

## UPGRADE OF THE LENS PROTON LINAC: COMMISSIONING AND RESULTS\*

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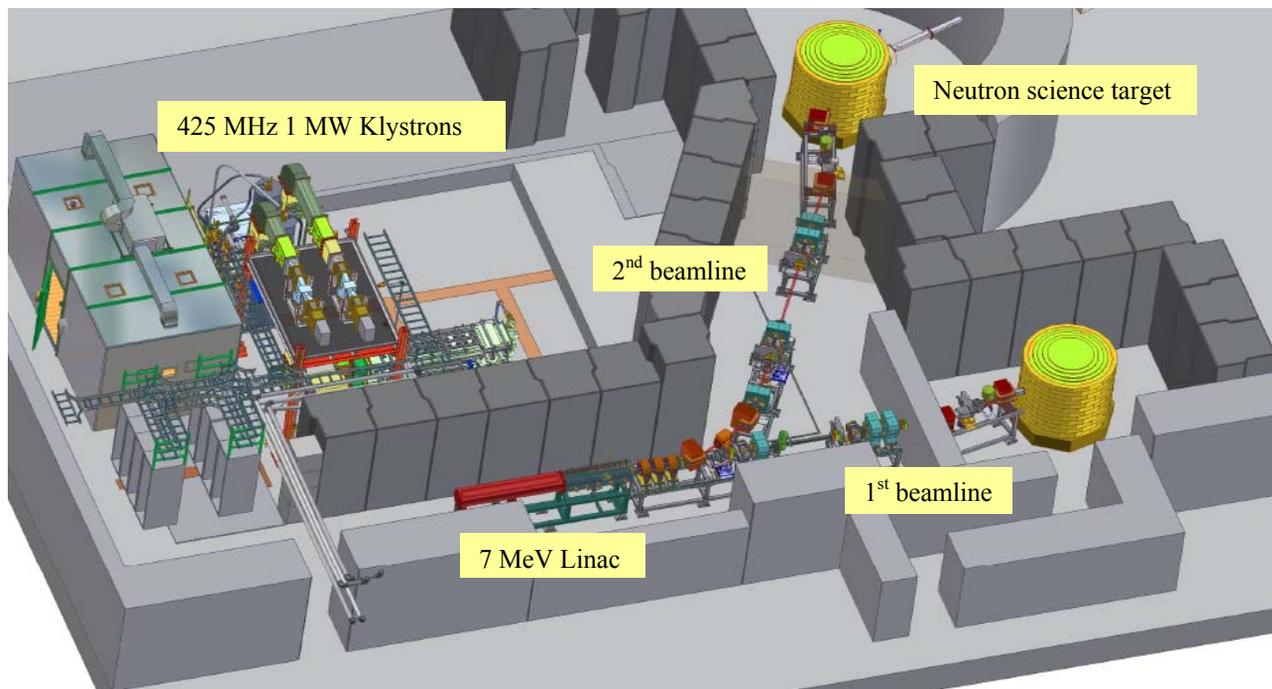


Figure 1: General layout of the LENS facility.

### Abstract

The Indiana University Cyclotron Facility is operating a Low Energy Neutron Source which provides cold neutrons for material research and neutron physics as well as neutrons in the MeV energy range for the neutron radiation effects studies. Neutrons are being produced by a 7 MeV proton beam incident on a Beryllium target. Since the first commissioning of the LENS Proton Delivery System (PDS) in December 2004 its performance has been significantly improved. The RF system of the accelerator has been upgraded by replacing 350 kW 425 MHz 12 tube amplifiers with two Litton 5773 klystron RF tubes capable of running at 425 MHz and 1.25 MW. Since the commissioning of the klystrons, a proton current of 25 mA at 7 MeV and 0.6% duty factor has been successfully delivered to the Beryllium target. A future part of this upgrade will introduce a new 6 MeV DTL section to increase proton beam energy from 7 to 13 MeV. The 3 MeV RFQ and 4 MeV DTL will be powered by one klystron and the 6 MeV DTL will be powered by the second klystron. The expected output is 25 mA and 13 MeV of proton current at 0.6% duty factor. A second target station has been added to allow separate source optimization for the two primary research programs (cold

neutrons and radiation effects). Other upgrades include increasing the RF duty factor to 3% through the installation of a new power supply for the klystrons. In this contribution we discuss the results of the commissioning of the new RF system, second beamline and second target station, as well as improvement in the beam parameters after these upgrades. The future plans will also be outlined.

