A TECHNIQUE TO TRANSVERSELY MATCH HIGH INTENSITY LINAC USING ONLY RMS BEAM SIZE FROM WIRE-SCANNERS *

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Abstract

A robust technique to do transverse matching is developed utilizing rms beam sizes obtained from four or more wire-scanners in series. This technique does not rely on any model or codes, and is robust against measurement uncertainties (tolerant up to 20% (3σ) uncertainties) and beam mismatches etc.

1 INTRODUCTION

The Spallation Neutron Source Linac consists of a Drift-tube Linac, a Coupled Cavity Linac followed by a Superconducting Linac. We studied feasible schemes of transversely matching the DTL to CCL of SNS Linac utilizing wire-scanners and obtained physics requirements on wire-scanners, which can be easily extended to SCL. A few matching schemes are tested using the Parmila code [1]. 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 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 $\alpha=0$ 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. 20% measurement uncertainty means that 3σ of Gaussian uncertainty distribution is 20% of the rms beam size.

In simulation test, optimization is done using a minimization routine of MATLAB®. This routine uses the simplex search method [2]. 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.

2 WIRE-SCANNERS NOT IN SERIES

According to the previous baseline design of SNS linac, there are two wire-scanners per CCL module, i.e. eight total in four CCL modules. Matching was attempted using the eight wire-scanners that are not placed in series. Somewhat reasonable matching is possible with up to 5% measurement certainty in rms beam size. However matching becomes unsatisfactory when there is 10% measurement uncertainty in rms beam sizes. This is dramatically shown in the Trace3D [3] envelope plots in Fig. 1. It should be noted that there are pronounced fluctuations in the rms emittance curves, which is a sign of some mismatch. It should be noted that pulse-to-pulse jitters should also be included in this number. So the measurement accuracy of rms beam sizes should be better than 5% is required for this scheme.

The obvious demerit of scattered wire-scanners in minimizing envelope beating is that a large beating can be generated in between the wire-scanners, even though the beating is minimized at the locations of wire-scanners.

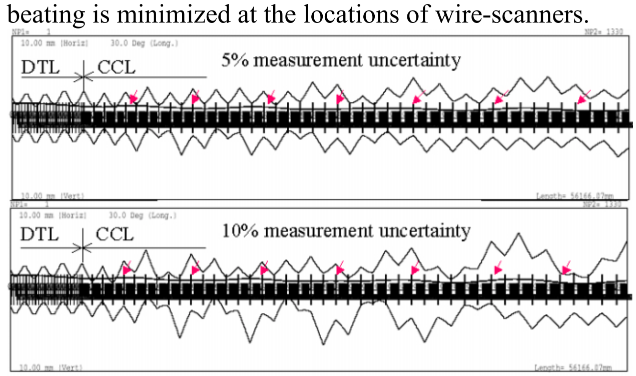

Figure 1: Trace3D plots after matching using wire-scanners not in series which are indicated by red arrows.

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3 FITTING RMS BEAM SIZES

As a second scheme, we study the possibility of accomplishing the transverse matching by fitting rms beam sizes to target values obtained from the model. The target values of rms beam sizes are obtained using a nominal input beam distribution. We are using the two wire-scanners in the CCL module 1 of the previous baseline design to study the feasibility of matching. Again, the initial beam distribution used for matching contains 30% transverse and longitudinal mismatches to account for the unknown mismatches that may be present in the real beam.

The drawback of this method is that it depends strongly on the availability of detailed information on the beam distribution and the machine such as the degree of mismatch, and the imperfections of the machine, and so on. In commissioning and during routine operations, only limited information on the beam will be available.

Figure 2 shows the rms emittance along the linac after matching. The top plot is obtained by using two wire-scanners in CCL module 1. The bottom plot is by using the four wire-scanners in CCL module 1 and 2. 0% measurement uncertainty and 20% uncertainty in the initial matching condition are assumed for both plots. Clearly this scheme is not effective even with 0% measurement uncertainty, when there are mismatches included in the beam. The matching becomes better when the four wire-scanners are used in CCL module 1 and 2. However, the quality of matching is still poor.

