TRANSVERSE BEAM MATCHING AND ORBIT CORRECTIONS AT J-PARC LINAC

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Abstract

In high intensity H- beam of J-PARC LINAC, precise control of transverse beam dynamics is extremely important to suppress beam loss. Transverse matching has been performed at several matching sections in LINAC, which consist of knob quadruple magnets (QM's) and wire scanners (WS's) for profile measurements. Mismatch factors of less than 5% have been achieved. Matching of Twiss parameters and dispersion at the RCS injection point has been also done with quadruple magnets at L3BT injection region with beam profiles measured with WS's and also multi-wire profile monitors (MWPM's) at RCS. Orbit corrections along the whole LINAC have been done with steering dipole magnets in the upstream of beam position monitors (BPM's). Orbit deviations were suppressed within 1mm in the whole LINAC.

TRANSVERSE MATCHING

The strategy of the LINAC transverse matching is as follows;

1. At MEBT1, we fit transverse and longitudinal Twiss parameters and emittance at the MEBT1 entrance.
2. Then, using the beam parameters, an initial QM field pattern at matching sections through LINAC and electric field and phase settings of Buncher 1 and 2 at MEBT1 is calculated requiring matching conditions with a model (TRACE3D).
3. Applying the calculated settings to QM's and Bunchers, we measure beam profiles from most upstream (MEBT1) to most downstream (L3BT injection section) in turn at each matching section. At sections after MEBT1 QM field is corrected to fulfil matching conditions.

The LINAC has 7 matching sections, each of which consists of 4 or more upstream QM's and 4 or more downstream WS's. At MEBT1, only fitting of initial beam parameters is done. At RCS injection section, special matching procedure is performed which is described later. At the rest of matching sections; SDTL entrance, MEBT2, L3BT straight, L3BT arc, L3BT collimator sections, lattices are periodic at each WS position; where the following common procedure has been applied.

1. Fit the XAL online model [2, 3] to measured horizontal and vertical beam widths at 4 WS's by varying (α_x, α_y, β_x, β_y, ε_x, ε_y) at an upstream position from the QM's. The fit is done with a response matrix calculated with the model.
2. Corrections of 4 QM field are calculated to require that α_x, α_y, β_x, β_y agree at each WS. The calculation is done by applying the response matrix calculated with XAL [2].
3. The above procedures 1 and 2 are iteratively applied until convergence.

In MEBT1, Procedure 1 is replaced by 1';

1'. In addition to transverse parameter (α_x, α_y, β_x, β_y, ε_x, ε_y), longitudinal parameters (α_z, β_z, ε_z) are varied to fit simultaneously beam widths at 4 WS's at MEBT1 and transverse emittance and Twiss parameters measured at a double-slit emittance monitor at MEBT1 bend line [4].

In L3BT injection section, Procedure 2 is replaced by;

2'. QM's after the collimator section (L3BT QM62-79) are used to tune transverse Twiss parameters and dispersion at the RCS injection point of the charge exchange foil.

These procedures are done with a newly developed application called "matcher" [2].

SDTL to L3BT Collimator Sections

Measured emittance is shown in Fig. 1 at 5 mA and 30 mA at all sections. At 5 mA, measured 1 σ emittance at 5 mA is 0.17 πmm-mrad and 0.25 πmm-mrad at 30 mA.

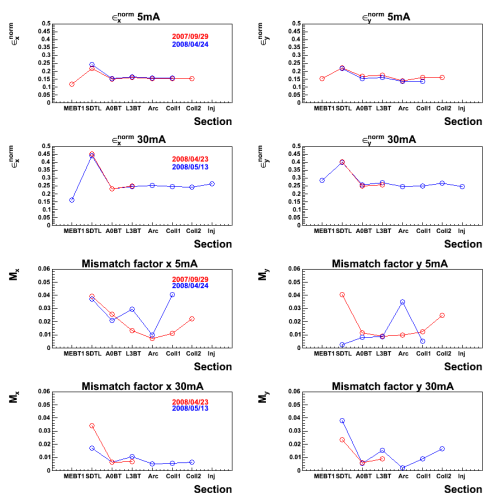

Figure 1: Normalized 1 σ emittance at 5mA (first row) and 30 mA (second row) in horizontal (left) and vertical (right) directions. Mismatch factors at 5 mA (third row) and 30 mA (forth row) in horizontal (left) and vertical directions (right).

Red and blue lines show matching results at two different periods, which proves good reproducibility of the matching procedure. Emittance growth at the SDTL entrance has been observed 5 mA and more enhanced at 30 mA. Mismatch factors of less than 5% have been achieved at 5 mA and 30 mA.

