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LANSCE BEAM TRANSPORT MODEL ENHANCEMENT AND VALIDATION

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Abstract

At the Los Alamos Neutron Science Center (LANSCE), accurate beam transport modelling is essential to understand the nature of beam instabilities and losses. The model analysis enables significant improvement in beam transport tuning. It is critical to ensure the beam envelope remains constrained and that the bunch structure is preserved as it traverses the distance from the 800-MeV Linac to the target downstream. Historically, all the high-energy beamlines (HEBT) have been simulated using the TRANSPORT code. Enhanced beamline models are developed in more modern accelerator physics codes such as MAD-X or elegant, which enable more detailed particle tracking and include some space-charge effects. These models may help us better understand the beam parameters during transport to the targets. This work presents the beamlines and their associated simulation models and, where applicable, comparison with experimental beam measurements.

INTRODUCTION

The Los Alamos Neutron Science Center (LANSCE), illustrated in Fig. 1, is a major experimental science facility that provides a high intensity and broad energy spectrum of neutron to multiple targets to study various materials.

Beams with two distinct energies are produced at LANSCE depending on target requirements. The Isotope Production Facility (IPF) receives a 100 MeV H+ beam while the four other user stations, namely, Proton Radiography (pRad), Ultra-Cold Neutrons (UCN), Lujan Center and the Weapons Neutrons Research (WNR) take the 800-MeV H- beam with various timing patterns. The beam is accelerated up to 800-MeV by two accelerating sections: the 201.25 MHz Drift Tube Linac (DTL) to bring the beam energy from 0.75 MeV to 100 MeV and the 805 MHz Side Coupled-Cavity Linac (CCL) from 100 MeV to 800 MeV.

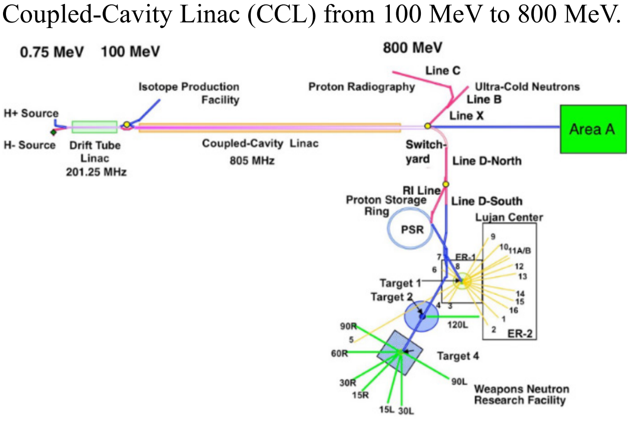

Figure 1: Overview of the LANSCE facility [1].

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The high-energy beamlines downstream of the CCL transport the 800-MeV beam to the Proton Storage Ring (PSR) and the experimental areas. These beamlines are historically simulated with the TRANSPORT [2] code. Enhancing the modelling of the beamlines in modern beam dynamics codes such as MAD-X [3] or elegant [4] is necessary to better understand the beam transport and losses.

This contribution presents the beam transport model enhancement and validation of the beamlines downstream, especially north of the Linac: Line B and Line C. First, we introduce succinctly the beamlines. Then, we will describe the modelling of the beamlines and compare the simulation results with experimental data.

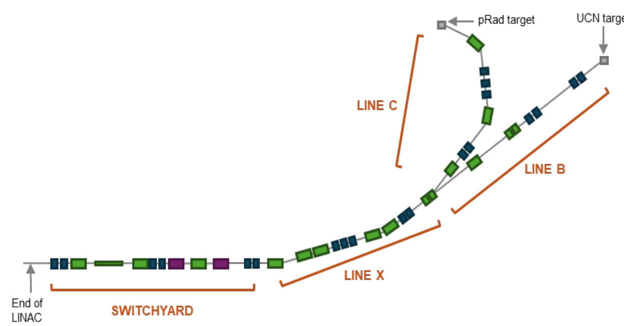

Figure 2: Layout of the Lines B and C with their main sections: joint Switchyard and Line X and the specific Line B and Line C. The quadrupoles are represented in blue, the bending magnets in green and the kicker magnets in violet.

