



bending magnets with an intervening quadrupole. The beamline continues with a nonlinear beam spreading system which utilizes octupole magnets in a configuration similar to the first beamline. The second beamline is presently under commissioning. In the first experiments on the second beamline we were able to deliver to the target more than 20 mA of proton beam with 0.02% duty factor. At the end of both beamlines there are two 12° bending magnets in a dogleg configuration to limit activation of accelerator and beamline equipment from back-streaming neutrons.

Octupole magnets are inherently nonlinear elements that couple the particle motion in x and y dimensions. To minimize coupling, a beam at the entrance to an octupole is tuned to be very narrow in one dimension and wide in the other. Moreover, octupole magnets require very precise positioning relative to the beam. The beam position at the entrance to both octupoles needs to be accurate to  $\pm 1$  mm. To control the beam profile and position we have installed beam profile monitors – harps – at the entrance of each octupole and in the two dogleg sections [6]. Each harp provides a beam profile in x-y dimensions. The harp electronics readout is programmed in a way that allows background subtraction. The 20 micron diameter of the harp wires limits the operational range of the harps to low power level. The estimated temperature of the wires exposed to 20 mA with a 20  $\mu$ s pulse width at 16 Hz is slightly below 1500 °C. This temperature is a reasonable limit for taking accurate measurements with wires. At higher temperatures thermionic emission of electrons disturbs the accuracy of measurements.

As a way of monitoring the shape of a beam going to the target we have installed a scintillator viewer on an actuator mechanism located between two bending magnets in the dogleg area. This viewer is a water cooled carbon plate coated with a dusting of alumina powder. The uniformity of the  $\text{Al}_2\text{O}_3$  powder was poor and so the viewer was only used as a qualitative assessment of the beam profile.

Light produced by the beam hitting the viewer is captured by a radiation resistant CID camera [7]. The camera is connected to a computer through a frame grabber and operates through a LabView interface. This gives us a way to manipulate and analyze beam images.

High power beam can seriously damage equipment in the event of undesirable beam losses. To monitor beam losses we are developing a system based on Bergoz [8] current transformers (CT). There is a CT installed at the exit of the accelerator. In addition, each beamline has a CT measuring the current of the beam going to the target. Comparing the readouts of the CTs at the beginning and at the end of the beamlines will be one way of estimating beam losses.

All slits and collimators along the lines are made from carbon to reduce the possible neutron production from beam lost in the transport lines. To protect the beamlines in case of the target failure we have installed fast valves,

which close the beamlines and isolates vacuum within 7 - 8 ms.

At the end of each beamline there is a diagnostic beam stop capable of measuring proton beam current. When the dogleg bending magnets are turned off, beam is directed onto this beam stop.

### Simulations

The basic parameters of the beamlines were defined in the first order simulations with TRANSPORT [9]. These simulations give us the settings of the beamline elements that produce the required beam profiles at the entrance to each octupole. The results of the first order simulations are shown in Fig. 2. The 3<sup>rd</sup> order effects of octupole focusing as well as misalignment effects were studied with TURTLE [10]. The details can be found at [11].

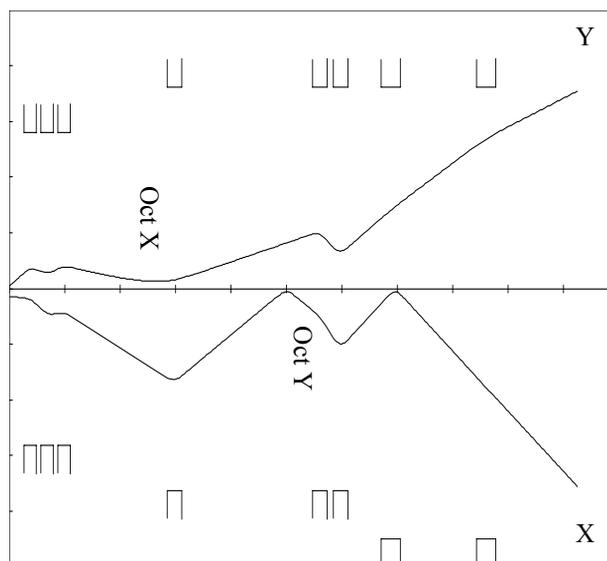


Figure 2: Transport calculation of the beam envelope in the first beamline. The beam is tuned for the octupoles.

## EXPERIMENT ON BEAM SPREADING

### Beamline Alignment

The first results of the beam spreading system were obtained on the first beamline. Strong tolerance on the beam position in front of an octupole required a good alignment of the beamline. Moreover we discovered that the proton beam was coming out from the accelerator with a horizontal angle on the order of a few mrad. A steerer magnet was installed at the exit of the accelerator to correct this angle. We used the harps for measuring the position of the beam center. Harp positions were aligned using optical surveying techniques. Each quadrupole magnet position was adjusted until its steering effect was less than 1 mm, as measured by the harps.

