FIRST TRACK SIMULATIONS OF THE SNS LINAC*

B. Mustapha†, J. Xu, V.N. Aseev and P.N. Ostroumov, ANL, Argonne, IL 60439, USA
D. Jeon and S.D. Henderson, SNS, ORNL, Oak Ridge, TN 37831, USA

Abstract

In an effort to benchmark the code TRACK against the recent commissioning data from the SNS linac, we started updating the code to support SNS-type elements like DTL's and CCL's. 2D electric field tables were computed using Superfish and 3D magnetic fields from PMQ's were calculated using EMS-Studio. A special DTL routine was implemented and successfully tested. The first results of TRACK simulations of the SNS-DTL are presented. A comparison with the code PARMILA are also presented and discussed.

INTRODUCTION

In this collaborative effort between Argonne and SNS, we meant to expand the domain of applicability of the code TRACK [1] to new elements not previously included such as long Drift Tube Linac (DTL) and to benchmark the code against the commissioning data from the SNS linac. This work constitutes a first of many developmental steps towards the realization of the concept of the "Model Driven Accelerator", where TRACK could be used to fully support machine operations in the SNS linac or any future facility based on linear accelerators.

After briefly describing the code TRACK and the SNS linac lattice, the ingredients and method used for the DTL simulation as well as the first results are presented. A detailed comparison between TRACK and PARMILA [2] for the simulation of the DTL section starting from the MEBT is presented and discussed. Future steps of this work are discussed at the end.

THE CODE TRACK

The beam dynamics code TRACK has been developed at Argonne over the last few years [3]. TRACK is a ray-tracing code that was originally developed to fulfill the special requirements of the RIA (Rare Isotope Accelerator) accelerator systems [4]. It is, however, a general beam dynamics code for hadron linacs (protons and heavy-ions) design and simulation with possible extension to electron linacs. The most recent version of TRACK supports an extensive number of different types of beam line elements with 3D fields including fringe fields. 3D space charge forces for intense beams are included by solving the Poisson equation of the beam after every tracking step. It also includes the simulation of all possible sources of machine errors, beam monitoring tools, corrective transverse steering and longitudinal corrections as well as automatic longitudinal and transverse tuning of single and multiple charge state beams. Reference [1] contains a brief description of the code. For more details with specific applications of TRACK, see [5] and [6].

THE SNS LINAC

The SNS accelerator facility [7] is designed to provide a 1 GeV, 1.4 MW proton beam to a liquid mercury target for neutron production. The accelerator complex consists of a H^- injector capable of producing 38 mA peak current, a 1 GeV linac, an accumulator ring and associated beam transport lines to experimental areas. The linac consists of a 2.5 MeV, 38mA H^- front-end injector, a six-tank 402.5 MHz DTL to accelerate the beam to 87 MeV, a four-module 805 MHz Coupled Cavity Linac (CCL) to accelerate the beam to 187 MeV, and a superconducting linac (SRF) to accelerate the beam to 1 GeV. Figure 1 shows a schematic layout of the SNS linac.

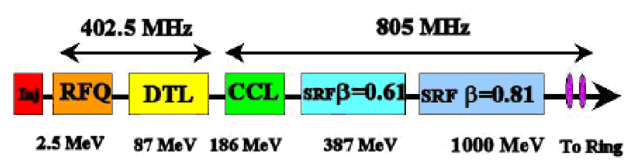

Figure 1: Schematic layout of the SNS linac.

SIMULATION OF THE DTL

The DTL section is composed of 6 tanks with a total of 216 cells to accelerate the beam from 2.5 MeV to 87 MeV. Each DTL tank is driven by a separate 402.5 MHz, 2.5-MW klystron. The focusing is provided by permanent magnet quadrupoles (PMQs) positioned within specific drift tubes. The focusing lattice is FFODDO where every third drift tube is kept empty for possible beam diagnostic devices. The cell length is equal to $\beta\lambda$ and the transverse focusing period length is $6\beta\lambda$.

Before being able to simulate the DTL using TRACK, three major steps needs to be performed, they are:

- Preparation of 3D electromagnetic fields for every cell including fringe fields
- Building the lattice with the exact dimensions (length and aperture) as well as electric and magnetic field strengths for every cell.
- Implementation of a special tracking routine for the DTL where a whole DTL tank is considered as a single element with many cells.

* Work supported by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. W-31-109-ENG-38.
† brahim@anl.gov

3D Fields in RF Gaps and PMQ's

Every DTL cell contains an accelerating RF gap and one or two PMQs as shown in figure 2.

