THE LENS 7 MeV, 10 mA PROTON LINAC*

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Abstract

The Indiana University Cyclotron Facility (IUCF) has constructed and placed in operation a Low Energy Neutron Source (LENS) using a 10 mA, 7 MeV proton beam incident on a beryllium target. The proton delivery system (PDS) consists of a 25 keV proton injector, an AccSys Technology, Inc. PL7 Linac [1] and a proton beamline (PBL) with non-linear beam spreading [2]. The accelerator and beamline equipment used in this construction are refurbished and upgraded components from the IUCF CIS/Cooler synchrotron [3] facility. After commissioning the beam current at 7 MeV will be 10 mA with a pulse width of up to 300 μs and > 1% duty factor. The PDS was constructed and commissioning started in 2004. First operating results will be described.

INTRODUCTION

The IUCF Low Energy Neutron Source is the first university-based accelerator driven pulsed neutron source [4]. It will provide beams of cold neutrons with variable pulse length from 5 μs to 1 ms. The intensity of these neutron beams is suitable for applications in material science, studies of neutron moderators, and exploring new ideas in neutron technologies and instrumentations.

Neutrons are being generated in a (p,nx) reaction on beryllium. To provide a competitive flux of neutrons the facility will eventually use a 100 mA, 13 MeV proton beam with a duty factor as high as 5%. These final requirements for the proton beam are being achieved in two phases. The main accelerator parameters for each phase are listed in the Table 1. To date the accelerator has routinely operated at 10 mA beam current with 200 μs pulse length and 30 Hz repetition frequency.

Table 1: List of LENS accelerator parameters

Parameter	Phase I	Phase II
Initial beam energy	25 keV	75 keV
Final beam energy	7 MeV	13 MeV
Peak current	20 mA	100 mA
Beam duty factor	~1%	~5% (50 mA)
Pulse width	5-300μs	0.5-1300 μs
Pulse repetition frequency	1-30 Hz	1-200 Hz
Peak beam power	≤0.14 MW	≤1.3 MW
Average beam power	≤1.4 kW	≤32.5 kW
Operating frequency	425 MHz	425 MHz

After acceleration, protons are delivered to the Target-Moderator-Reflector (TMR) system by a non-linear beam transport line. In Phase II, the target will be designed to handle an average beam power of 32.5 kW. The non-linear beam transport line is designed to limit the power to less than 650 W/cm^2.

Once produced, neutrons slow down in a frozen CH_4 moderator. Cold neutrons are distributed to the experimental hall via three neutron beamlines. One is for a Small Angle Neutron Scattering apparatus. One is for radiography studies. And one neutron beam line is for the investigation of new instruments. We also plan to construct a second target station, which will be devoted to research into neutron radiation effects in electronics.

PROTON INJECTOR

The duty of the Proton Injector (PIJ) (Figure 1) is to form a 22 mA, 25 keV proton beam matched to the acceptance of the RFQ. The principal components of the PIJ are the microwave ion source and Low Energy Beam Transport system (LEBT).

The design of the LENS microwave ion source is similar to the source on the IUCF cyclotrons [5]. Power from a 1.2 kW, 2.45 GHz magnetron excites the plasma. Protons are extracted through a 7 mm emission aperture by a three electrode extraction system. The geometry of the extraction system and beam transport to the RFQ was calculated with PBGUNS [6]. Results of the simulation are shown in Figure 2.

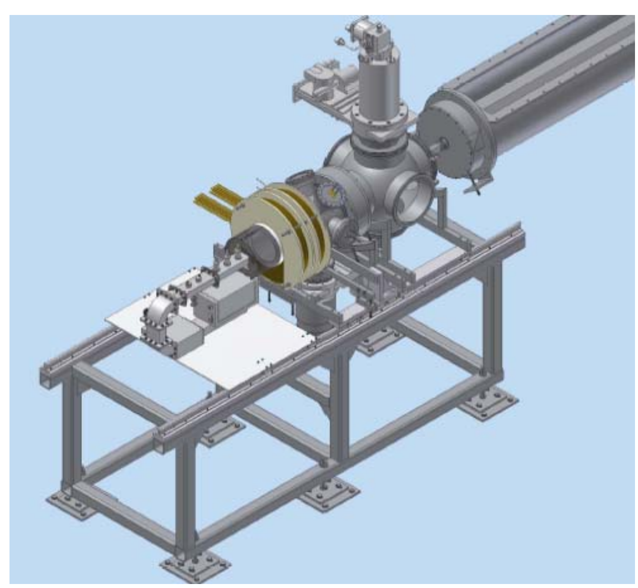

Figure 1: LENS ion source.

* This work is supported by the National Science Foundation under grants DMR-0220560, and DMR-0320627, by the Indiana 21st Century Science and Technology Fund, by the Department of Defense and by the Indiana University.

