CIS, A LOW ENERGY BOOSTER SYNCHROTRON FOR IUCF

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1 INTRODUCTION

In late 1994, Indiana University and the NSF jointly funded the construction of a dedicated Cooler injector synchrotron (**CIS**) to increase the luminosity of polarized beam experiments in the Cooler[1]. Presently, stored Cooler beam intensities are limited ($\leq$2 mA) by the modest intensities available from the cyclotrons ($\approx$ 2 μA), and by coherent transverse beam instabilities induced by the high peak currents (phase space densities) resulting from electron-cooling and rf bunching required for accumulation at injection[2]. The new booster is designed to avoid these problems by the bucket-to-bucket injection and longitudinal stacking of over 2.5×10^{10} particles per pulse in the Cooler, filling it with 10^{11} polarized light ions in a few seconds without resorting to electron-cooled accumulation techniques.

The booster is filled via the strip injection of H- ions pre-accelerated to 7 MeV by a coupled RFQ/DTL Linac. For initial ring commissioning, 25 keV H$^-$ from a pulsed Duoplasmatron source and LEBT will be used to fill the ring with unpolarized protons. Construction of a new 200 μA polarized negative ion source for CIS injection will proceed in parallel with this commissioning, leaving the present High Intensity Polarized Source[3] available for ongoing experimental programs. Injected protons are adiabatically captured into a 1st harmonic rf bucket and accelerated to a maximum energy of 216 MeV using a ferrite tuned rf cavity[4, 5], and then single turn fast extracted for transfer and injection into the Cooler ring. CIS, a weak focussing synchrotron, operates below transition[6, 7], and has a cycle time of 1 Hz, although all ramped systems are capable of operating at up to 5 Hz. There are no intrinsic depolarizing resonances and one weak imperfection resonance (108 MeV) for protons accelerated to 216 MeV. A small solenoid ($\int$ Bdl=0.018 T-m) is located in the ring to maintain polarization during ramps. The transmission line from CIS to the Cooler contains two superconducting spin precession solenoids ($\leq$ 1.6 T-m) separated by a 42° bend to permit free selection of spin orientation at Cooler injection. Protons extracted from CIS are injected into the Cooler via an existing injection path and kicked onto the closed orbit using a fast kicker identical in design to the CIS extraction kicker. The Cooler can therefore be filled with beams from either the cyclotron or the CIS ring, a capability which permits the uninterrupted use of the Cooler for experiment during the booster assembly and commissioning period. The layout of the CIS ring, the linac pre-accelerator and the injection and extraction beam lines relative to the existing Cooler ring is provided in Fig. 1. Proton beam performance goals and the ring lattice parameters are summarized in Table I.

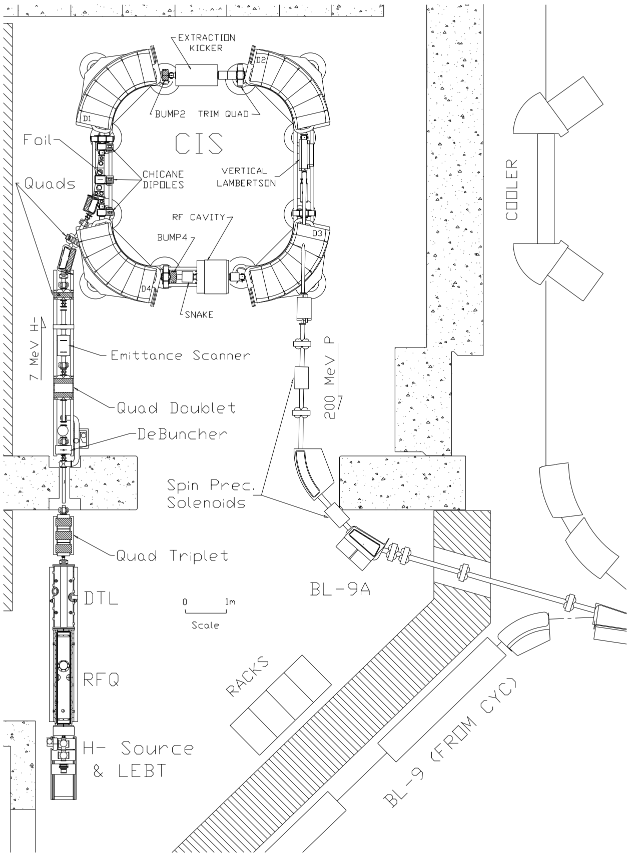

Figure 1: CIS Ring layout.