Figure 2 shows fit of beam widths measured from L3BT straight section to L3BT collimator sections to XAL. The XAL model without emittance growth describes very well the data at L3BT.

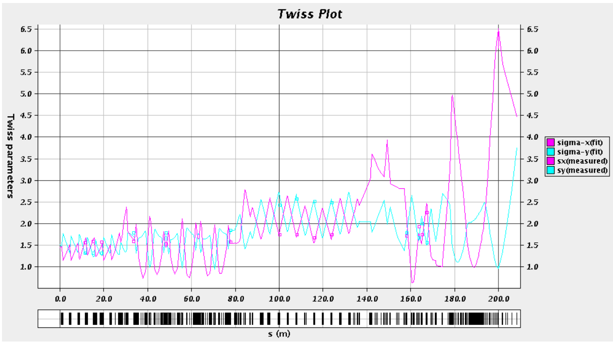

Figure 2: Horizontal (pink) and vertical (blue) 1 σ beam widths [mm] at L3BT fit to XAL model at 30 mA.

MEBT1 Section

The main goal of this section is to determine transverse and longitudinal beam parameters. Using above method 1', we have fit beam widths at WS's in the straight line, and emittance and Twiss parameters at the emittance monitor at the bend line.

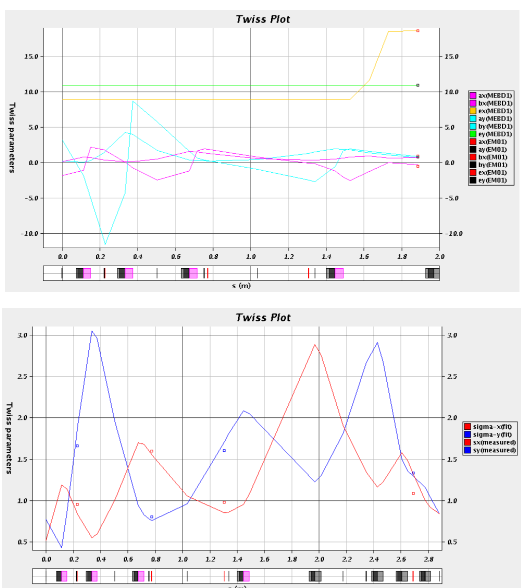

Figure 3: Top: measured transverse emittance and Twiss parameters with the double-slit emittance monitor at MEBT1 bend line. Bottom: measured profile widths with wire scanners at MEBT1. The curves show simultaneous fit with entrance transverse and longitudinal emittance and Twiss parameters.

Reasonable fit has been obtained as shown in Fig. 3. The resulting 5 σ longitudinal emittance at 5 mA and 30 mA is 582 and 477 π deg-keV. The values are similar to preliminary PARMTEQM calculations [7] of 550 and 410 π deg-keV.

L3BT Injection Section

This section tunes Twiss parameters and dispersions at the RCS injection point. The following three sets of beam parameters and QM configurations have been set and measured;

1. "Matched" setting where (α_x, α_y, β_x, β_y) are matched with those of RCS circulating beam.
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.

Figure 4 shows results of "Half-matched" configuration and fit to the XAL model, which shows beam parameters can be actually controlled by LINAC QM's.

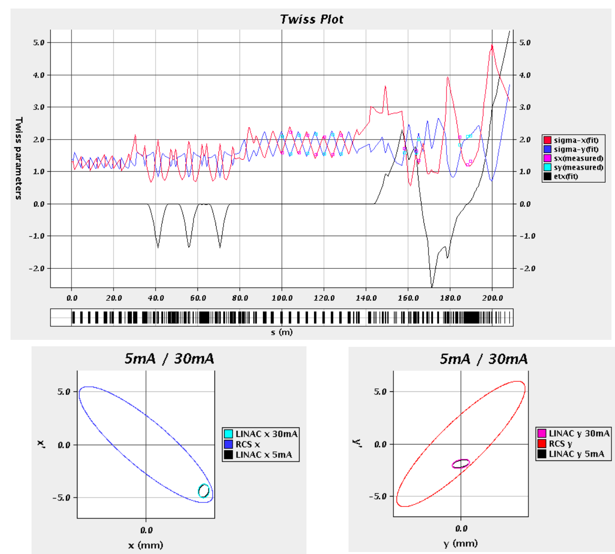

Figure 4: Top: Horizontal (red line) and vertical (blue line) envelopes fit to profile widths (points) and dispersions (m) (black line) calculated by the model at different sets of QM field for "Half-matched" setting at 5 mA. Bottom: Horizontal (left) and vertical (right) phase ellipses of LINAC beam at the injection point at 5 mA and 30 mA with "Half-matched" setting compared to RCS phase ellipse.

