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HIGH ENERGY BEAM TRANSPORT ALONG THE 68-m LANSCE 1L BEAMLINE TO OPTIMIZE NEUTRON PRODUCTION *

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Abstract

An 800 MeV proton beam of up to 150 μA is accumulated in the LANCSE Proton Storage Ring (PSR) for 1800 turns and delivered to the Lujan Center, one of five user facilities at the LANSCE linear accelerator center, to generate an intense beam of pulsed neutrons for studies in academia, national security and industry. The Lujan Center beam transport line, known as 1L beamline, is over 68 meters in length, starting from a wire scanner ROWS01 in the extraction line of PSR. The beamline consists of several bending and focusing elements and ends at the 1L target where the beam spot size is nominally 3 cm (2RMS). The next 1L target, Mark IV target, has been designed to optimize the neutron production for the Lujan center to improve high energy flux and resolution. As part of the safety review of this design, it is necessary to know the beam intensity and size on the new target. Alignment data of the beam line was measured with a laser tracking system and was compared with legacy measurements. Using the new measurement of the beamline, calculated beam sizes using the LANL version of the beam envelope code TRANSPORT and CERN code MAD-X are compared. The input beam parameters for the codes were extracted from an ORBIT code [1] analysis of the proton storage ring beam. The beam envelope measurements were made at various locations throughout the beamline using wire scanners. The predicted beam envelopes and measured data agree within expected errors.

INTRODUCTION

An 750 keV H$^-$ beam is accelerated using a Drift Tube Linac (DTL) and a Couple Cavity Linac (CCL) to an energy of 800 MeV and transported to user facilities [2–4]. One of the facilities is the Lujan Center (1L) that utilizes 800 MeV proton beam for neutron production. The 1L beam transport line, starting from wire scanner ROWS01, is composed of many bending and focusing elements before it reaches the 1L target system, where the beam spot size is nominally 3 cm (2RMS). Small field variation of the beamline quadrupoles and/or bending magnets from the standard tune can frequently lead to significant radiation from beam spill, beamline elements damage, and beam-time loss, etc. Therefore, simulation of the beam envelope throughout the length is crucial in understanding the beam bunch distribution during transport. Once the envelope is in good agreement with diagnostics measurements, this information will significantly improve our ability to predict how each optical element responds with various beam conditions. Though the 1L beam transport line was studied previously using the code TRANSPORT [5], many updates have been conducted over the years. Moreover, it is a good opportunity to utilize the modern MAD-X [6] code that is used across the accelerator community for accelerator design at present. Comparison of the measured beam envelope and the prediction from codes is important.

In this report, we present the beam sizes obtained using the Fermilab modified version of the TRANSPORT beam envelope code, modern accelerator design code MAD-X, and beam size measurements along the beamline. The input beam parameters for the codes were extracted from an ORBIT [1] analysis of the proton storage ring beam. The input parameters utilized in the codes are discussed. Measured data are compared to models and the results are extracted to have an estimate of the beam size at the 1L target.

1L BEAMLINE

The 1L beamline starting at ROWS01, consists of 20 quadrupole, 8 bending magnets, 5 wire scanners for beam profile measurements, 11 beam position monitors (BPMs), current monitors, vacuum system, and associate mechanical and electrical systems. The effective lengths of each quadrupole vary from 0.56 m to 0.7 m with half aperture 0.05 m to 0.077 m. These magnets are powered for 1.7 kG to 3.88 kG field. Three 30° beam bending magnets are located upstream of the target, and used to bend the beam a total of 90° to place the beam on target which is surrounded by a safety shielding. Detail of the 1L beamline is not addressed in this report.