2 CIS CONSTRUCTION STATUS

2.1 *Source, Pre-accelerator and Injection.*

Protons are injected into the booster by stripping the 7 MeV H$^-$ linac beam on a 4.5μg/cm^2 carbon foil located in the injection straight (see Fig. 1). Tracking calculations predict that beams with a normalized emittance (ϵ_n) of 1.2π μm and a 90% Δp/p of 1% require an intensity $\geq$ 65μA to achieve

Table I. CIS BOOSTER PARAMETERS

I. P. Beam Performance:	**Inj.**	**Ext.**
T Initial Design (MeV)	7.0	216.0
Momentum (MeV/c)	114.8	644.45
Rigidity (Tm)	0.383	2.24
Max. Accum. Emitt. (m)	34.0 π	10.0 π
Dyn. Aperture (Vt,Hz mm)	550×250	380×130
Orbit Period (usec)	0.477	0.0994
Rev. Frequency (MHz)	2.097	10.056
Δ Q @ 2.5×10^{10} part.	0.03	0.006
Ave. I_{circ}. @ 2.5×10^{10} (mA)	6.0	27.0

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	120
Magnetic Field Max. (T)	1.68
5×10^{-4} dB/B Aperture (Vt,Hz mm)	50 $\times$ 90
Hz Tune (Q_x)	1.463
Vt Tune (Q_y)	0.779
Chromaticity (x/y)	-0.53/-0.16
Transition Energy (γ_T (MeV))	1.271 (254)

2.5×10^{10} p/pulse at extraction, assuming reasonable transmission through the ring[8]. Hence, the source, LEBT and linac were designed to transmit a peak beam intensity of $\leq$2.0 mA. The source plasma boundary and LEBT optics were modeled to match the linac injection $\epsilon_n(\leq 1.0\pi\mu\text{m})$, radius ($\leq$1.3mm), and convergence (125 mrad) requirements using the programs *Trak* and *EMP*. A prototype source has delivered a 25 keV pulsed beam (200 μsec pulse width) with a peak intensity of 270 μA. The measured ϵ_n was 0.25π μm, within 10% of the predicted value. The production source and LEBT system, which includes a multi-wire harp emittance measurement system, is installed in the linac vault, and undergoing further development to achieve higher peak intensities ($\approx$ 1 mA). The harp[9], a new diagnostic device for IUCF, was tested during the prototype source commissioning, where it provided accurate realtime beam profile and position data. The Harp was also successfully tested with 7 MeV protons from the IUCF injector cyclotron. This test beam was pulsed to simulate the linac beam pulse structure (200 μs at 1 Hz).

The model PL-7 linac, consisting of a 3 MeV RFQ coupled directly to a 4 MeV DTL, manufactured by AccSys Technology, Inc[1], is on schedule for delivery to IUCF in July, 1996. The RFQ vain assembly and vacuum enclosure are complete. A low power Al cold model DTL chamber was constructed to finalize the cavity dimensions, and fabrication of the production chamber is complete. Assembly of the linac structure and 425 MHz, 360 kW rf amplifiers is continuing. Final linac acceptance tests will be conducted at IUCF in July.

The booster injection beam line optics were calculated using the codes *Trace3d* and *Transport*. This beam line (see Fig. 1) is used to debunch, transmit and match the 7 MeV H$^-$ beam to the ring acceptance at the stripper foil. A quad triplet immediately following the linac produces a double waist at the debuncher (15 mm dia aperture), and is followed by 4 additional quads which can vary the beam at the foil from a 6 mm dia. waist to a ring acceptance match. Provisions are made for non-destructive beam TOF energy measurements, multi-wire harp beam profile and emittance measurements, and BPM position measurements. All 7 quadrupoles and power supplies were obtained as surplus equipment, while the steerers and diagnostics were fabricated in-house. This beam line and all injection system utilities were installed in the linac vault during an accelerator shutdown period beginning this April. Commissioning of the booster injection system will begin upon delivery of the Linac in July, 1996.

2.2 Ring Dipoles and Quadrupoles

The ring design energy and small bending radius (see Table I) require the use of 90° C-shaped laminated dipoles with a radius of 1.27 m, producing a sagitta of 37 cm and a maximum required field of 1.68 T. Axially symmetric 2-d and 3-d field calculations using the computer code *MagNet* [1] were used to optimize the magnet lamination cross section and the dipole endpack pole tip shape to minimize the integrated sextupole field component, now calculated to be smaller than 0.02 m^{-3} at injection over a dipole radial width of 10 cm. Eddy current field aberrations induced by the 1 mm wall inconel dipole vacuum chambers (VC), which are 10 times larger than this at 1 Hz (dB/dt$\leq$4 T/sec), will be corrected with passive windings following the contour of the VC chambers similar to those used on the AGS booster[10]. Design of the VC and correction windings is now in progress.

