DEVELOPMENT OF MATLAB-BASED APPLICATION PROGRAMS FOR THE OPTICS MATCHING, BEAM STEERING, AND INJECTION CONDITIONING IN TPS COMMISSIONING

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Abstract

Taiwan Photon Source (TPS) is a 3GeV 3rd generation synchrotron light source. Its first beam commissioning is scheduled in 2014. Many high-level application programs based on matlab middle layer (MML) developed for operation and commissioning are available around accelerator community. But the application programs based on AT and MML for optics matching, beam steering and injection conditioning of booster and storage ring are seldom mentioned. Hence, we have developed these application programs. With these application programs, we expect to speed up the commissioning process from LINAC to storage ring, because we do not need to swap between different packages anymore.

INTRODUCTION

The optics at the exit of LINAC usually is unknown. We need to measure these parameters in the beginning of commissioning. These parameters will serve as the launching optics of the LTB transfer line, and then use optics matching application program (AP) to re-match the LTB optics. This AP adopts a built-in function of MATLAB '*fminsearch*', similar to the SIMPLEX algorithm used in MAD, to find a solution to minimize the optics difference between calculations and constraints. Due to unavoidable magnet misalignment error in installation, we need an AP to assist us to fine tune the injection angle and position at the exits of LTB and BTS transfer lines. The MATLAB built-in function '*fminsearch*' is used to find a solution to minimize the trajectory difference between model and measured.

Detailed procedures and mathematical algorithm for optics matching and injection conditioning will be described later. The improvement of beam steering AP is still in progress.

OPTICS MATCHING APPLICATION PROGRAM FOR TRANSFER LINES

The acceptance test of TPS 150 MeV LINAC had been done in 2011 [1, 2]. In which, the used particle beam line design for the LINAC beam parameter measurement was a temporary design similar to the TPS LINAC diagnostic sub-branch (LTD) [3]. We prepared two versions of LINAC beam parameter measurement application programs (APs), using the quadrupole scan method to calculate the launching optics of the LTB transfer line, one is the thin-lens quadrupole model and the other is thick-lens hardedge model [4]. Figure 1 and 2 were the beam parameter measurements of the 150 MeV LINAC performed in 2012. Table 1 shows the calculation results of the beam parameters measured in the September 2012. All of them meet the specifications. Those data have been used as the launching conditions in the optics matching of the LTB transfer line.

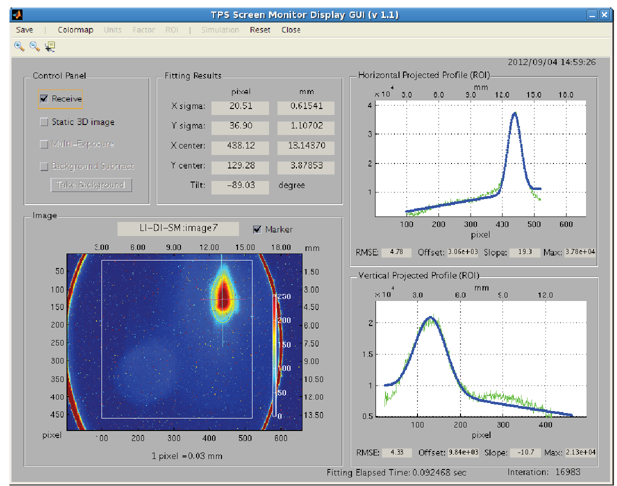

Figure 1: The beam size measurements on the screen after the quadrupole triplet and before the bending magnet were performed for calculating the Twiss functions and emittance of the 150 MeV LINAC.

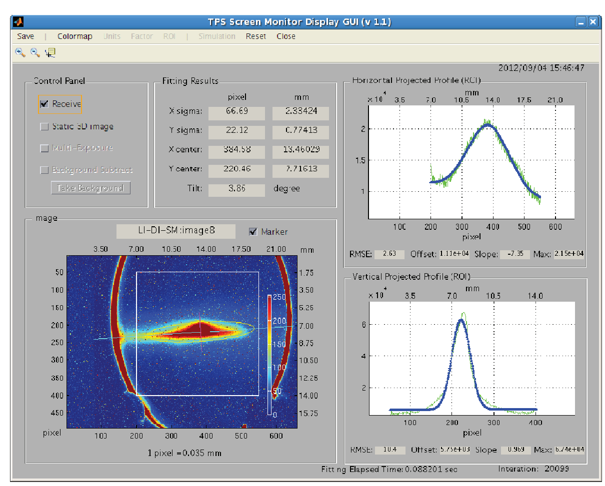

Figure 2: The beam size and beam center measurements on the screen located at the high dispersion region behind the bending magnet were performed for calculating the energy spread and energy variation of the 150 MeV LINAC.