Table 1: Basic Relationship of Twiss Parameters

Parameters		
Beam	Horizontal (x)	Vertical (y)
Beam size (cm)	$x = \sqrt{\sigma_{11}} = \sqrt{\varepsilon_x \beta_x}$	$y = \sqrt{\sigma_{33}} = \sqrt{\varepsilon_y \beta_y}$
Divergence (mr)	$x' = \sqrt{\sigma_{22}} = \sqrt{\varepsilon_x \gamma_x}$	$y' = \sqrt{\sigma_{44}} = \sqrt{\varepsilon_y \gamma_y}$
x- x' correlation	$\alpha_x = \frac{r_{12}}{\sqrt{1-r_{12}^2}}$	$\alpha_y = \frac{r_{34}}{\sqrt{1-r_{34}^2}}$
Twiss parameter	$\beta_x = \frac{\sqrt{\sigma_{11}}}{\sqrt{\sigma_{22}}} \sqrt{\left(1+\alpha_x^2\right)}$	$\beta_y = \frac{\sqrt{\sigma_{33}}}{\sqrt{\sigma_{44}}} \sqrt{\left(1+\alpha_x^2\right)}$

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BEAM PARAMETERS

To calculate the beam parameters, some basic relations of Twiss parameters are listed in table 1. The symbols have their usual physics meanings.

The beam emittance for x and y distributions, at the wire scanner ROWS01, were calculated as 3.60×10^{-5} m-rad and 4.72×10^{-5} m-rad for a beam size (2rms) of x=2.096 cm and y= 1.3265 cm. Also, correlation parameters r_{12} and r_{34} of -8.8762×10^{-1} and 1 (dimensionless), respectively, were used. These parameters produce a horizontal beam converging parameter (α_x)=1.927, and a vertical divergence parameter (α_y)=-0.4. Thus, the ratio of square of the beam size and emittance for corresponding horizontal and vertical directions were of β_x=12.175 m, and β_y= 3.72m. The beam bunch length is calculated by

$$SIGT = \frac{P_W \times C_{ring}}{TOF} = 73.093m \tag{1}$$

where, $P_W = 290 \times 10^{-9}$s is the pulse pattern width and the circumference of the ring, C_{ring}, is 90.26 m. From the frequency of 201.25×10^6Hz, a reference frequency of 2.792×10^6 Hz is created for the ring. This produces a Time of revolution (TOF) of 358.112×10^{-9}s for the ring.

Additional input parameters such as: (1) the phase length deviation, (2) momentum, and (3) the momentum-spread were required. These were calculated as follows.

Longitudinal beam extension: Once the phase is given in units of radian, the longitudinal beam extension is equal to $\frac{\phi}{2\pi} \times 90.27m$ or 14.30 m for 1 rms and we have used 28.72 m for the 2rms configuration.

Momentum and momentum spread : The beam momentum at the center of beam axis (p_0) is

$$p_0 = \beta_{(800)}\gamma_{(800)}\frac{E_0}{c} \tag{2}$$

where the proton rest energy E_0=938.25 MeV. The momentum of central trajectory, p_0, of a 795.1 MeV beam with $\gamma_{(800)}$=1.847, and $\beta_{(800)}$=0.841 is 1.457 (GeV/c). In general, the energy equation is

$$E^2 = P^2 + M^2 \tag{3}$$

and the spreads are related by

$$2E(\delta E) = 2P(\delta P) \tag{4}$$

or

$$\frac{\delta P}{P} = \frac{E}{P^2}\delta E \tag{5}$$

The total energy (E) of the beam is 1.733 GeV (rest energy plus K.E. of the beam of 795.1 MeV). The momentum (P) is 1.457 GeV/c for 795.1 MeV, energy spread of the beam (δE) = 2.3249×10^{-3} GeV, which leads $\delta P/P$ = 5.559×10^{-4}. In general, $\delta P/P$ is expressed in percent in the TRANSPORT code. Thus, $\delta P/P$=0.056%.

For the given energy, the beam rigidity($B\rho$=3.3356× momentum in GeV/c) is 4.862 Tesla-meter.

