SNS LINAC COMMISSIONING – TRANSVERSE MATCHING *

Dong-o Jeon#, ORNL, Oak Ridge, TN37830, USA
J. Stovall, LANL, Los Alamos, NM87545, USA

Abstract

The Spallation Neutron Source Linac consists of a few distinct sections which require careful transverse matching. Robust techniques for transversely matching various sections of the SNS Linac have been identified and will be presented. These techniques do not require us any knowledge of machine optics, and are robust against up to 20% measurement uncertainties, beam mismatch, etc.

INTRODUCTION

The Spallation Neutron Source Linac consists of a Drift-tube Linac, a Coupled Cavity Linac followed by a Superconducting Linac [1]. We studied feasible schemes of transversely matching various sections of SNS Linac utilizing wire-scanners or emittance measurement devices. A few matching schemes are tested using the Parmila code [2]. We assume ideal longitudinal matching and concentrate only on transverse matching. The following are the assumptions and conditions under which the study is done:

- About 10% uncertainty in the initial matching quad gradient between the model and real machine is assumed.
- A certain level of measurement uncertainty (10 to 20%) in rms beam size or emittance is assumed.
- As input distribution, we use a beam distribution tracked from the DTL with the initial 30% transverse and longitudinal mismatches.
- Optimization is done with 10 000 macro-particles input distribution using the Parmila code.

The uncertainty in the initial matching condition is assumed, because actual transverse matching condition may be different from that obtained from the model (Trace3D etc) due to various reasons such as the uncertainty in longitudinal set-point of cavities, machine imperfections, and beam distributions. The 10% measurement uncertainty in rms beam size means that 3σ of Gaussian error distribution is 10%. In reality this uncertainty includes pulse-to-pulse jitter and measurement uncertainties in rms beam sizes. Also we use a beam distribution including mismatch as stated in the third bullet. 30% mismatch means that the beam distribution is transformed by $x \rightarrow 1.3x$ where α=0 and momentum is adjusted accordingly to preserve phase space area. By doing so, we can study the effect of unknown mismatch present in the real beam and can see how reliable the matching routine is. It should be noted that these are very pessimistic assumptions.

Measurement accuracy in this note is defined by the accuracy of rms beam size converted from the wire-scanner data or emittance data. 20% measurement uncertainty means that 3σ of Gaussian uncertainty distribution is 20% of the actual value.

In simulation test, optimization is done using a minimization routine of MATLAB®. This routine uses the simplex search method [3]. This is a direct search method that does not use numerical or analytic gradients. The optimization procedure consists of 20 iterations. Simulations are carried out from DTL tank 6 (the last DTL tank) to the end of SCL (Superconducting linac) to explore the matching.

MATCHING MEBT TO DTL

Matching with wire-scanners

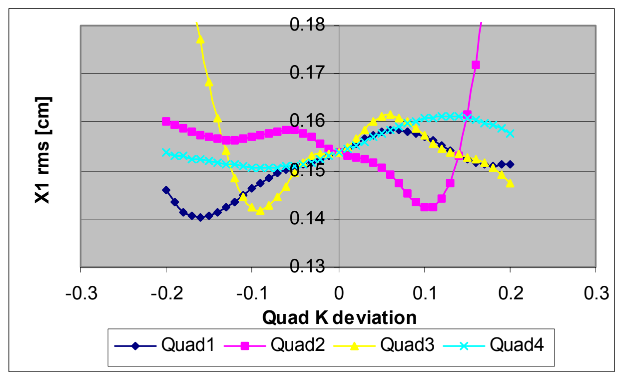


Figure 1: x rms beam size [cm] vs. quadrupole strength change. The wire scanner is located at the end of DTL tank 1. 0.1 Quad K deviation means that quadrupole gradient is 110% of design value (that is 10% more).

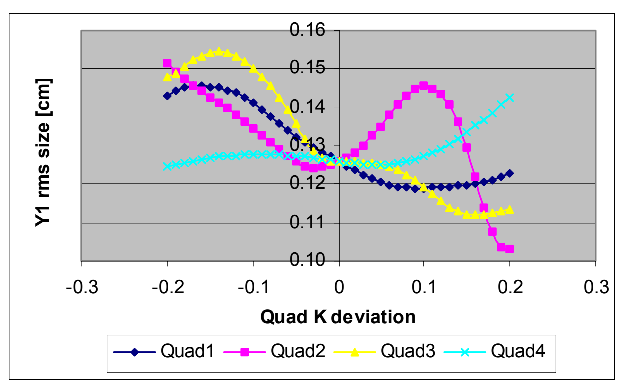


Figure 2: y rms beam size [cm] vs. quadrupole strength change. The wire scanner is located at the end of DTL tank 1.

The behavior of rms beam sizes is investigated with respect to the four matching quadrupole gradients at the end of MEBT. Figures 1 and 2 strongly indicate that

* SNS is managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. Department of Energy.
#jeond@ornl.gov

there could be more than one solution that generates the prescribed x and y rms beam sizes. And the variation of rms beam sizes is quite nonlinear. Therefore it is expected that the matching result won't be so robust. As an alternative, we try using the rms emittance.

