TRANSVERSE BEAM TUNING AND INJECTION TO RCS AT J-PARC LINAC

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Abstract

Since December 2006, LINAC commissioning has been performed. Transverse beam matching has been carried out every time when a beam condition has been changed, which is essential to suppress beam loss in LINAC. We show reproducibility of the tuning procedure and show the resulting beam emittance. LINAC beam injected to RCS reflects performance of RCS beam at various modes. We have established a method to determine field of quadrupole magnets in L3BT injection region to set Twiss parameters and dispersions to designed values at the RCS injection point. We have defined sets of quadrupole field, applied them, and observed that the designed Twiss parameters and dispersions have been actually achieved.

INTRODUCTION

As shown in Refs. [1,2], there are seven matching sections where wire scanners are installed; MEBT1, SDTL, A0BT, L3BT straight section, L3BT arc section, L3BT collimator section, and L3BT injection section. Each section consists of 4 or more knob quadrupole magnets (QM's) each of which has an individual power supply, and 4 wire scanners (WS's) with an exception of 8 WS's at the L3BT collimator section. Except for MEBT1 and L3BT injection sections, the lattice is periodic at each wire scanner, where matching condition is to have an identical Twiss parameters (α_x, α_y, β_x, β_y) at all wire scanners. MEBT1 and L3BT injection sections have no periodic lattice. MEBT1 section is for beam tuning between RFQ and DTL1, and L3BT injection section is for beam tuning to the RCS injection point.

TRANSVERSE MATCHING IN LINAC

Matching Method

The matching procedure is described in detail in Ref. [2]. Here only the outline is described. An initial QM field is calculated with TRACE3D model. Except for matching sections, field of QM's is fixed. At each matching section, beam profiles are first measured with wire scanners. For a measured beam profile distribution, we subtract baseline then fit the distribution with a Gaussian. We define the beam width as a sigma of the fit. Then, we fit the sigmas at 4 WS's to the XAL model [3] with fit parameters of Twiss parameters and emittance (α_x, α_y, β_x, β_y, ε_x, ε_y) at an upstream position of the section. Then, field of 4 QM's are calculated so that (α_x, α_y, β_x, β_y) at 4 WS's agree to each other. These calculations are done by the Newton-Raphson method with a response matrix calculated from the XAL model [2].

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Matching Results

Comparison of beam profiles at beam current of 10mA is shown in Fig. 1. It is clearly seen that the tail part is enhanced between SDTL and A0BT sections both in horizontal and vertical profiles. The source of tail enhancement might be in beam acceleration at SDTL tanks.

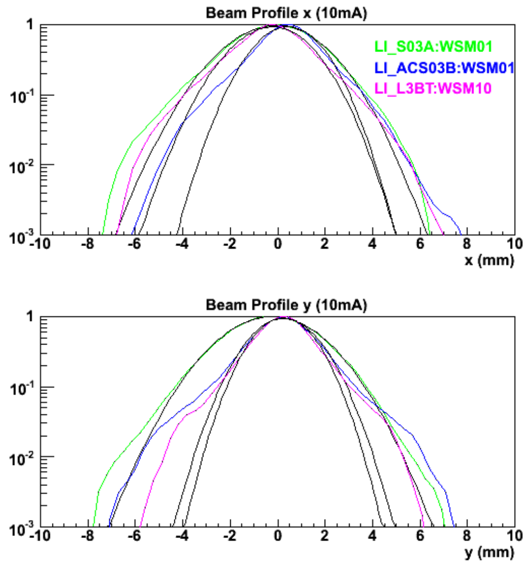


Fig. 1: Horizontal (top) and vertical (bottom) beam profiles measured at SDTL (green), A0BT (blue), and L3BT (magenta) matching sections. Note that horizontal coordinates are not corrected for beam energy. Therefore an apparent larger width is seen for SDTL ($\beta\gamma$~0.33) compared to A0BT and L3BT ($\beta\gamma$~0.65).

Fig. 2 shows normalized 1σ emittance of beam profiles (πmmmrad) obtained by fit to beam widths at each section at beam current of 5mA and 30mA, where the beam width is defined as a sigma of a Gaussian fit to a profile distribution. Emittance at 30mA is larger than that at 5mA by about 50~60%. Both at 5mA and 30mA, emittance at SDTL section is larger than other sections by about 50~70%. This might be due beam mismatch between MEBT1 and SDTL sections. Emittance obtained with the standard deviation of the profile distribution has, on the other hand, no significant enhancement at SDTL, but it is similar to the emittance at downstream sections. Therefore the apparent emittance decrease from SDTL to A0BT with the Gaussian sigma may be due to dramatic enhancement of the profile tails between SDTL and A0BT.

Blue and red lines in Fig. 2 show data at two time-separated commissioning runs. The difference of emittance at two runs reflects reproducibility of the transverse matching procedure. It is seen the emittance agrees very well at the two runs, which proves good reproducibility of the matching procedure. The mismatch factor, defined as $M=(\sigma_{max}-\sigma_{min})/(\sigma_{max}+\sigma_{min})$ where σ_{max} and σ_{min} are maximum and minimum standard deviations of 4 WS's, are compared also at two runs. At both runs mismatch factors of less than 4% have been achieved, which shows an excellent matching power of the present method.