For a given energy spread of δE= 2.324×10^{-3} GeV, the relative energy spread (SIGE) is defined by

$$SIGE = \frac{\delta E}{E_{total}} = 1.343 \times 10^{-3} \tag{6}$$

The product of the beam bunch and relative energy spread is defined as longitudinal emittance, which is

$$\varepsilon_{longitudinal} = SIGE \times SIGT = 1.341 \times 10^{-3} m-rad \tag{7}$$

TRANSPORT AND MAD-X ENVELOPES

Based on the beam parameters and geometrical configuration of the beamline, the beam envelope was simulated using the codes TRANSPORT and MAD-X. The input beam size (2rms) is x=2.096 cm and y= 1.3265 cm as mentioned early. The calculated beam size along the beam line depends on the beam properties. Figure 1 shows a comparison of the beam envelope as calculated by TRANSPORT and MAD-X. Figure 2 shows the β functions along the beamline calculated using MAD-X. Figure 3 shows dimensionless parameters α, dispersion and phase advance along the beamline as calculated using MAD-X. The beam profile along the beamline was measured using wire scanners as mentioned early. These devices were installed in the beam axis using remote control systems when needed, and removed from the beam line after use. Figure 4 shows measured beam profiles at diagnostics locations (black dots) and the predicted envelope (hollow circles in dotted lines) using TRANSPORT and MAD-X. The top and bottom graphs represent horizontal and vertical profiles along the 1L beamline. There are some differences between simulation and measurements.

A dispersion η causes different beam positions for different energies

$$\Delta x = \eta\frac{\Delta E}{E} = \eta \times SIGE \tag{8}$$

For a relative energy spread ($SIGE = \Delta_E/E$) of 1.343×10^{-3} and for a dispersion of η =5 m (obtained using MAD-X output at around 65m distance), Δx =0.77cm.

CONCLUSION

The input beam parameters for the codes were extracted from an ORBIT code [1] analysis of the proton storage ring beam. The envelope measurements were made at various locations throughout the beamline using wire scanners. The predicted beam envelopes and measured data agree within expected errors. Although the comparison of measurements and models results were studied to better understand the beamline tuning process, further work is needed to optimize the size at target location and find what causes the differences of the beam size near the target between simulation and measurements.

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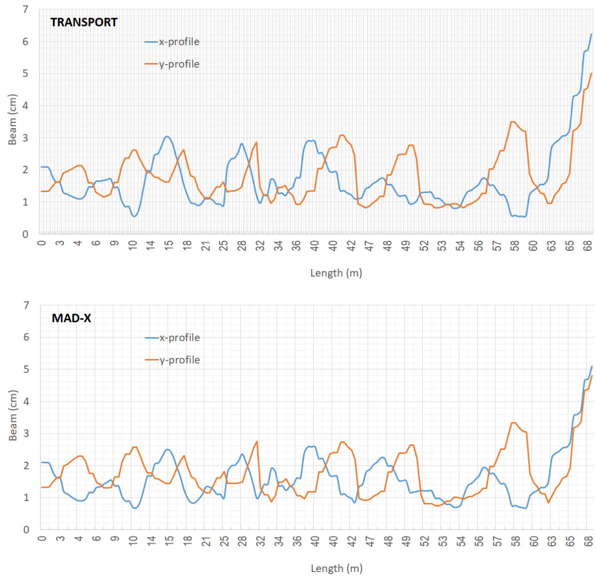

Figure 1: Calculated horizontal and vertical beam profiles: using TRANSPORT (top) and MAD-X (bottom). Although the envelope patterns look similar, the sizes are slightly different due to conversion error in some parameters.

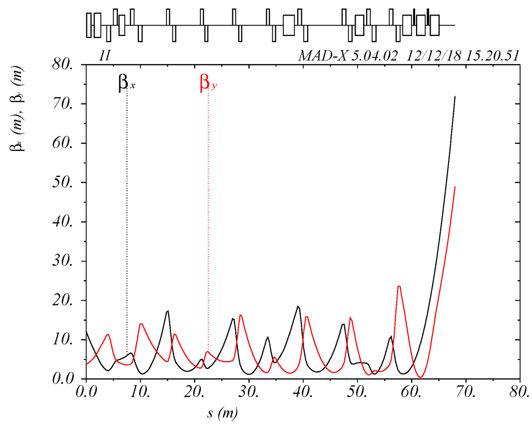

Figure 2: Calculated Twiss parameter β (a ratio of square of the beam size and emittance) of the 1L beamline using MAD-X.