Matching with rms emittances

The behavior of rms emittances with respect to the gradient change of the four MEBT matching quadrupoles and rf phase and amplitude offset of DTL tank 1 are studied. Figures 3 and 4 indicate that rms emittance is minimum when matching is proper and that there exists only one minimum. In the case where DTL tank 1 rf amplitude and phase are varied (see Figs 3 and 4), this alters transverse matching due to the change of transverse rf defocusing force and the design matched condition is no longer matched.

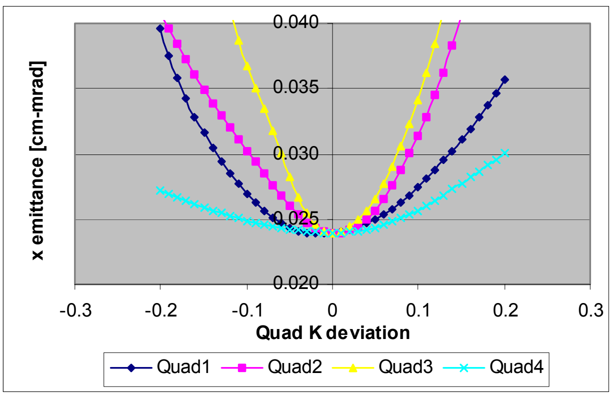


Figure 3: Plots of x emittance in cm-mrad with respect to the change of quadrupole gradient. 0.1 on x-axis means quadrupole strength is off by +10% of design value. When the gradient of quadrupole 1 is varied, the gradients of the rest three quadrupoles are set to its design values.

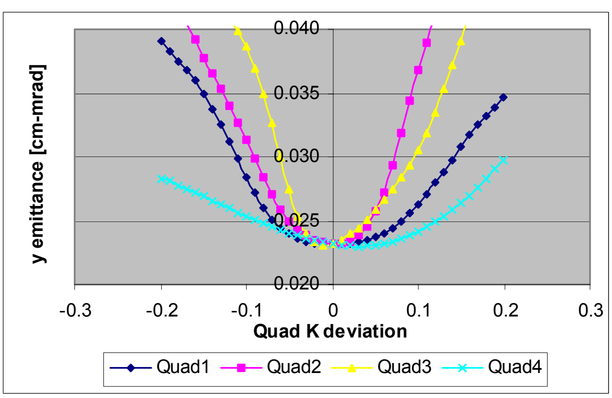
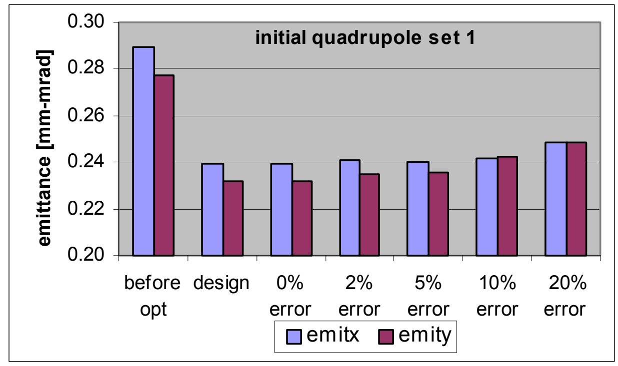


Figure 4: Plots of y emittance in cm-mrad with respect to the change of quadrupole strength. 0.1 on x-axis means quadrupole strength is off by +10% of design value. When the gradient of quadrupole 1 is varied, the gradients of the rest three quadrupoles are set to design values.

Figure 5 shows the x and y rms emittances after optimization vs. various levels of measurement error from 0% to 20%. 20% error on x-axis means 20% emittance measurement error. This means that 3σ of normal error distribution are equal to 20% of the measured quantity. "before opt" means the rms emittances before optimization. Compared with design values, a reasonable level of transverse matching can be accomplished using rms emittances. 20% measurement error seems tolerable.



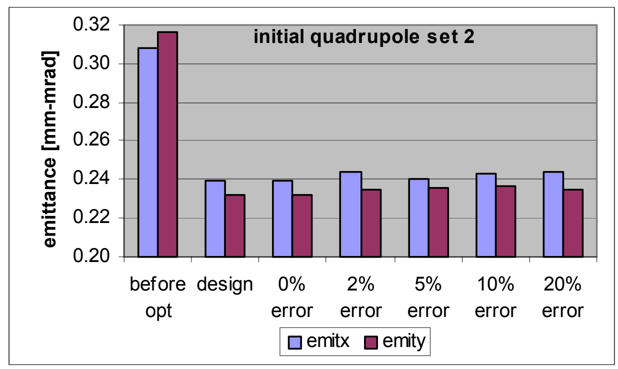


Figure 5: Plots of rms emittances vs. emittance measurement errors. 20% error means that 20% measurement error is included in rms emittance values, which means that 3σ of normal error distribution are equal to 20% of the quantity.