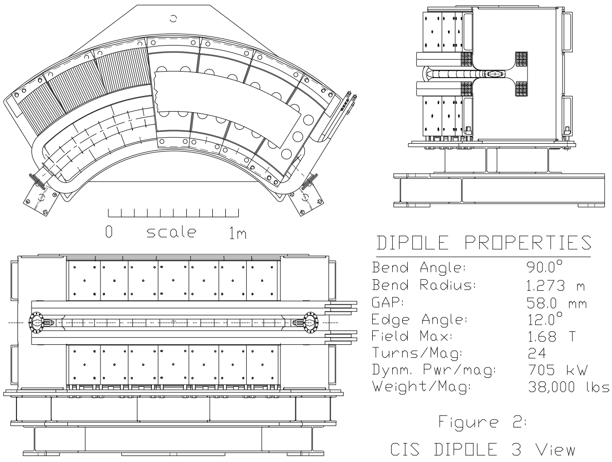

Figure 2: CIS DIPOLE 3 View

The CIS dipole and quadruple magnets are fabricated from 1.5 mm thick modified 1006 steel laminations which were pre-coated with a B-stage epoxy resin prior to stamping. The B-stage resin (Remisol EB-540) serves both as lamination insulation and bonding agent during fabrication, making for a very clean and easy stacking and baking procedure. The main dipole, shown in Fig. 2, is fabricated from 5 wedge shaped and 2 endpack modules which are individually stacked, baked and machined, and then assembled on a precision base plate assembly. The dipole and coil assemblies are being fabricated by Elma Engineering, Inc. The four ring trim quads and two rf cavity bias quads were precision EDM machined from rectangular cores fabricated from sheered rectangular cross section laminations that were stacked and baked in-house. The 1st main dipole arrived at IUCF on April 30, and field mapping is now in progress. All quad cores and coils are fabricated, and the 1st trim quad mapping is complete. Field mapping of the 1st dipole to verify the endpack design is in progress. Delivery of the remaining three dipoles is scheduled for August and September of 1996.

2.3 Fast Extraction

Beam is single turn extracted from CIS via a 0.052 T-m ferrite loaded traveling wave kicker magnet similar to the FNAL 2 m Tevatron injection kickers[11]. The 1 m long CIS kicker produces a 24 mrad horizontal bend causing the beam to jump the 7 mm septum of a Lambertson magnet located 90° downstream (see Fig. 1). The resulting 12° vertical bend steers the beam through a hole bored in the top yoke of the downstream main dipole and out of the ring for transmission to the Cooler. The fast kicker risetime must be $\leq$50 nsec to extract 216 MeV protons who's orbit period is 100 nsec. The physical size and performance of the FNAL design, which required extensive development, is well matched to the CIS kicker requirements. Consequently, we are using the design with only minimal modifications (1 m length, increased impedance), which significantly reduces our development time for this device. In fact, the H-frame CMD5005 ferrite used in our kicker was obtained surplus from FNAL. 2-d and 3-d *MagNet* design of the asymmetric extraction Lambertson dipole is complete, and detail mechanical design of this and the fast extraction kicker are nearly complete, with fabrication beginning in July.

3 CONCLUSION

Assembly of the CIS ring injection system (source, Linac and injection beamline) is complete, and commissioning with beam will begin in July. Final assembly of the CIS ring will take place during an extended IUCF accelerator shutdown beginning in September of 1996. All utilities and vault modifications are installed and ready for final ring element installation. Fabrication of the hardware for the ferrite tuned, quad biased rf cavity is complete, and final assembly is started. The cavity and low level electronics will undergo off-line testing through September, prior to installation in the ring in October. Detail design of the ring straight sections, multi-foil stripping mechanism and vacuum enclosures is underway as well. The ring construction schedule published in March, 1995 called for completion of the ring assembly and the start of internal beam commissioning by the end of March, 1997. Although the first ring dipole was delivered to IUCF 2 months later than scheduled, this still remains a viable possibility today.

The present CIS ring design and construction status is a direct consequence of the work and experience of the IUCF technical and professional staff, as well as several faculty and graduate students, without whom this report would not be possible. In addition, we wish to acknowledge the helpful support, both in ideas, and equipment, of the staff of AGNL, BNL and FNAL. This work is funded by Indiana University and the NSF under grants NSF 48-308-30875 and NSF PHY 93-14-783.

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