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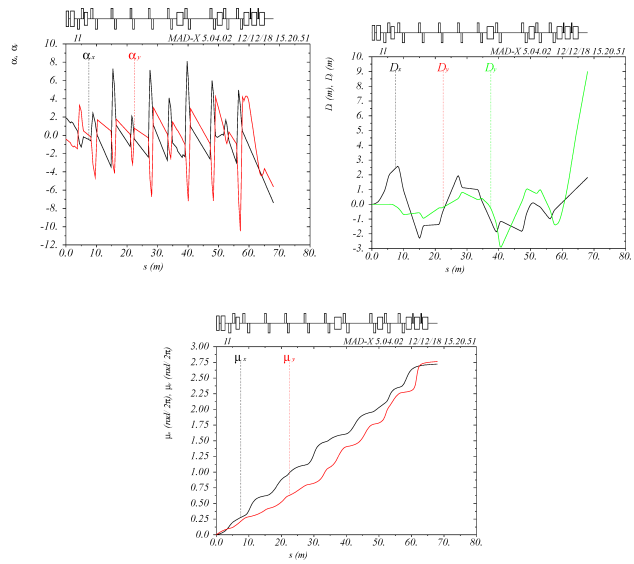

Figure 3: MADx results: top left: Beam divergence, top right: beam dispersion, and bottom: phase advance.

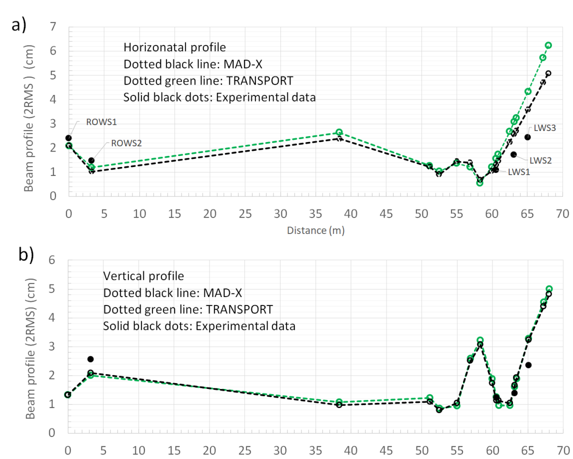

Figure 4: Measured (black dots in solid line) and calculated (hollow circles in dotted line) profiles along the beamline. (a) A horizontal and (b) a vertical profile.

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REFERENCES

[1] J. A. Holmes, "Recent Enhancements to the ORBIT Code", in *Proc. 1st Int. Particle Accelerator Conf. (IPAC'10)*, Kyoto, Japan, May 2010, paper TUPEC080, pp. 1901–1903. See also, J. A. Holmes *et al.*, *ICFA Beam Dynamics Newsletter*, vol. 30, 2003.

[2] T. Wangler and P.W. Lisowski, "The LANSCE National User Facility, Los Alamos Science", number 28, p. 138, 2003.

[3] K.E. Kippen, R.D. Fulton, E. Brown *et al.*, "AOT & LANSCE Focus: Proton Radiography Facility", Los Alamos, LA-UR-13-24376, June 2013.

[4] P. W. Lisowski and K. F. Schoenberg, The Los Alamos Neutron Science Center, *Nucl. Instrum. Methods Phys. Res. A*, vol. 562, pp. 910-914, 2006.

[5] K. L. Brown, F. Rothacker, D. C. Carey, Ch. Iselin, "TRANSPORT a computer program for designing charged particle beam transport systems", SLAC-91, rev. 3, available from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

[6] "MAD-X–Methodical Accelerator Design", CERN program Library entry: T5001, CERN, Geneva, 1990.