to IUCF is scheduled to occur in June of 1996. Beam development of the linac and injection beam line should begin in the fall of 1996. Many of the ancillary items required for the injection and extraction beam lines, rf accelerator cavity and de-buncher, and ac power distribution systems are either designed or have been acquired as surplus equipment. The completion of ring assembly and start of beam commissioning is scheduled for the first quarter of 1997.

VI. ACKNOWLEDGEMENTS

Many IUCF staff members provided significant contributions to the CIS design presented here, which are reported elsewhere in these proceedings. In addition, three visiting scientists, Dag Reistad and K. Hedblom from the Svedberg Laboratory, Uppsala, and Boris Sukhina from INP, Novosibirsk, have provided many usefull discussions and ideas which are incorporated into the present CIS design. This work is funded by Indiana University and the National Science Foundation under grants NSF 48-308-30875 and NSF PHY 93-14-783.

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