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Table 1: Beam parameters at the LINAC exit

Beam Parameter	LINAC Specification	Measurement (Sep. 2012)
β_x (m)	N/A	3.1
α_x	N/A	-0.28
ε_{xn} (mm-mrad) $\varepsilon_{xn} = \beta\gamma\varepsilon_x$	0.167 50	0.069 21
β_y (m)	N/A	4.0
α_y	N/A	0.036
ε_y (mm-mrad) $\varepsilon_{yn} = \beta\gamma\varepsilon_y$	0.167 50	0.13 40
δ_x energy spread	< 0.5% (rms)	0.22% (1σ)
Δ_E energy variation	<0.25% pulse-to-pulse	0.057% std (140 pulses)

The optics matching can be done by the lattice design codes such as MAD or WinAgile. We have tried to develop an MATLAB AP based on AT and MML. This AP adopts a built-in function of MATLAB '*fminsearch*', similar to the SIMPLEX algorithm used in MAD, to find a solution to minimize the following objective function:

$$F(k_{Q1},\dots,k_{Qn}) \equiv \sum_j w_j \cdot (Twiss_j^{Calculation} - Twiss_j^{Constraint})^2$$

where 'Twiss' means the Twiss parameters, w is the weighting factor associated with the constraints. k_{Q1}, … , k_{Qn} are the strengths of used quadrupoles. If the constraint is inequality, a careful treatment should be taken. Figure 3 is a demonstration of the optics re-matching of the LTB transfer line with the measured beam parameters of LINAC .

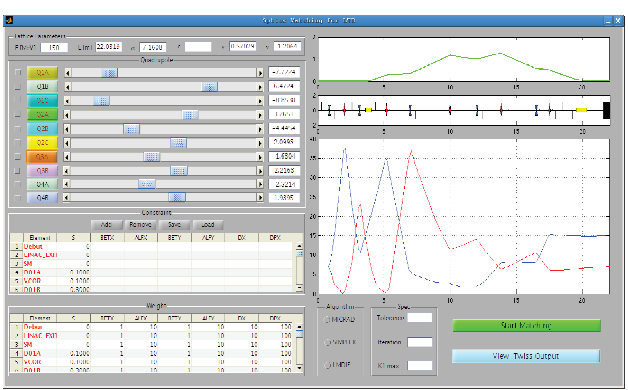

Figure 3: The optics matching application program in MATLAB has been tested in the optics re-matching of the LTB transfer line.

INJECTION ANGLE AND POSITION TUNING APPLICATION PROGRAM FOR TRANSFER LINES

This application program is used to fine tune the injection angle and position at the exits of LTB and BTS transfer lines. The transfer matrix M for a transfer line from point s0 to s takes the form

$$\begin{pmatrix} \sqrt{\frac{\beta}{\beta_0}}(\cos\Delta\phi + \alpha_0 \sin\Delta\phi) & \sqrt{\beta\beta_0}\sin\Delta\phi \\ \frac{(\alpha_0 - \alpha)\cos\Delta\phi - (1+\alpha\alpha_0)\sin\Delta\phi}{\sqrt{\beta\beta_0}} & \sqrt{\frac{\beta_0}{\beta}}(\cos\Delta\phi - \alpha\sin\Delta\phi) \end{pmatrix}$$

where the subscript '0' means that the Twiss parameters are at point s0, $\Delta\phi$ $(= \phi - \phi_0)$ stands for the phase advance from point s0 to s. The orbit response at BPM due to a corrector is given by

$$\begin{pmatrix} x \\ x' \end{pmatrix} = M \cdot \begin{pmatrix} 0 \\ \theta \end{pmatrix}$$

where θ is the kick angle of corrector.
After little algebraic manipulation, we arrive at

$$x = \theta \cdot \sqrt{\beta\beta_0}\sin(\varphi - \varphi_0)$$

$$x' = \theta \cdot \sqrt{\frac{\beta_0}{\beta}}(\cos(\varphi - \varphi_0) - \alpha\sin(\varphi - \varphi_0))$$

If more than one corrector is used to fine tune the injection angle and position, then we have

$$x = \sum_{i=1}^{n} \theta_i \cdot \sqrt{\beta\beta_i}\sin(\phi - \phi_i)$$

$$x' = \sum_{i}^{n} \theta_i \cdot \sqrt{\frac{\beta_i}{\beta}}(\cos(\phi - \phi_i) - \alpha\sin(\phi - \phi_i))$$

The above two equations can be cast as

$$R \cdot \theta = \begin{pmatrix} \Delta x \\ \Delta x' \end{pmatrix} \equiv \begin{pmatrix} x \\ x' \end{pmatrix}_{injection\quad point}^{target} - \begin{pmatrix} x \\ x' \end{pmatrix}_{injection\quad point}^{measured}$$

where R is the response matrix between BPM and corrector.
A model lattice is used to fit the measured electron trajectory. The fitting parameters are the launching conditions x, x' and energy deviation δ. Here, a built-in function of MATLAB '*fminsearch*' is used to find a solution to minimize the trajectory difference between model and measured trajectory.

$$F(x, x', \delta) \equiv \sum_j (x_j^{Model} - x_j^{Measured})^2$$

According to the launching conditions obtained from fitting, we can get the x and x' at each BPM by transfer matrix. Finally, apply SVD to decompose the response matrix R to calculate the desired corrector strengths to fine tune the injection angle and position with the target values.

$$R = U \cdot W \cdot V^T$$

$$\theta = V \cdot [diag(1/w)] \cdot U^T \cdot \begin{pmatrix} \Delta x \\ \Delta x' \end{pmatrix}$$

By SVD, the response matrix R is decomposed to a product of three matrixes U, W, and V^T. The superscript T means transpose.

