ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-TUPJE049

TPS LINAC RELOCATION AND BEAM TEST OF THE LTB TRANSFER LINE

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Abstract

The Taiwan Photon Source (TPS) 150 MeV linac has been relocated from its 2011 test site to the TPS linac tunnel in 2014. After functional test of the linac hardware modules, the beam parameters were carefully examined at a 31-degree bend diagnostic beam line LTD (linac to beam dump) and compared with previous results. Then, the 150 MeV electron beam was delivered to the linac to booster transfer line (LTB) for beam commissioning. The beam optics matching at both the LTB entrance (i.e. linac exit) and the LTB exit (i.e. injection point of booster) was performed for injection optimization purpose. The LTB lattice setting was verified in the beam steering through LTD and LTB with the help of diagnostics tools such as beam profile monitors (SM) and beam position monitors (BPM). The overall performance of the linac and LTB will be described in this report.

INTRODUCTION

The goal of TPS linac relocation and beam test of the LTB is to meet the requirement of the TPS beam commissioning planned in 2014. Relocation of the TPS linac was well prepared in 2013 and initiated when the TPS linac tunnel was available for the linac installation in 2014. Beam test of the linac and LTB has been performed on time in August 2014 according to the beam test scenario set by the Taiwan Atomic Energy Council [1-3].

We summaries the milestone of the TPS linac relocation processes as followings:

- May 2011 ~ Nov 2013: The linac was under the routine operation after its acceptance. The main tasks were performed during this period includes: familiar with system operation, training platform for colleagues, trouble shooting and failure analysis, and preparation for relocation.
- Nov 2013 ~ Feb 2014: The preparation for relocation includes the cable labelling of power and signal cables, disassembly of acceleration sections and waveguides.
- Feb 2014 ~ May 2014: On-site installation of functional modules and their testing.
- Jun 2014 ~ Aug 2014: Linac rf processing, beam test of linac, LTD, and LTB.

The overall performance of the linac and LTB transfer line will be described in the following sections.

TPS LINAC RELOCATION

The 150 MeV TPS linac has been operating at its test site since the acceptance test in 2011 [4,5]. It was shut down and packaged for the relocation in November 2013 and then it was moved to the TPS linac tunnel in February 2014. Linac installation was finished in three months. It included the installation and functional test of each linac module such as electron gun, the magnets (solenoid, corrector, and quadrupole), modulators etc. The rf processing was then performed for the preparation of beam test. Figures 1 and 2 show the relocated TPS linac and power supplies at the TPS site.

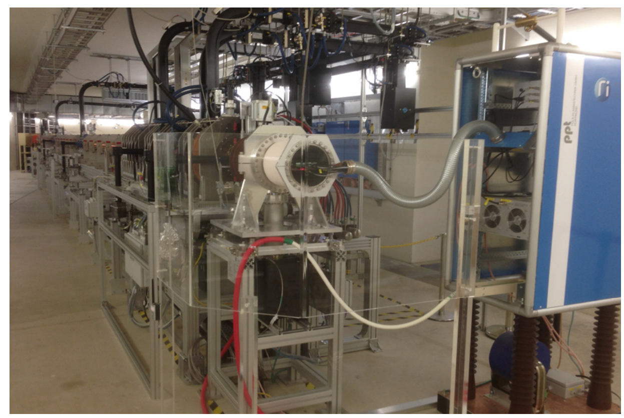

Figure 1: The linac installed in the TPS tunnel.

Figure 2: The power supply area of the TPS linac.

BEAM PARAMETERS MEASUREMENT

As illustrated in Figure 3, the 31-degree bend LTD is used as the linac diagnostic beam line [6]. Beam parameters at the exit were verified with profile monitoring, lattice manipulation and compare with the matching calculation.

The linac and LTB were ready for beam test in July 2014. On August 1, the Atomic Energy Council issued the permission of TPS radiation protection plan for beam commissioning. Beam test of linac and LTB was

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performed right away with the help of radiation safety colleagues. The electron beam was extracted from the linac with minor tuning and beam properties were verified immediately at the LTD. Beam energy of 150 MeV and energy spread of 0.3% were obtained. Then, the bending magnet was switched from 31 degree (LTD) to 11 degree (LTB) for LTB commissioning. The energy parameters were further confirmed at the high dispersion area. With proper settings of magnets, the electron beam arrived at the end of LTB, as shown in Figure 4.

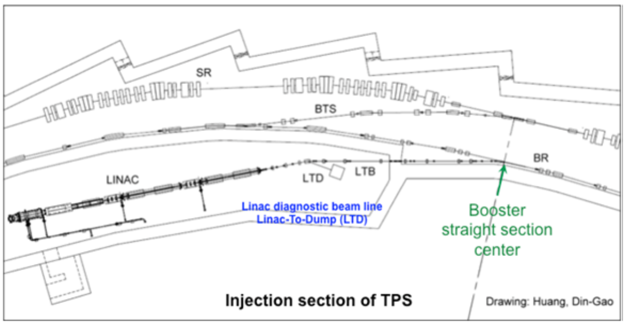

Figure 3: Layout of TPS injection sections of booster and storage ring including linac, LTD, LTB, and BTS.

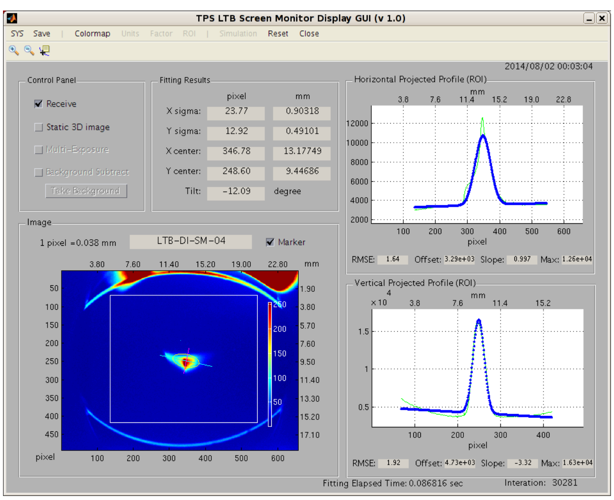

Figure 4: Beam profile at the end of LTB.

