ERROR AND SENSITIVITY STUDIES FOR LANSCE ACCELERATOR MODERNIZATION PROJECT*

S. Sosa Guitron, K. Bishofberger, G. Dale, D. Dimitrov, B. Garnett, D. Gorelov, S. Kurennoy,
J. Lewellen, L. Rybarcyk, J. Upadhyay, H. Xu, LANL, Los Alamos, USA

Abstract

The LANSCE Accelerator Modernization Project (LAMP) aims to modernize the existing LANSCE front-end technologies. Two existing 750 keV Cockcroft Waltons are planned to be replaced by a single radio-frequency quadrupole (RFQ), and a new 100 MeV DTL will be installed. The new LAMP front-end is required to deliver beams with similar timing patterns to what is currently delivered to the experimental stations. Using the physics model of the LAMP front-end, we evaluate errors and sensitivities of multiple transport components and study the effect on the beam intensity and timing.

INTRODUCTION

The LANSCE accelerator facility at LANL has delivered high-power beams to multiple experimental facilities for over 50 years. Critical components in the facility front-end like the Cockcroft Walton (CW) generators are difficult to service or have already required major repairs like the Drift Tube Linac (DTL). To keep the unique beam capabilities that LANSCE provides in years to come, the LANSCE Accelerator Modernization Project (LAMP) [1] plans to replace the two 750 kV CWs with a single RFQ and to install a new 100 MeV DTL. The new front-end will match into existing facilities at the end of the DTL. With these configuration changes, the new injectors, low-energy beam transport (LEBT), and medium-energy beam transport (MEBT) lines need to produce the same beam patterns that LANSCE can currently deliver. We have developed a physics design concept for the front-end that meets the LAMP project requirements [2]. We are now studying the errors and tolerances to evaluate the feasibility of the ideal design under more realistic conditions. In this paper we describe our approach at studying errors and tolerances in the LAMP front-end and discuss preliminary results on applying errors to the LEBT.

Low Energy Beam Transport

The 65 keV LEBT transports both H^+ and H^- beams from the injectors to the RFQ and consists of two independent beam lines that merge at a 30° included angle for injection into the RFQ. The LEBT has solenoids for transverse beam focusing and beam choppers to produce the different temporal structures required by the experimental stations. Figure 1 shows a preliminary mechanical layout of the LAMP LEBT concept and Fig. 2 shows the rms envelope of the Lujan beam in the H^- LEBT using the LANL particle code PARMILA [3]. The Lujan beam is the beam to the Lujan Neutron Science Center target that is accumulated in the Proton Storage Ring.

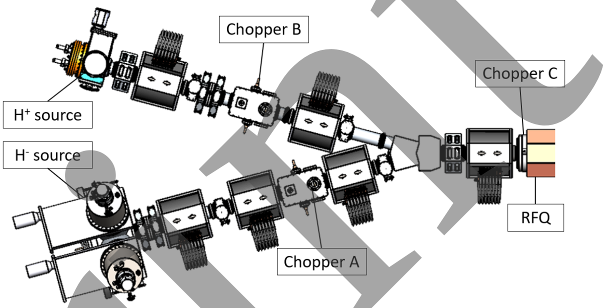

Figure 1: Preliminary mechanical layout of the 65-keV low energy beam transport concept for LAMP.

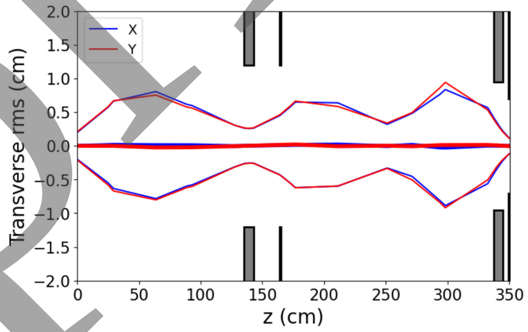

Figure 2: Transverse rms envelopes of the Lujan beam in the LAMP LEBT using PARMILA.