### INTRODUCTION

The Low Energy Neutron Source at Indiana University is an accelerator driven pulsed neutron source [1]. Neutrons are generated in (p, nx) reactions on a beryllium target. LENS is designed to provide cold neutrons as well as neutrons in MeV energy range with a pulse length variable from 10  $\mu$ s up to  $\sim$  1.4 ms. The areas of potential research for the facility include material science, studies of neutron moderators, neutron technology and instrumentation development [1] and neutron radiation effects research [2].

The general layout of the LENS facility is shown in the Fig. 1. Two separate target assemblies have been installed. The first target with a high energy, high average neutron flux will be devoted to the neutron radiation effects research program (NRERP). The second target is coupled to a custom moderator tailored to generate cold and very cold neutrons for neutron scattering applications.

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Both target assemblies share the same design of the beryllium target.

The first beamline has been in routine operation since December 2004. In March 2007, an octupole beam spreading system was tested on the first beamline [3]. The system makes a proton beam uniformly distributed over the surface of the target to prevent the excessive thermal load. Construction of the second beamline was finished in May 2007.

Table 1 summarizes the accelerator parameters for LENS in both present configuration and the design goals for the present accelerator after upgrades to the power supply and cooling systems. Further below we describe the details of these upgrades.

Table 1: LENS Parameters

	<b>Achieved</b>	<b>Goal</b>
Initial beam energy, keV	25	25
Final beam energy, MeV	<b>7</b>	<b>13</b>
Peak current, mA	25	25
Beam Duty factor, %	<b>0.6</b>	<b>2.5</b>
Pulse width, $\mu$ s	<b>10 – 300</b>	<b>Up to 1400</b>
Pulse frequency, Hz	<b>5-20</b>	<b>Up to 30</b>
Peak beam power, kW	<b>175</b>	<b>325</b>
Average beam power, kW	<b>1</b>	<b>8</b>
Neutron Flux, n/s	<b><math>10^{12}</math></b>	<b><math>10^{13}</math></b>

## LENS RF SYSTEM UPGRADE

The construction and initial tests of the new RF system consisting of two Litton 5773 klystron RF tubes was completed in December, 2006 [4]. Details on the LENS klystron systems are presented elsewhere at this conference [5]. After the accelerator conditioning the power delivered to the accelerator was  $\sim 900$  kW with the klystrons running at 0.9% duty factor. Transmission through the accelerator was more than 60%; the total  $H^+$  beam measured at the RFQ entrance was about 42 mA and at 7 MeV was over 25 mA. Overall experience with the klystron based RF system proved to be very positive. The klystrons operate reliably with only a few trips.

Installation of the klystrons allowed us to decrease proton pulse length to 10  $\mu$ sec with a rise time of 2  $\mu$ sec in addition to increasing the available peak current from 10 mA to 25 mA. The smaller pulse width is a significant improvement over the minimum pulse length of 50  $\mu$ sec available with the old RF system and this feature will be exploited for some of the studies on neutron instrumentation and moderators at LENS.

Currently, the 1 A, 100 kV high voltage supply which powers the klystron tubes sets a limit on the beam duty factor to 0.6%. In October, 2007 we are planning to replace the existing high voltage supply with a supply capable of providing 5 A at 100 kV. After this upgrade the klystrons can operate with a duty factor more than

4%. However potential overheating of the existing accelerator will limit the RF duty factor to  $\sim 3\%$ . At present this corresponds to a beam duty factor of roughly 2.5%, but modifications to the RF system are being prepared that should allow us to increase the beam duty factor by reducing the RF turn-on and shut-off times [5].

## ACCELERATOR UPGRADES

### *New 13 MeV, 50 mA DTL*

The accelerator will be upgraded to 13 MeV beam energy in the fall of 2007. A new DTL designed by AccSys Technology, Inc. [6] will accept a 50 mA proton beam from the existing PL-7 [7] and accelerate it to 13 MeV with the transmission of essentially 100%. The maximum RF duty factor of the new DTL is 6%. RF pulse width can be varied in the range from a few  $\mu$ sec up to 2 msec, while RF repetition rate is anything from 1 to 120 Hz. The new DTL will be connected directly to the PL-7 with no matching section. The 1.8 m long DTL tank will consist of 17 drift tubes with a FODO focusing structure. To produce the designed accelerating field, the new DTL will consume 450 kW of peak power at 425 MHz with no beam loading. Acceleration of 50 mA beam will require 750 kW of peak power, which will be coupled into the linac inductively using a water cooled drive loop. The new DTL section will be powered by the second klystron while the existing PL-7 will be powered by the first klystron.

The new DTL is designed to operate at RF duty factor up to 6%, however the maximum average power that the existing PL-7 accelerator can handle sets the limit on the RF duty factor to  $\sim 3\%$ . At this high duty factor a number of measurements on the PL-7 temperature will be performed to estimate the potential overheating problem. Going higher than 3% requires considerable changes in the PL-7 cooling system as well as a redesign of drive loops on both the pre-existing RFQ and DTL.