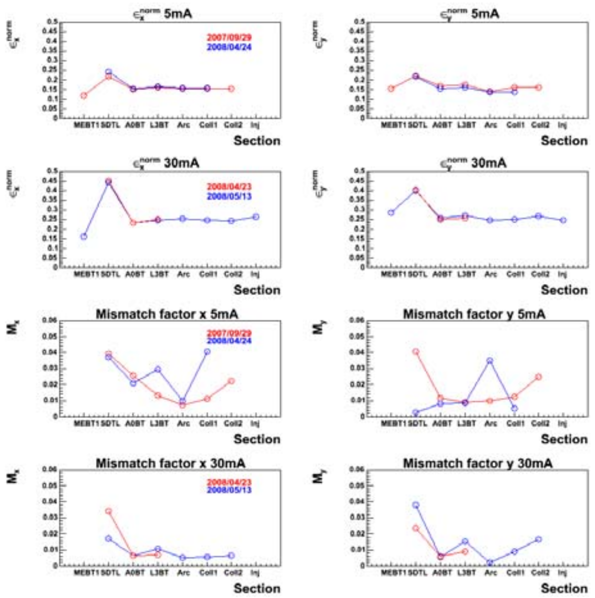


Fig. 2: Normalized one sigma emittance at 5mA (first row) and 30mA (second row) in horizontal (left) and vertical (right) directions. Mismatch factors at 5mA (third row) and 30mA (fourth row) in horizontal (left) and vertical directions (right).

TUNING OF RCS INJECTION

Tuning Method for RCS Injection

There are 18 QM magnets after the L3BT collimator section which can be used as knobs to set Twiss parameters and dispersion at RCS injection point at the charge exchange foil.

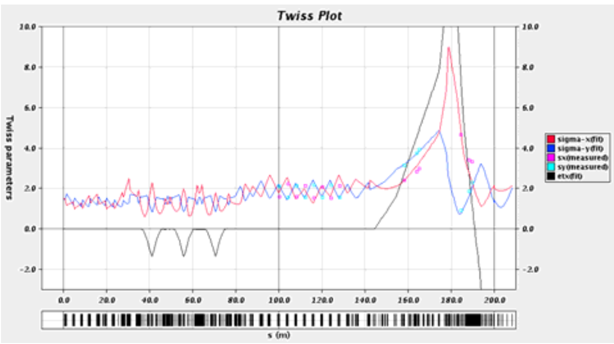
The procedure of tuning RCS Twiss parameters and dispersion is as follows. Beam profiles of L3BT collimator sections, L3BT injection sections are measured with WS's, and downstream profiles to the RCS injection point are measured with MWPM's (Multi-Wire Profile Monitors). Sigmas of Gaussian fit to these profiles are fit to the XAL model by varying (α_x, α_y, β_x, β_y, ε_x, ε_y) at the beginning of L3BT with a similar response matrix method as the matching procedure. Then fixing the parameters, optimum QM fields are calculated. This is done by constructing a response matrix with QM field as input parameters and difference between Twiss parameters of the model to goal Twiss parameters at the foil position as output parameters. In case dispersion matching is required, dispersion difference is also included as output parameters. Then, by calculating a pseudo-inverse matrix through SVD (Singular Value Decomposition), and multiplying it with the difference between current Twiss parameters (and dispersion) and their goal values, corrections to QM field are derived. Ideally the whole procedure should be iterated until the goal values are reproduced. Due to limited time for beam experiments, however, iteration of this procedure has not been done.

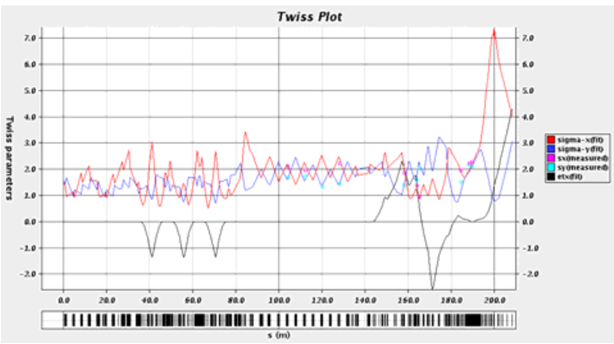
Tuning Method for RCS Injection

We have calculated three sets of QM field. The following 3 sets of parameters are defined;

1. "Matched" setting where (α_x, α_y, β_x, β_y) are matched with those of RCS circulating beam at the foil.
2. "Dispersion matched" setting where $D_x=0$, and $D'_x=0$ at the foil.
3. "Half-matched" setting" which is a default setting with Twiss parameters and dispersions between "Matched" and "Dispersion matched" settings.

We applied them and measured beam profiles with WS's and MWPM's. The resulting envelopes fit to measured Gaussian sigma of profiles and dispersions calculated with the model are shown in Fig. 3.