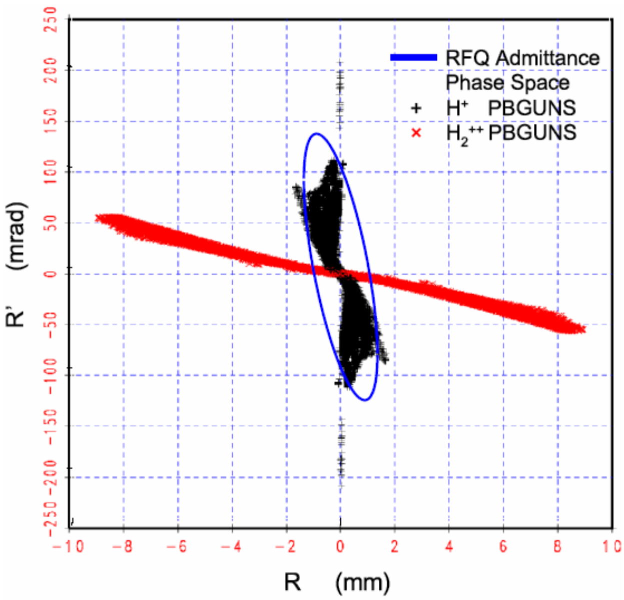

Figure 2: Calculated phase space of H$^+$ and H^{2+} beams at the entrance of the RFQ. The Twiss parameters of the RFQ admittance ellipse are α=0.87, β=0.0137 mm/mrad, ε=1.0 π·mm·mrad (normalized to β·γ).

The extraction system and source body are water cooled. The first extraction electrode has a molybdenum insert to reduce sputtering. It is isolated from ground and attached to a -10 kV power supply. The second electrode can serve as an electron suppresser and is designed to hold up to -1 kV

The 25 keV LEBT consists of two solenoids which match the beam to the RFQ. A set of steerers between the solenoid corrects for misalignment. The LEBT also has two water cooled tantalum apertures which collimate the beam and eliminate the beam halo. Beam current is measured by water-cooled, compensated Faraday cup. Transmission through the LEBT is greater than 80%. The RFQ was originally designed for a large emittance, 1 mA polarized H$^-$ beam but was determined to be able to accelerate up to 20 mA with 85% transmission. To measure the beam current injected into RFQ we installed AC beam current transformer.

During development the ion source produced 42 mA of continuous beam current containing ~85% protons. The same peak beam current was measured while pulsing the magnetron on for 1 ms at 30 Hz. The rise time of beam pulse is about 200 µs compared to the user requirement of a 5 µs beam pulse. A relatively long rise time imposes a limit for the minimum pulse length coming out of the ion source but turning on the accelerator after the ion source pulse reached the full current seems to be acceptable and in this way a 25 µs pulse width with a rise time of less than 3 µs is achieveable.

ACCELERATOR

To accelerate protons we use an AccSys Technology, Inc. PL7 Linac formerly used as an injector for the IUCF Cooler Injector Synchrotron [3]. This accelerator consisting of a 3 MeV RFQ coupled directly to a 4 MeV DTL, and was originally designed to accelerate 1 mA of H$^-$ ions. Two 350 kW, 425 MHz amplifiers power this linac and were built for a duty factor less than 0.2%. To accommodate the PL7 linac to LENS operation several upgrades were undertaken. The RFQ vanes were rotated by 90 degrees to provide a matched H$^+$ beam to the DTL. Increasing the duty factor required redesigning the cooling systems for the RFQ, DTL and Post Couplers, adding higher power supplies for the tube anodes and improving the cooling of the tubes on the amplifier. The cooling system is now capable of removing 6 kW from the RFQ and DTL cavities, and 1.3 kW from the post couplers with the temperature regulated to ±0.1°C. The 12-tube 425 MHz amplifier assemblies were modified to operate at a duty factor of up to 2.0% but tube reliability limits the pulse width to less than 300 µs. The manufacturer's recommendation is to run under the maximum power of 350 kW at < 100 µs pulse length. Since these tubes are no longer in production, extending its lifetime becomes an important issue.

The normal operating with the Linac is for 10 mA of proton beam with 200 µs pulses at 20 Hz repetition rate delivered to the neutron target. With the currently installed 350 kW amplifiers the maximum we can reach is a 30 Hz repetition rate and 300 µs of 10 mA beam.

The maximum power of the amplifiers also limits the total beam current. Loading the DTL amplifier with >10 mA at 0.5% duty factor leads to saturation of the DTL amplifier. We have been able to get almost 12 mA through the with a 25 µs pulse length, however, problems with the DTL amplifier tripping preclude reliable operation in such a mode.