### *New 75 kV Injector and 3 MeV, 100 mA RFQ*

Future upgrades of the accelerator system include a construction of a new 3 MeV, 100 mA RFQ designed by TechSource, Inc. [8] as well as a new "LEDA style" (Low Energy Demonstration Accelerator) 75 kV proton injector [9]. The new RFQ is designed to provide 100 mA of 3 MeV beam with 6% duty factor. Additionally the RFQ will also be capable of delivering 3MeV, 50 mA of proton beam at 6% duty factor matched to the existing PL-7 DTL. The RFQ will be 3 m long and will consume no more than 1 MW of peak power to accelerate 100 mA of beam current. The new RFQ will be close coupled to the existing PL-7 accelerator with no matching section. Currently the RFQ is under construction in ACCEL Instruments GmbH [10]. The construction is scheduled to be completed in August, 2007. However, installation of this new RFQ will require additional funding to construct a new injector and additional RF power.

As an injector for the new RFQ we have designed a 75 kV extraction and low energy transport line for the

existing ion source. [11] The proton injector is roughly based on the design of the LEDA source [9]. The 75 kV injector will provide 115 mA of 75 keV beam matched to the new RFQ. We hope to secure the funding for installation of the new 3 MeV, 100 mA RFQ and construction of the new 75 kV proton injector within the next 3 years.

## PROTON BEAMLINES

The LENS facility utilizes two beamlines that deliver a proton beam to each target station. Both beamlines have similar configuration. Both lines feature a nonlinear beam spreading system, which is used to make a beam uniformly distributed over the target surface. The first beam transport line provides a proton beam for the NRERP target. The second beamline delivers a beam to the target devoted to the neutron scattering experiments.

We have developed beam profile monitors (harps) to monitor beam profiles and position. There are three harps along each beamline. Our harp design utilizes 20 micron tungsten wires with 2 mm wire spacing for profile measurements. A number of measurements with the harps were taken to determine beam emittance at the exit of the accelerator. A quadrupole scan technique was applied. The emittance derived from these measurements is described in Fig. 2. Operation of the harps is limited to low beam power to prevent the harp wires from being destroyed by a beam. For monitoring of a beam at high power we are developing beam position monitors.

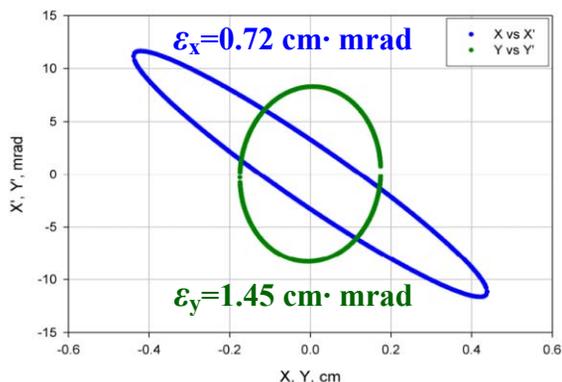


Figure 2: Measured beam emittance at the exit of the accelerator.

Other diagnostics include a beam imaging system based on a CID camera [3] capable of running in high radiation environment. Beam losses along the beamlines will be estimated by a system based on Bergoz Current Transformers (CT) [12] installed at the exit of the accelerator and at the end of each beamlines. More details on the beamline performance can be found in [3].

## NEUTRON PERFORMANCE

The installation of the second target station was completed in May, 2007. The second target will be devoted to neutron scattering experiments and material science. Under construction are beamlines for small angle

neutron scattering experiments and for neutron spin echo scattering angle measurements (SESAME) [13].

A significant contribution of the LENS can be envisioned in the experiments with long neutron pulses (on the order of milliseconds) as well as in the area of research with cold and very cold neutrons ( $T_{\text{spec}} < 10$  K). The scientific emphasis for neutron scattering at LENS will be the development of very-cold neutron moderators (to increase the brightness at long wavelengths) and the exploration of large-scale structures in materials using those long-wavelength neutrons.

## CONCLUSION

Currently the LENS facility is going through a series of upgrades. These upgrades include the installation of a new RF system based on the Litton 5773 klystron RF tubes, construction of a second beamline, installation of an addition DTL section to raise the energy from 7 MeV to 13 MeV, and construction of a second target station for neutron scattering experiments. By December 2007, we expect to get 25 mA of 13 MeV proton beam at up to 2.5% duty factor delivered to either of two targets. Target irradiation will be uniform to avoid an excessive thermal load. Neutron flux will be improved by an order of magnitude over previous operation.

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