DESCRIPTION OF LINES B AND C

The Lines B and C are defined as the beamlines from the end of the Linac to, respectively, the UCN target and the pRad target (Fig. 2).

The Switchyard receives the 800 MeV H- beam and guides it to the Line X with bending magnets. Two quadrupole doublets focus the beam. The final kicker magnet diverts a portion of the beam to the north.

Then, the beam enters the Line X, which consists of seven quadrupoles and seven bending magnets. The beam is directed in the north direction with its size constrained. The last bending magnet performs a left bend to Line C or a right bend to Line B.

Finally, the two beamlines, Line B and Line C, direct the beam to two different targets, respectively the UCN target and the pRad target. The Line B goes straight to the target. The beam shape and size are controlled by two quadrupole doublets. For the Line C, three bending magnets guide the beam left to the pRad target and five quadrupoles constrain the beam.

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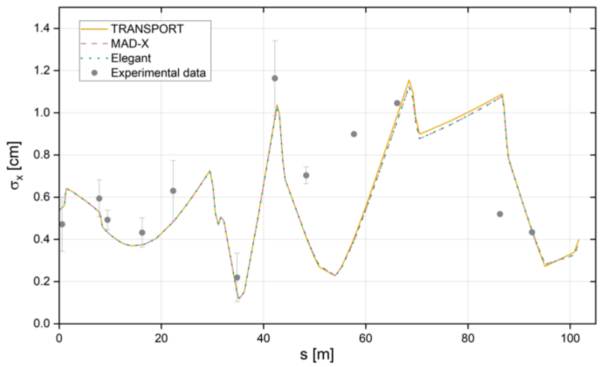

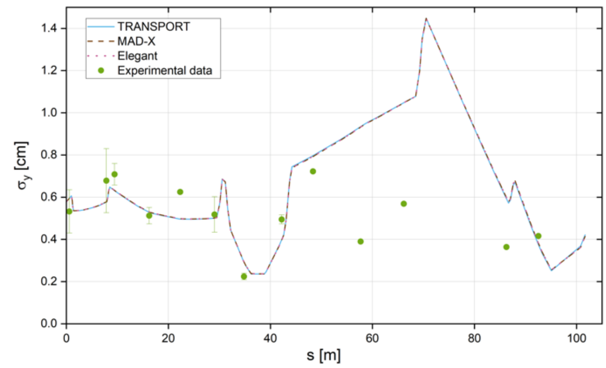

Figure 3: Line B horizontal (left) and vertical (right) rms beam size in TRANSPORT, MAD-X and elegant compared with experimental beam measurements (points).

BEAMLINES MODEL ENHANCEMENT

Historically, the high-energy beamlines are simulated with the TRANSPORT code, a particle tracking code with matrix-based description of beamline elements. However, this code has a limited space-charge model that can restrain our understanding of the beam physics. TRANSPORT also adds difficulties for us to integrate it into operations as a legacy code. Therefore, we develop models of the beamlines in more modern codes widely used by the accelerator physics community such as MAD-X and elegant.

MAD-X (Methodical Accelerator Design) is an optics code for single particle dynamics developed at CERN. It has the advantage of being very flexible with a convenient language and incorporates different modules. On the physics side, the transport matrix is calculated up to the second order and a space-charge model has been recently implemented.

Elegant, developed at the Advanced Photon Source, is a 6D particle tracking code with matrices. It integrates a longitudinal space charge model and has a lattice file structure similar to MAD-X.

A Python program was developed locally to translate the existing TRANSPORT lattices into MAD-X and elegant ones. The beamlines elements have equivalent in all the codes and a matrix representation of the elements is chosen. However, some elements require special attention. In TRANSPORT, the magnetic strength of the quadrupoles is defined by the pole tip field B_0 in kG while MAD-X and elegant use the normal quadrupole coefficient K_1 in m^{-2}. This coefficient is calculated by

$$K_1 = \frac{1}{B\rho}\frac{B_0}{a},$$

where $B\rho = 4.877$ T/m is the design magnetic rigidity and the quadrupole magnetic half aperture a is in m.

The angles are given in degree in TRANSPORT and are converted in radian for both MAD-X and elegant. Another difference is the declaration of the bending magnet element. In TRANSPORT, the bending magnet parameters are defined with different beamlines elements. Their translation in MAD-X and elegant are listed in Table 1.