ERROR STUDIES

The purpose of the error studies is to determine tolerances on manufacturing, alignment and field errors in accelerator facilities [4]. This quantifies the average magnitude of error or a given type that can be tolerated before beam quality or other performance metric is unacceptably degraded. For LAMP, we plan to first study the effect of errors applied to individual sections: sources, LEBT, RFQ, MEBT and DTL. Integrated studies using the per-section error thresholds will then be conducted via start-to-end simulations. Ultimately, because the LAMP front-end matches into the 800 MeV cavity coupled linac, the tolerance on errors in all the sections should produce a beam within the acceptance of the LANSCE Linac [5]. Here we are starting to investigate static errors in the LEBT, mainly mechanical alignment and displacements, roll angle and errors in the magnetic field amplitudes. One potential consequence of degraded beam quality is an increase of beam loss, which can damage the accelerators and transport lines, as well as radioactivation concerns at high

---

* This work benefitted from the use of the LANSCE accelerator facility. Work was performed under the auspices of the US Department of Energy by Triad National Security under contract 89233218CNA000001.

energies which can limit, for example hands-on maintenance. In this study, we consider the Lujan beam because it is the highest average power beam, and thus the main source of losses at LANSCE. Here we discuss preliminary results on errors applied to the solenoids in the LEBT using the Lujan beam.

Beam Acceptance of the RFQ

A natural criterion to evaluate the error tolerance in the LEBT is the RFQ acceptance. The RFQ is designed for a specific current and beam emittance and has specific design values for the Twiss parameters of the input beam that result in a periodic solution inside the RFQ. Deviations from the design RFQ input beam result in degraded output beam quality and increased beam loss within the RFQ. To characterize the RFQ acceptance, we use the code PARMTEQ-m [6] to vary the input beam Twiss parameters around the design values, calculate the input mismatch factor M defined through:

$$M = \sqrt{\frac{1}{2}\left(R + \sqrt{R^2 - 4}\right)} - 1,$$

$$R = \beta_0\gamma - 2\alpha\alpha_0 + \gamma_0\beta.$$

and examine the resulting beam transmission and output beam emittance.

The Trace 3D [7] definition of the mismatch factor, it quantifies the difference between two beam ellipses defined by the Twiss parameters with the same center and area. In this definition, a mismatch factor of zero corresponds to perfect agreement between the two ellipses and a mismatch factor 0.1 corresponds to a difference of 10%.

Using PARMTEQ-m we perform several RFQ simulations with varying input beams. Figure 3 shows a 2D contour plot of the beam transmission vs. the input Twiss parameters. Similarly, Fig. 4 shows the normalized output beam emittance and Fig. 5 shows the corresponding input beam mismatch factor.

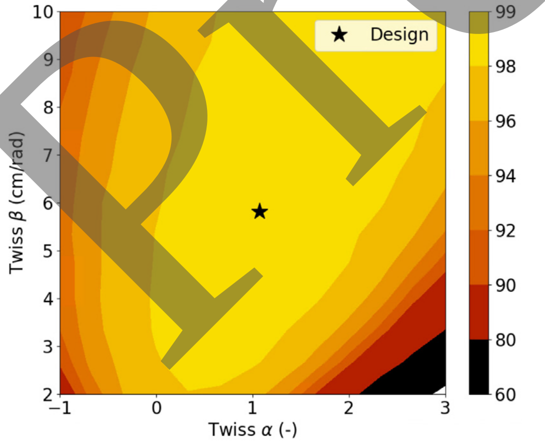

Figure 3: RFQ transmission vs. input beam Twiss parameters calculated with PARMTEQ-m.

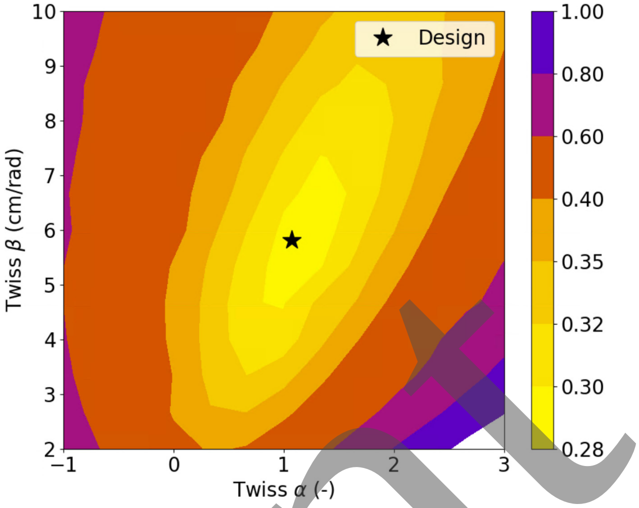

Figure 4: Output normalized beam emittance (π mm mrad) vs. input beam Twiss parameters.