### Experiment

Two goals were set for the experiment. The first goal was to get a uniformly distributed beam on the viewer.

Secondly we wanted to analyze the performance of the alumina powder that covers the viewer. The initial tests with the viewer showed that the alumina powder didn't have enough dynamic range to prove useful in the low power mode that is required for harps. For this reason in the low power experiments we used beryllium oxide ceramic as a scintillator material. In our experiment the average beam current was reduced to  $\sim 100$  nA and the peak current of  $\sim 1$  mA was quite enough for measuring beam profiles on the harps and scintillator.

The strategy of tuning the beam with the octupoles follows. Once the misalignment of the beam line elements was corrected, we adjusted the quadrupoles and used the harps to verify that the beam had the required shape in front of each octupole. By tuning the octupole magnets we were able to observe a beam that was uniformly distributed over  $2 \times 2$  cm<sup>2</sup>. The effect of the octupoles on the beam is shown on screenshots from the LabView program (Fig. 3). On the left side of the screenshot is an image of the beam from the CID camera with background subtracted. On the right side is the beam profile measured as grayscale intensity distribution along any desired line (green lines in Fig. 3). A dip at the center of the X-profile corresponds to a gap between 2 pieces of Be oxide that were glued together. However the Y-profile shows the typical distribution with "batman ears".

### CONCLUSION AND FUTURE DEVELOPMENT

To prevent excessive thermal stress caused by a proton beam at the surface of the Be-target we use an octupole beam spreading system to produce a beam with uniform intensity distribution. The experiments with low beam power showed the effectiveness of our octupole system. However more experiments are planned to test the system at high power. We are also discussing an image intensifier as a possible way to monitor beam scintillation on the residual gas. Optimization of the imaging system includes tests of different scintillator materials and adding camera filters. The final goal is to get a uniform beam on the target instead of the viewer. It can be done by retuning the line according to simulations. To verify beam distribution on the target we are investigating possible ways of looking with a camera directly at the target.

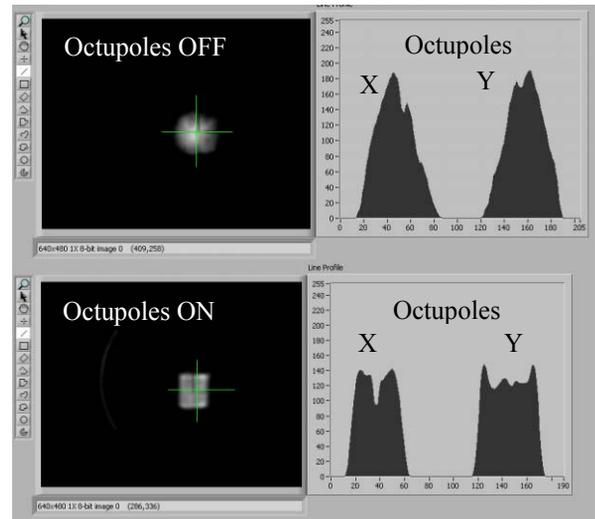


Figure 3: Beam spot on the viewer (left) and beam profiles (right).

### REFERENCES

- [1] A. Bogdanov et al., "Upgrade of the LENS Proton Linac: Commissioning and Results", this conference.
- [2] W. A. Reass et al., "The Klystron RF Systems for the Indiana University "LENS" Accelerator", this conference.
- [3] AccSys Technology, Inc., 1177 Quarry Lane, Pleasanton, CA 94566-4757.
- [4] D. Baxter et al., NIM A 542 (2005) 28-31.
- [5] B. von Przewoski, et. al., "Neutron Radiation Effects Program at the Indiana University Cyclotron Facility", ICANS-XVII, Santa Fe NM, 2005.
- [6] V. P. Derenchuk, et al., "The LENS 7 MeV, 10 mA Proton Linac", PAC'05, Knoxville, July 2005, p.3200.
- [7] Thermo Scientific, www.thermo.com.
- [8] Bergoz Instrumentation, www.bergoz.com.
- [9] PSI Graphic Transport Framework by U. Rohrer based on a CERN-SLAC-FERMILAB version by K. L. Brown et al.
- [10] PSI Graphic Turtle Framework by U. Rohrer based on a CERN-SLAC-FERMILAB version by K. L. Brown et al.
- [11] W. Jones, et al., "Non-Linear Beam Transport for the LENS 7 MeV proton beam", PAC'05, Knoxville, July 2005, p.1704.