Table 1: Bending Magnet Parameters in TRANSPORT, MAD-X and Elegant

Parameters	TRANSPORT	elegant/MAD-X *SBEND*
Bending angle	Angle in BEND	Angle
Roll angle about longitudinal axis	SROT	Tilt
Entrance and exit face/edge angle	ROTAT	E1 and E2
Fringe field integral	SPECIAL, FINT	FINT

To conduct the simulations using the different codes, run files are required. The TRANSPORT code needs the rms beam size and divergence with the correlation parameters. Both MAD-X and elegant require the emittance and Twiss parameters. The initial beam is measured downstream the 800-MeV linac, and the emittance and Twiss parameters are extracted. The beam size in cm is defined by $\sqrt{\varepsilon\beta}$ and the beam divergence in mrad by $\sqrt{\varepsilon\gamma}$.

In the simulations, we also include real experimental data. During the beam tuning, the magnet readouts are visualized with EPICS system. Experimental bending magnet values are not considered as the changes are not significant because bends define the lattice configuration. Magnetic field readouts are only considered for the quadrupoles.

To validate our models, we compared them to experimental data, primarily from wire scanner diagnostics and, near the target, from beam images at the beamlines end. Figures 3 and 4 present the simulated transverse rms beam sizes in x and y using the three models and their comparison with experimental beam size measurements for Line B and Line C, respectively. Figure 4 shows strong agreement between simulation and experimental data for the Line C with larger deviations after 50 meters where beam image diagnostics are used. For Line B (Fig. 3), the agreement is good overall, though significant discrepancies also appear for non-wire scanners data. Several factors could explain these discrepancies. Errors may occur during beam image

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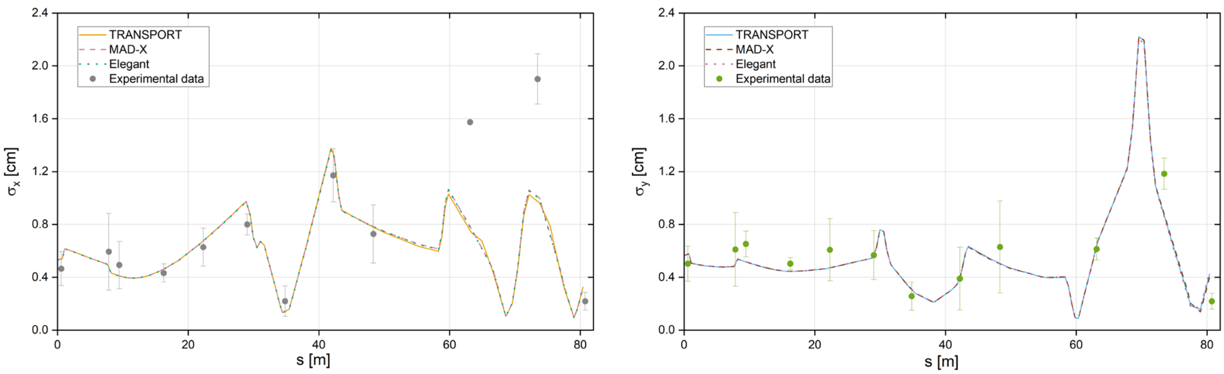

Figure 4: Line C horizontal (left) and vertical (right) rms beam size in TRANSPORT, MAD-X and elegant compared with experimental beam measurements (points).

analysis and measurement uncertainties could also contribute. Additionally, the initial beam conditions and magnet readouts used in the simulations may differ from those in the experimental setup. Furthermore, the models do not currently incorporate all relevant physical effects involved in beam transport. A further validation will need to be done to verify all the beam and lattice parameters used in both the simulation and the experiments.

CONCLUSION

Beam transport enhancement model at LANSCE could potentially help understand the beam dynamics and reduce the beam losses during transport. We present the improvement of beamlines modelling using different beam simulations codes (TRANSPORT, MAD-X and elegant) for Lines B and C. We compare our models with experimental beam measurement showing a reasonable agreement considering the measurement and models uncertainties. The results will be applied to the other beamlines downstream the Linac to enable the use of different simulation tools in the future. Additionally, benchmarking the model will be strengthened with updated experimental data.

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