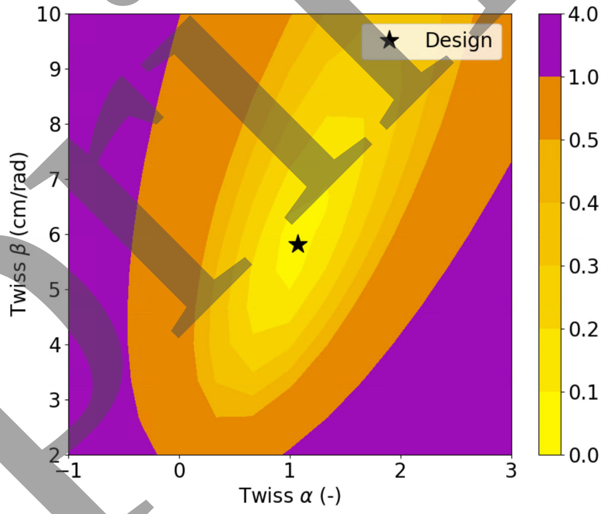

Figure 5: Mismatch factor vs input beam Twiss parameters calculated with PARMTEQ-m.

We see from Figs. 3 and 5 that the RFQ has very good beam transmission even when significantly mismatched. The output emittance is more sensitive to the input beam, resulting in increased beam emittance if the beam is not close to the RFQ match condition. Thus, the mismatch factor can be used to map the expected level of emittance growth in the RFQ from a particular type of error in the LEBT.

Error Studies in the LEBT

We have developed a routine in Python that generates and applies different errors to the LEBT magnets, runs PARMILA and saves the output beam emittance and the mismatch factor. We have so far implemented errors in the magnetic field amplitude, displacements of the solenoids and roll angle around the beam axis. We will now show an example where a uniformly distributed error is applied to the four solenoids in the H$^-$ LEBT. Figure 6 shows the distribution of errors for all solenoids, and the maximum amplitude of the error is 0.5%.

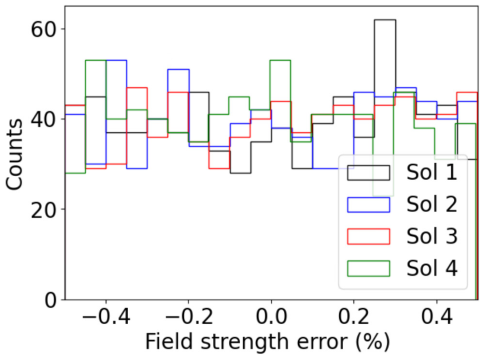

Figure 6: Uniform distribution of solenoid field strength errors. The maximum error amplitude is 0.5%.

Figure 7 shows the resulting distribution of mismatch factor calculated from the output beam distribution of individual runs. We distinguish between horizontal and vertical mismatch factors because the initial distribution used in the LEBT is not symmetric, and the merger magnet breaks the symmetry in the general case. In this example, we calculate mean values of the mismatch factor $<MMF_x>=0.0469$ and $<MMF_y>=0.0361$.

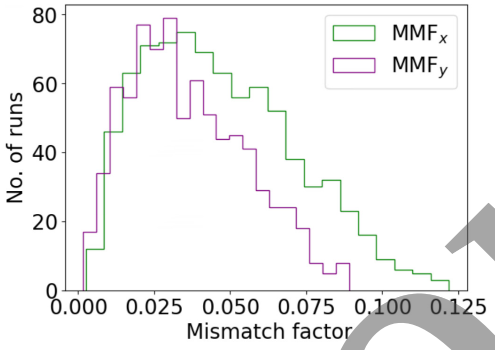

Figure 7: Histogram of mismatch factor for 1000 PARMILA runs with solenoid field error amplitude 0.5%.