MATCHING DTL TO CCL AND CCL TO SCL

We study the transverse matching scheme of DTL to CCL (and CCL to SCL) by minimizing the envelope beating using multiple wire-scanners placed in series [4]. It is possible that machine may not be running smoothly enough during the commissioning stage. So it's better to do matching by a series of short optimization pieces. The 20-iteration optimization is estimated to take up to two hours.

Simulation results indicate that minimum number of wire-scanners is mainly dependent on the uncertainty between the model matching condition and the actual one. When 10% uncertainty in initial matching quad gradient is assumed, four wire-scanners are required to obtain reasonable matching and the scheme is tolerant of up to 20% (at 3σ) measurement uncertainty in the rms beam size. Plots of rms emittance from the CCL to SCL are shown in Fig. 6 for two different measurement uncertainties of rms beam sizes, namely 0% and 10%. 20% uncertainty in the initial matching condition is assumed. These are results when four wire-scanners are used. Unlike the baseline configuration of wire-scanners, reasonable matching is obtained with 10% or more measurement uncertainty. It should be noted that the resulting match is better as there is less fluctuation in the rms emittance compare with Fig. 7. The beam envelope profiles in Fig. 7 are superior to those in Fig. 8 for the same 10% rms beam size uncertainty. Beam profiles obtained from using wire-scanners not in series for matching are shown in Fig.8.

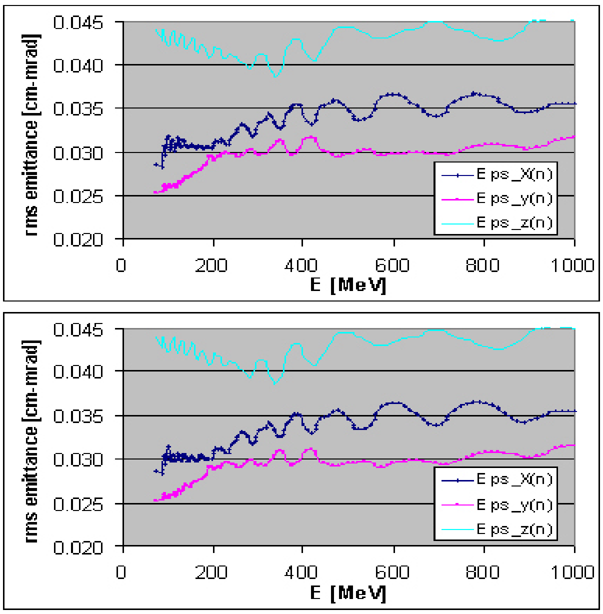


Figure 6: Plots of rms emittance for the cases with 10% (the top plot) and 20% rms beam size measurement uncertainties (the bottom plot). Four wire-scanners are used in series.

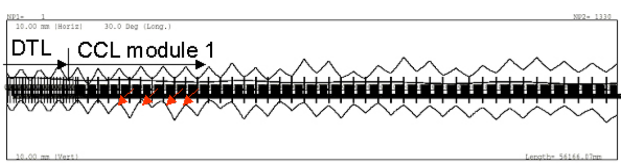


Figure 7: Trace3D [5] plots of beam envelopes after matching with 10% rms beam size uncertainty using four wire-scanners (red arrows) in series.

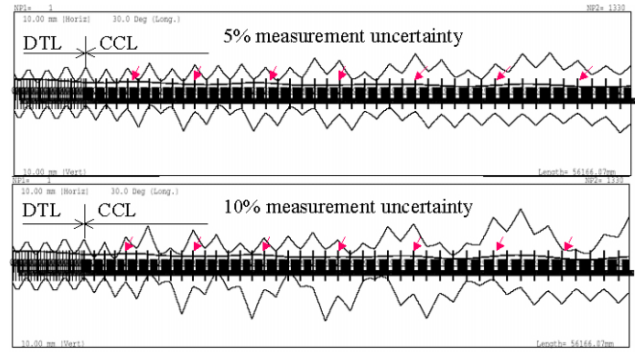


Figure 8: Trace3D plots after matching using wire-scanners (red arrows) not in series which are indicated by red arrows.

CONCLUSIONS

Most desirable ways of performing transverse matching are presented:

- Transverse matching of MEBT to DTL will be done by minimizing rms emittances.
- Transverse matching of DTL to CCL and CCL to SCL will be done using four wire-scanners in series.
- The proposed schemes are tolerant of measurement uncertainties, pulse-to-pulse jitters and beam mismatch, as well as it generates better matching.
- Measurement accuracy better than 20% is required for the proposed scheme to accomplish transverse matching.

REFERENCES

[1] J. Stovall et al, Proc. of 2001 Particle Accelerator Conference (Chicago, 2001) p. 446.
[2] H. Takeda, Parmila code.
[3] Lagarias, J.C., J. A. Reeds, M.H. Wright, and P.E. Wright, "Convergence Properties of the Nelder-Mead Simplex Algorithm in Low Dimensions," May 1, 1997. To appear in the SIAM Journal of Optimization.
[4] D. Jeon et al, Proc. of LINAC2002 conference (August 2002): MO422.
[5] K. Crandall and D. Rusthoi, An Interactive Beam-Transport Code, Los Alamos National Laboratory report LA-10235-MS (January 1985): the Trace3D code.