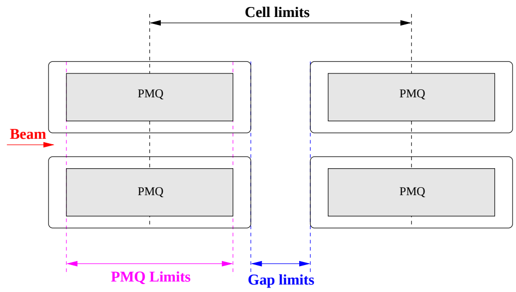

Figure 2: Approximate geometry of a DTL cell showing the relative location of the PMQs and RF Gap as well as the direction of the beam.

2D electric field (E) tables for the RF gaps are computed using Superfish [8], using the cylindrical symmetry we can determine the 3D E-field at any point within the aperture. Figure 3 shows the E-field components in the first cell along the Z axis at X=R_a/2 and Y=R_a/4 where R_a=1.25 cm is the aperture radius of the DTL.

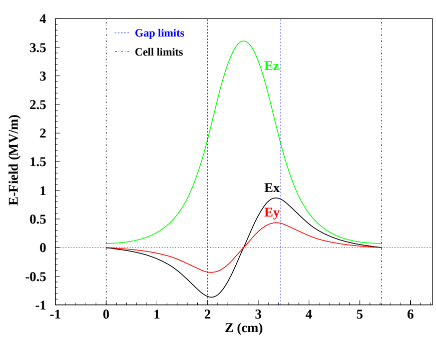

Figure 3: E-field components along the Z direction for X=R_a/2 and Y=R_a/4 calculated using Superfish for the first cell of the first DTL tank. The shown gap limits are approximate.

It is clear from figure 3 that the E-field penetrates under the PMQs. The magnetic field (B) from the PMQs is calculated using the field formula's used in Trace-3D [9] for Bx and By whereas the Bz component is taken from the original paper by Halbach [10]. The results of the formulas were confirmed using EM-studio for the exact geometry and material properties of the PMQ. Figure 4 shows the B-field components for the same conditions as figure 3 (first cell at X=R_a/2 and Y=R_a/4) where the first PMQ has a field gradient G=-3.7 kG/cm and the second with G=0 (empty drift tube).

From figure 3 and 4 it is clear that the E-field from the RF gap overlaps with the B-field from the PMQs due to PMQs fringe fields. Therefore a DTL cell should be treated as a single element with combined E-B fields. It is also important to notice that the penetration of the fields of a given cell to the next cell is minimal and could be neglected.

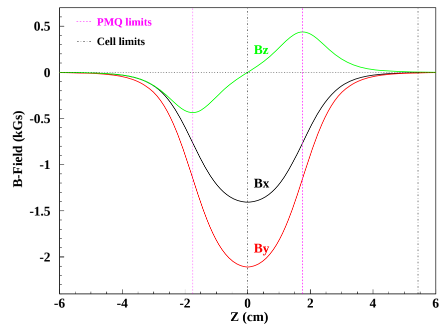

Figure 4: B-field components along the Z direction for X=R_a/2 and Y=R_a/4 calculated using Halbach's field formulas for the first cell. The first PMQ has a G=-3.7 kG/cm and the second with G=0.

DTL Lattice

In TRACK's main lattice input a DTL tank is represented by a single line specifying the total length, a harmonic number, a global E-field scaling factor, the input phase, the number of cells and a file number for more detailed cell information. The cell information file contains the length, aperture, E-field strength, B-field strength for both PMQs for every cell in the tank (1 line per cell). In this way we have the flexibility of changing any parameter which is especially important when we want to input measured values for field strengths.

Phase Setting and Tracking

As mentioned above the phase of a DTL tank is set once for a tank as a whole, and because every tank is driven by a single klystron no phase setting is allowed for individual cells for which the phases are set by the geometrical design. The DTL tracking routine is based on the existing RFQ routine described in [11]. When the beam enters a new cell the corresponding field data are loaded and the tracking performed by integrating the equation of motion for every particle in the 3D external and internal or space charge fields.

Results for the 1st DTL Tank

Figure 5 shows the results of the first TRACK simulations of the first DTL tank for a matched 0 mA H^- beam. The figure shows the evolution of the beam's RMS parameters for the case where PMQs are simulated as hard-edge quads and the case where realistic fringe fields are included. We notice that fringe fields may introduce some mismatch to the beam and could result in different beam dynamics in the subsequent sections of the linac.

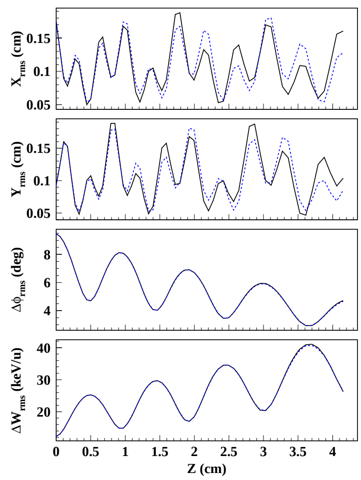

Figure 5: Track simulation results of the 1st DTL tank for a 0 mA H^- beam, shown are the RMS beam parameters in X, Y, ϕ and W. The solid-black curves were calculated with hard-edge quads and the dashed-blue curves were obtained with PMQs fringe fields included.