EMITTANCE GROWTH AT SDTL AND COMPARISON WITH IMPACT

In order to understand the observed evolution of emittance from MEBT1 to SDTL exit, we have compared the data with IMPACT simulation [6] at 30 mA. The initial particle phase space distributions are Gaussian with initial Twiss parameters and emittance from the measured values at MEBT1. Figure 5 shows comparison of measured profiles at the second WS in MEBT1, the first WS in SDTL entrance, and the third WS at the MEBT2 section with IMPACT. Another distributions with α_x, and α_y deviated by ~25% to make mismatch by ~30% at the DTL1 entrance are also simulated. In that case, IMPACT does not deviate from measured profile data very much. IMPACT in both cases apparently underestimates the beam width at the SDTL entrance, and fails to create tails at the SDTL exit.

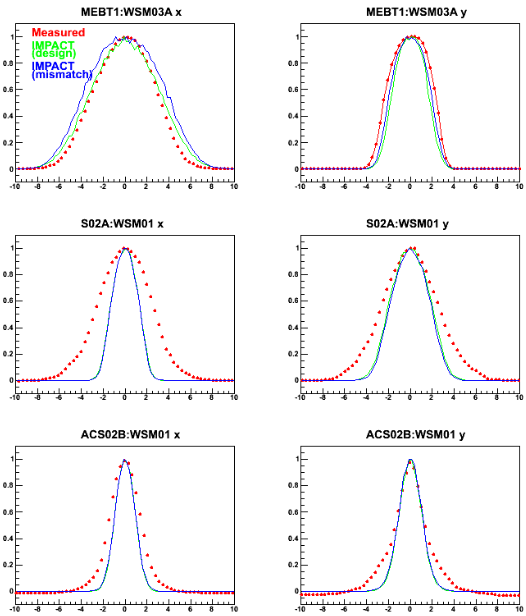

Figure 5: Horizontal (left) and vertical (right) beam profiles at MEBT1 (top), SDTL entrance (middle), and SDTL exit (bottom). Red dots show measured data with WS's. Blue lines show IMPACT calculations with the initial beam parameters from fit at MEBT1. Green lines show IMPACT calculations mismatched at the entrance of DTL1 by deviating initial Twiss parameters

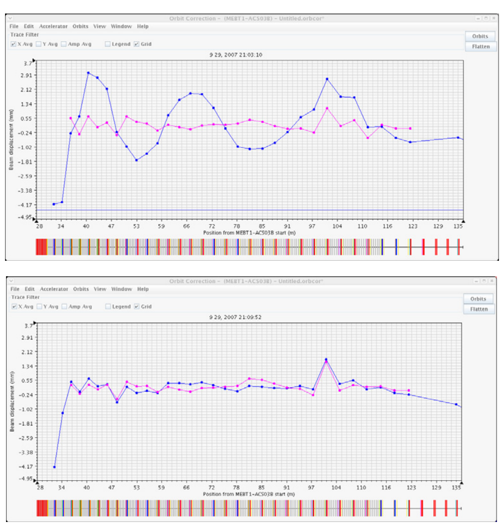

Figure 6: Horizontal orbit positions as a function of a distance at SDTL before correction (top) and after correction (bottom). Blue lines show measured beam positions, and pink lines show predicted positions.

ORBIT CORRECTIONS

Orbit corrections are performed for good beam transport and beam loss suppression. Main sources of orbit deviations are alignment errors of magnets, and magnetic and electric field errors. Beam positions are measured with beam position monitors (BPM's), and orbits are corrected with dipole steering magnets. The corrections are calculated with XAL in the application "orbitcorrect" as shown in Fig. 6 [5]. Orbit references and steering field patterns are saved, and orbit corrections are started with the restored field patterns and the orbit references. After the corrections, the orbit deviations are suppressed within 1 mm. The dipole field patterns have been stable at different runs.

CONCLUSIONS

Procedures of transverse matching in the whole LINAC have been established. At MEBT1, longitudinal and transverse initial beam parameters have been obtained. From SDTL to L3BT collimator sections, mismatch factors less than 5% have been achieved with good reproducibility. Twiss parameters at the RCS injection point have been controlled by QM's at LINAC. Emittance enhancement has been observed at SDTL entrance, and profile tails have been developed after SDTL. They are not reproduced by IMPACT by causing mismatch by varying initial transverse Twiss parameters in the constraint of profile data at MEBT. This problem is not critical for beam loss and emittance enhancement. However, to solve this problem it is necessary to improve precision of geometry, magnetic and electric field at MEBT1, DTL and SDTL. Orbit corrections have been successfully performed with orbit deviation within 1 mm.

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