We repeat this process for different values of the error amplitude, Figure 8 shows the resulting mean value of the mismatch factor for various average solenoid field error amplitudes. In this case a field error of 1% results in mismatch factor of 0.1, from Figs. 4 and 5 we expect, on average normalized emittance better than 0.3 π mm mrad at the RFQ exit.

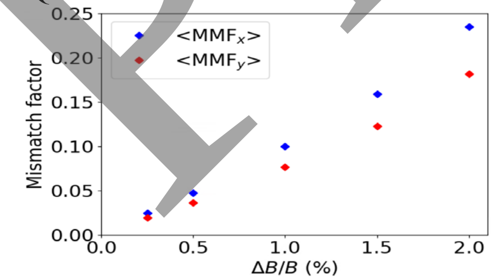

Figure 8: Mismatch factor vs. error amplitude for the case of field strength errors in solenoid magnets.

A similar plot shown in Fig. 9 can be constructed based on errors applied to transverse displacements of the solenoids. In this case, the resulting mismatch factor for typical transverse alignment standard at LANSCE, 0.0127 cm [8], results also in acceptable emittance growth.

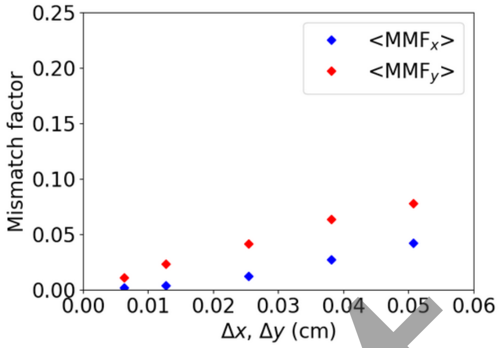

Figure 9: Mismatch factor vs. error amplitude for the case of transverse offsets of solenoid magnets.

CONCLUSION

We presented preliminary results and discussion of ongoing work on the study of errors and tolerances of the LAMP front-end. We have adopted an initial piece-wise approach where we first study the effect of errors on the main sections of the front-end followed by more realistic simulations that include the combined effects of tolerable errors throughout the front-end. We discussed preliminary results in applying individual static errors to the LEBT solenoids and using the RFQ acceptance and the mismatch factor to determine the tolerance to errors based on acceptable transmission and emittance growth. We plan to determine tolerances in the MEBT based on the expected RFQ output beam and the acceptance of the DTL, together with individual studies on the RFQ and DTL. Finally, we will perform high resolution simulations of the entire front-end including tolerances found by individual section studies.

REFERENCES

[1] K. Bishofberger *et al.*, “An overview of the LAMP front-end upgrade at LANSCE”, *in Proc. IPAC’24*, Nashville, TN, USA, May 2024, paper TUPS18. `doi:10.18429/JACoW-IPAC2024-TUPS18`

[2] S. Sosa Guitron *et al.*, “The LANSCE accelerator modernization project front-end design and model”, presented at IPAC’26, Deauville, France, May 2026, paper WEP4332, this conference.

[3] H. Takeda and J. H. Billen, “Recent Developments in the Accelerator Design Code PARMILA”, in *Proc. LINAC'98*, Chicago, IL, USA, Aug. 1998, paper MO4047, pp. 156-158.

[4] M. A. Baylac, J.-M. De Conto, E. Froidefond, and E. Zh. Sargsyan, “Error Study of LINAC 4”, in *Proc. EPAC'06*, Edinburgh, UK, Jun. 2006, paper MOPCH108, pp. 294-296.

[5] R. Garnett, “LAMP Emittance Budget Rev. 2”, Los Alamos National Laboratory, Los Alamos, NM, USA, Rep. LA-UR-25-25340, June 5, 2025.

[6] K. R. Crandall *et al.*, “RFQ design codes”, Los Alamos National Laboratory, Los Alamos, NM, USA, Rep. LA-UR-96-1836, Dec. 2005.

[7] K. R. Crandall and D. P. Rusthoi, “TRACE 3-D documentation”, Los Alamos National Laboratory, Los Alamos, NM, USA, Rep. LA-UR-97-886, May 1997.

[8] J. Medina, private communication, AOT-MDE, 2026.