COMPARISON: TRACK VS. PARMILA

Figure 6 and 7 show a detailed comparison between TRACK and PARMILA simulations results for the DTL section (MEBT + 6 Tanks). In this case a 38 mA H^- beam is simulated by tracking 10^5 particles. The E and B field strengths are set to the experimentally measured values. A good overall agreement is obtained, the differences could be explained by the fringe fields from the PMQs and a possible difference in the space charge calculations. As discussed earlier fringe fields could cause a beam mismatch which is visible on the transverse beam parameters in figure 6. Starting from the second DTL tank (Z $\sim$ 14 m) we notice a longitudinal mismatch on TRACK results. We believe that this difference is due to a phase ramping procedure used in PARMILA to adjust the phases of the first and last cells in a DTL tank to ensure phase matching between successive tanks. This procedure is not directly reflected on the design geometry used as input to TRACK. This phase mismatch is responsible of producing a more pronounced beam tail on the phase space plots of figure 7.

SUMMARY AND FUTURE WORK

We have successfully implemented and simulated the DTL section of the SNS linac using the code TRACK. The next steps includes building the rest of the lattice (CCL and SRF) and perform end-to-end simulations including machines errors in order to compare the results with the existing commissioning data.

REFERENCES

[1] V.N. Aseev et al, Proceedings of PAC-05 Conference, Knoxville, Tennessee, May 16-20, 2005.

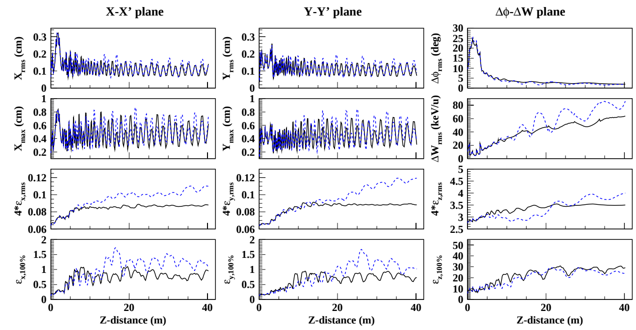

Figure 6: Comparison of PARMILA and TRACK simulation results of the SNS-DTL section. The plots show and compare the evolution of most important beam parameters along the DTL. The solid-black curves corresponds to PARMILA and the dashed-blue curves to TRACK.

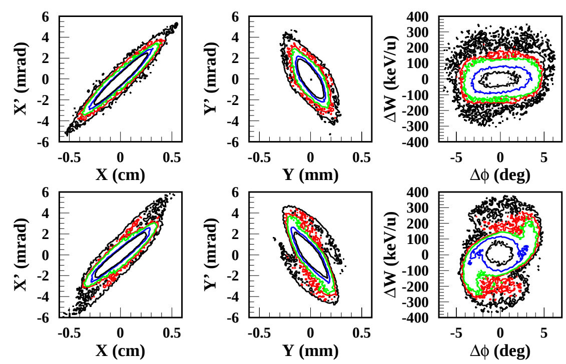

Figure 7: Comparison of phase space plots at the exit of the SNS-DTL section obtained using PARMILA and TRACK. The top plots are from PARMILA and the bottom ones are from TRACK. The colored contours represent different levels of particle density.

[2] J.H. Billen and H. Takeda, PARMILA Manual, Report LA-UR-98-4478, Los Alamos, 1998 (Revised 2004).

[3] P.N. Ostroumov and K.W. Shepard, Phys. Rev. ST. Accel. Beams 4, 110101 (2001)

[4] P.N. Ostroumov, J.A. Nolen and B. Mustapha, Nucl. Instr. and Meth. A 558 (2006) 25

[5] P.N. Ostroumov, V. N. Aseev, and B. Mustapha. Phys. Rev. ST. Accel. Beams 7, 090101 (2004).

[6] B. Mustapha and P.N. Ostroumov, Phys. Rev. ST. Accel. Beams 8, 090101 (2005).

[7] N. Holtkamp, Proceedings of PAC-03 Conference, Portland, Oregon, May 12-16, 2003.

[8] J.H. Billen and L.M. Young, Poisson-Superfish Manual, Report LA-UR-96-1834, Los Alamos, 1996 (Revised 2005).

[9] K.R. Crandall, TRACE-3D Manual, Report LA-11054-MS, Los Alamos, 1987.

[10] K.Halbach, Nucl. Instr. Meth. 187 (1981) 109-117

[11] P.N. Ostroumov, V. N. Aseev, and A.A. Kolomiets, J. of Instr., JINST 1, P04002, 2006