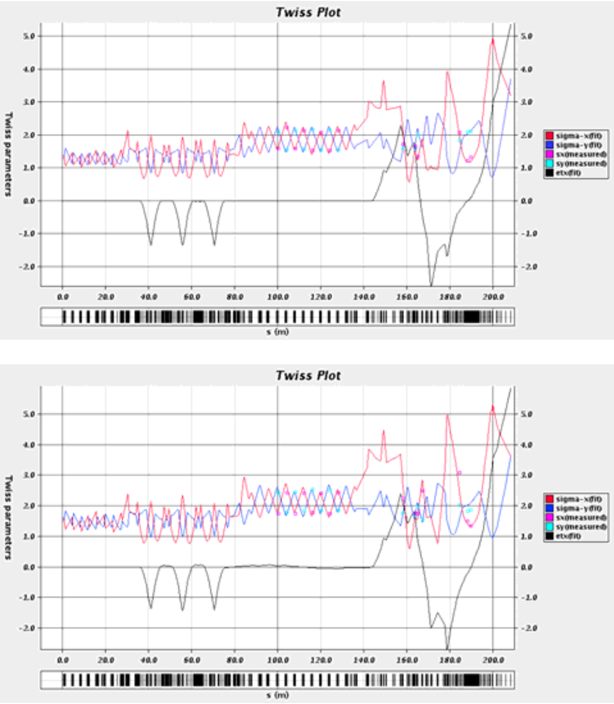
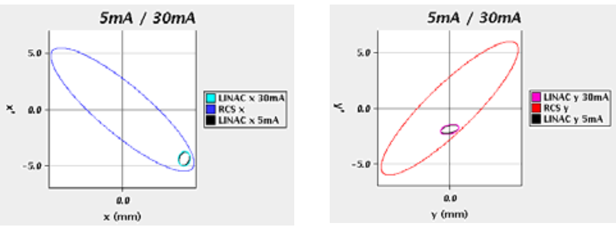


Fig. 3: Envelopes (mm) in horizontal (red line) and vertical (blue line) directions fit to profile widths (points) and dispersions (m) (black line) calculated by the model at different sets of QM field; First row: 5mA Matched, second row: 5mA Dispersion-matched, third row: 5mA Half-matched, fourth row: 30mA Half-matched. The RCS injection point at the charge exchange foil corresponds to the z position of about 190 m.

We have then calculated Twiss parameters at the foil and compared phase ellipse with RCS as in Fig. 4 for "Half-matched" settings at 5 and 30mA. At both current, very similar ellipse has been obtained. Fig. 4 also shows comparison of LINAC ellipse for all settings. The emittance of the LINAC ellipse in the figure is with $\sqrt{5}\sigma$ of the Gaussian fit of a beam profile, which is 1.6 πmmmrad at 5mA and 2.0 πmmmrad at 30mA as unnormalized emittance, which corresponds to the fraction of the about 85% of the total beam.



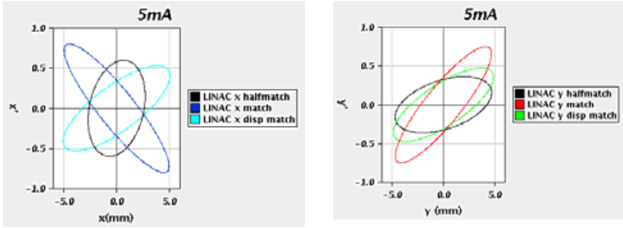


Fig. 4: Top: Horizontal (left) and vertical (right) phase ellipses of LINAC beam at the charge exchange foil at 5mA and 30mA with "Half-matched" setting; compared to RCS circulating beam. Bottom: Horizontal (left) and vertical (right) LINAC beam for "Matched", "Dispersion-matched", and "Half-matched" settings.

SUMMARY

In summary, we have developed a procedure for transverse matching at LINAC matching sections with periodic lattice from SDTL to L3BT collimator sections with a response matrix calculated from a model. The matching results are reproduced at two time separated runs, and excellent mismatch factors less than 4% have been achieved. Measured emittance is larger at 30mA than that at 5mA by about 50~60%. Apparent emittance enhancement by about 50~70% compared to other sections has been observed with fit of profiles at each section. This effect may be due to uncertainties of acceleration electric field or magnetic field in MEBT1, DTL, and SDTL, are going to be investigated in detail utilizing muli-particle simulations. We also tuned LINAC beam injected to RCS, with varying quadrupole magnets after L3BT collimator section. The method to calculate quadrupole field setting for designed Twiss parameters and dispersions at the injection point has been developed, with a response matrix calculated with a model, similarly to the transverse matching procedure. We have applied 3 sets of Twiss parameters at the injection point, and measured resulting beam profiles. Expected Twiss parameters have been obtained from the measurements. To study the optimum beam parameters for RCS, data analysis of orbit and beam profiles in the RCS ring is planned.

REFERENCES

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[3] J. Galambos, *et al*, "XAL Application Programming Framework", ICALEPCS 2003, Gyeongju, Korea.