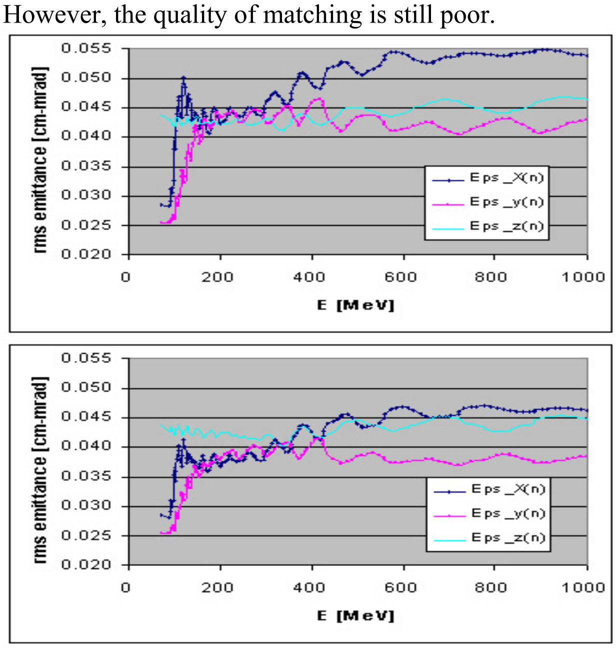

Figure 2: Plots of rms emittance by fitting rms beam sizes to do transverse matching. The top plot is obtained by using two wire-scanners in CCL module 1. The bottom plot is obtained by using the four wire-scanners in CCL module 1 and 2. 0% measurement uncertainty is assumed for both plots. The resultant matching is not satisfactory.

4 WIRE-SCANNERS IN SERIES

As an alternative, we study the transverse matching scheme by minimizing the envelope beating using multiple wire-scanners placed in series. 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. 3 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 five 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. 2. The beam envelope profiles in Fig. 4 are superior to those in Fig. 1 for the same 10% rms beam size uncertainty.

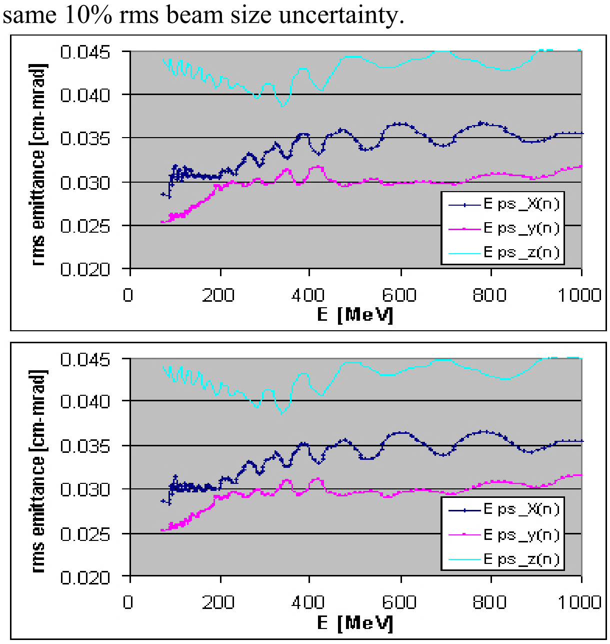

Figure 3: Plots of rms emittance for the cases with 10% (top plot) and 20% rms beam size measurement uncertainties (bottom plot). Four wire-scanners are used in series.

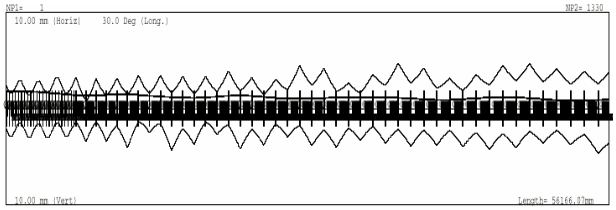

Figure 4: Trace3D plots of beam envelopes after matching with 10% rms beam size uncertainty.

5 CONCLUSIONS

The following is the physics requirement on wire-scanner for a few schemes. The accuracy requirement also includes the pulse-to-pulse beam jitter.

- The proposed scheme is more tolerant of measurement uncertainties, pulse-to-pulse jitters and beam mismatch, as well as it generates better matching.
- Four or more wire-scanners are required depending on the actual uncertainty in matching quad gradient.
- Matching by fitting the rms beam size is dependent on the detailed information of beams, which may not be available during the commissioning. This scheme is not recommended.
- Measurement accuracy better than 20% is required for the proposed scheme to accomplish transverse matching.

6 REFERENCES

[1] H. Takeda, Parmila code.
[2] 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.
[3] K. Crandall and D. Rusthoi, An Interactive Beam-Transport Code, Los Alamos National Laboratory report LA-10235-MS (January 1985): the Trace3D code.