Figure 4 and 5 shows the GUI of this AP. The operation procedures are described as the following.

First, users should choose the BPM data source and then press the button 'Get BPM data'.

Second, click the check box to choose fitting variables and then press the button 'Fit BPM data'. The 'Zoom in' and 'Zoom out' buttons, and the slider bar at the bottom of GUI are used to select the fitting region. Only those BPM located within the selected region will be chosen to fit the trajectory. In this stage, it will spend a few seconds to find out the launching conditions.

Third, click the check box to choose correctors, input the target value of injection angle and position, and then press the button 'Injection Tuning'. It will start to calculate the corrector strength by SVD to fine tune the injection angle and position.

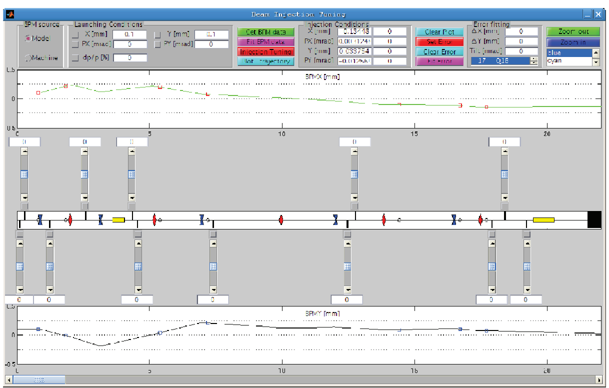

Figure 4: Injection angle and position tuning application program (LTB).

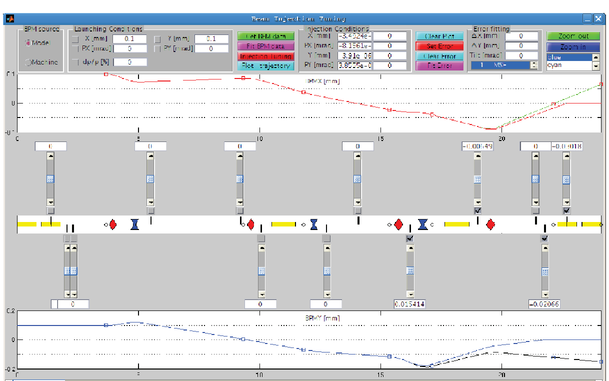

Figure 5: Injection angle and position tuning application program (BTS).

The GUI of this application program is developed by matlab script, instead of GUIDE tool of matlab. Hence, it is machine- (or lattice-) independent. The number of used uicontrol associated with the magnets is dynamic. It is based on the global variable 'THERING' of AT to show the uicontrol. If it finds the field name "FamName" of the variable "THERING" is "HCOR" or "VCOR", a vertical slider bar (a uicontrol) will be displayed above or below the associated corrector magnet. If users move the slider bar with mouse, the model trajectory will be displayed immediately.

BEAM STEERING

The beam steering AP aims at assisting us to bring the electron beam to pass through the whole ring for first turn. It is still under improvement. We adopt the idea of H. Grote [5]. His algorithm is described below:

Refer to Figure 6, use two correctors C2 and C1 at the upstream of BPM2 to correct the electron trajectory such that the reading of BPM2 and BPM1 are close to 0. The phase advance between BPM2 and BPM1 should avoid a multiple of π, so does the phase advance between two correctors.

Here, we can use 'for loop' to go through the whole lattice by the same token to bring the electron beam to pass through the whole ring.

$$M_{C1-BPM1}\left[M_{C2-C1}\begin{pmatrix}0\\ \theta_2\end{pmatrix}+\begin{pmatrix}0\\ \theta_1\end{pmatrix}\right]+\begin{pmatrix}x_1\\ 0\end{pmatrix}=0$$

$$M_{C1-BPM2}\left[M_{C2-C1}\begin{pmatrix}0\\ \theta_2\end{pmatrix}+\begin{pmatrix}0\\ \theta_1\end{pmatrix}\right]+\begin{pmatrix}x_2\\ 0\end{pmatrix}=0$$

where $M_{C1\text{-}BPM1}$ is the transfer matrix from C1 to BPM1 etc. θ_2 and θ_1 are the kick angles of corrector C2 and C1, respectively.

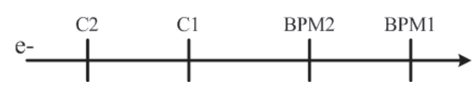

Figure 6: Correction scheme for beam steering

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