PROTON BEAMLINE

In Phase II, a crucial design issue is that the Be target will be exposed to a significant amount of beam power. In the final design the average thermal load of the Be target will be limited to 650 W/cm^2. To achieve this power density, the beam needs to be uniformly distributed over 6x6 cm^2 area and incident on a target mounted at 45° to the beam. Beam spreading will be achieved by a non-linear beamline designed at IUCF. Our proton beam line (PBL) makes use of two octupole magnets (Figure 2) to transform a Gaussian beam profile into a rectangular profile. Details of the PBL design are reported at this conference [2]. The octupole magnets require very precise positioning relative to the beam. In fact, the beam position at the entrance to both octupoles needs to be accurate to ±1 mm. To control the beam position we will install beam profile monitors – harps – at the entrance of each octupole and in front of the Be target. Each harp provides a beam profile in x-y dimensions. Our harps, which will use a tungsten wire of 0.002 cm in diameter, were designed with great help from LANL and SNS [7,8]. A major design concern is to keep the wire temperature within an operational range. The estimated temperature of

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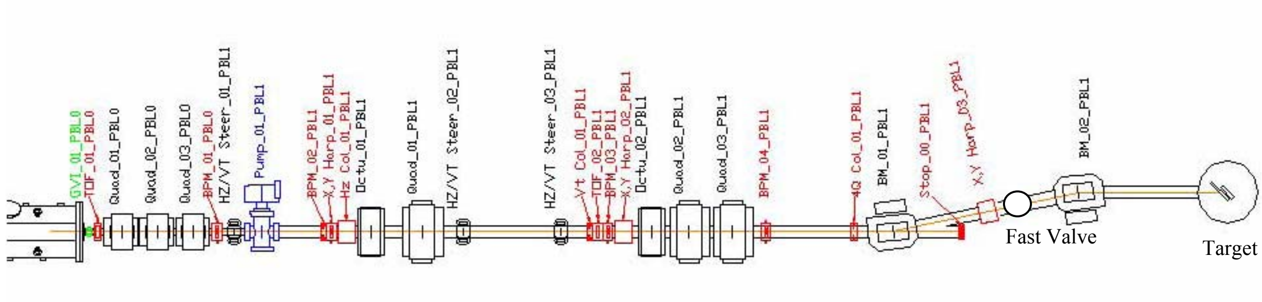

Figure 3: LENS non-linear beamline.

wires exposed to 20 mA with a 20 μs pulse width at 16 Hz is slightly below 1500 ºC. This temperature is a reasonable limit for taking measurements with wires [8]. Increasing the beam current to 100 mA requires reducing both the beam pulse length and repetition rate to 10 μs and 2 Hz to keep wires from melting. An important engineering issue of our harp design is to measure the profile of beam which is very small in one dimension at the entrance of each octupole. The calculated beam size at the entrance of the 1st harp is 4 cm x 0.3 cm. To measure the profile of such a beam, a vertical spacing of ~0.4 mm was designed.

High power beam in Phase II can seriously damage equipment in the event of undesirable beam losses. We are planning to develop beam spill control system enable to shut down the beam as soon as beam hitting any equipment or vacuum chamber is detected or beam losses exceed the certain value. Radiation safety however is not in particular concern. All slits and collimators are made from Carbon to reduce the possible neutron production. To protect the beamline in case of the target failure we have installed a fast valve, which closes the PBL and isolates vacuum within 7-8 ms. Two bending magnets installed in the last section of the PBL help to shield the accelerator from neutrons going backward from the TMR assembly. When the bending magnets are off, beam is directed onto a beam stop.

RESULTS OF NEUTRON EXPERIMENTS

At a proton beam energy of 7 MeV, the expected neutron yield is 10^{13} n/s/mA. At the final design energy of 13 MeV we expect more than 3 times greater yield [9]. The first neutron experiments were conducted with a simple room-temperature polyethylene moderator at 14 μA average proton current [10]. A sample collected thermal neutron spectrum is shown in Figure 4. At writing of this paper, we have begun to commission a frozen methane moderator. To date the performance of the LENS is within expectations.

ACKNOWLEDGEMENTS

We thank Jim O'Hara of LANL and Mike Plumm of SNS for their professional assistance in designing harps. Also special thanks to Alexander V. Klyachko for running the PBGUNS simulation in this paper. The hard work of many IUCF employees has made this construction project a success.

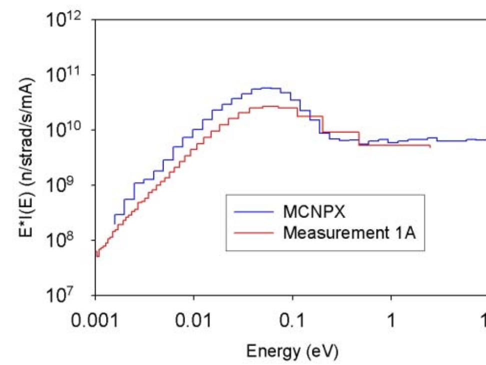

Figure 4: Measured and calculated thermal neutron spectrum at 7 MeV 14 μA average proton current [10].

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