The linac performance was verified by measuring beam parameters and compares with the specifications. The results are summarized in Table 1. With the measurement results obtained in LTD, the calculated optics at the linac exit is used for later on LTB optics matching. The primary beam test indicates that the linac and LTB is ready to provide electron beam for TPS commissioning.

OPTICS MATCHING AND LTB BEAM COMMISSIONING

The LTD beam measurement and optics calculation provides information concerning the LTB launching conditions at linac exit. The beam parameters propagate along LTB follows the optics re-matching calculation results. The detailed parameter verification methods are categorized as follow [4,7]:

Table 1: The Linac Beam Parameters and Specifications

Parameter	Specification	Measurement
Bunch train length [μs]	0.2 to 1 (LPM) FWHM ≤ 1ns*	0.2 to 1 FWHM < 0.8 ns*
Energy [MeV]	≥ 150	≥ 150
Pulse to pulse energy variation [%]	≤ 0.25 (rms)	0.02
Relative energy spread [%]	≤ 0.5 (rms)	0.35 0.11*
Normalized emittance (1σ) [πmm.mrad]	≤ 50 (both plane)	(x,y) = (36, 49) (x,y) = (48, 35)*
Single bunch purity [%]	< 1	< 1
Pulse to pulse time jitter [ps]	≤ 100	56 49*

*SBM: single bunch mode

Quadrupole Scan Method

Using the transfer matrices of drift spaces and quadrupoles, one can construct the transfer matrix from the linac exit to the SM2 where the beam measured.

$$M=\begin{pmatrix} C & S \\ C' & S' \end{pmatrix}=M_{D3}\cdot M_{Q2}\cdot M_{D2}\cdot M_{Q1}\cdot M_{D1} \quad (1)$$

Beam optics propagates from linac exit to SM2 is

$$\begin{pmatrix} \beta \\ \alpha \\ \gamma \end{pmatrix}=\begin{pmatrix} C^2 & -2SC & S^2 \\ -CC' & (S'C+SC') & -SS' \\ C'^2 & -2S'C' & S'^2 \end{pmatrix}\begin{pmatrix} \beta_0 \\ \alpha_0 \\ \gamma_0 \end{pmatrix} \quad (2)$$

Apply the following beam matrix σ to the above relation,

$$\sigma\equiv\begin{pmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{12} & \sigma_{22} \end{pmatrix}=\varepsilon\begin{pmatrix} \beta & -\alpha \\ -\alpha & \gamma \end{pmatrix} \quad (3)$$

the squares of beam emittance and beam size are

$$\sigma_{11}\cdot\sigma_{22}-\sigma_{12}^2=\varepsilon^2 \quad (4)$$

and

$$\sigma_{11}=\varepsilon\beta=\left(\sqrt{\varepsilon\beta}\right)^2=\sigma_{x,y}^2 \quad (5)$$

One obtains the equation related to the measured beam size and the optics located at the linac exit.

$$\sigma_{11}(SM2)=C^2\cdot\sigma_{11}^0+2SC\cdot\sigma_{12}^0+S^2\cdot\sigma_{22}^0 \quad (6)$$

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The measured beam size variation verses quadrupole strength at SM2 is fitted with equation (6) and the beam emittance information is extracted.

Thin-lens Quadrupole Approach

The thin-lens quadrupole approach is generally adopted to simplify the data fitting. The square of beam size, i.e., equation (6), becomes a second order polynomial of the integrated quadrupole strength. One obtains:

$$\sigma_{x,y}^{\ 2}\left(kl_q\right) = \underline{A} + \underline{B}\cdot\left(kl_q\right) + \underline{C}\cdot\left(kl_q\right)^2$$

(8)

where

$$L \equiv l_1 + l_2 + l_q \qquad ,$$

(9)

and

$$\begin{aligned}\underline{A} &= \varepsilon\beta_0 - 2L\varepsilon\alpha_0 + L^2\varepsilon\gamma_0 \\ \underline{B} &= -2l_2\cdot\left[\varepsilon\beta_0 - \left(l_1 + L\right)\varepsilon\alpha_0 + l_1 L\varepsilon\gamma_0\right] \\ \underline{C} &= l_2^2\left(\varepsilon\beta_0 - 2l_1\varepsilon\alpha_0 + l_1^2\varepsilon\gamma_0\right)\end{aligned} \qquad .$$

(10)

It is easier for data fitting calculation.

Figure 5 and Figure 6 give typical example of a set measurement and their re-matching results. It includes the beam optics at the linac exit and re-matched optics of the LTB transfer line.

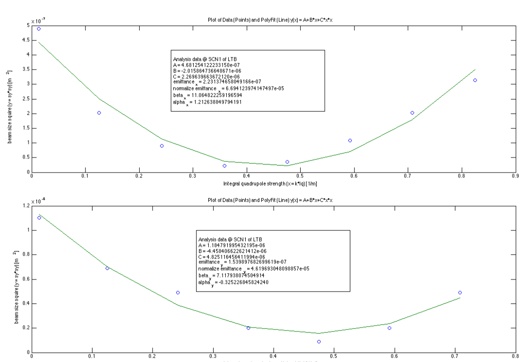

Figure 5: Beam size variation with quadrupole scan and data fitting.

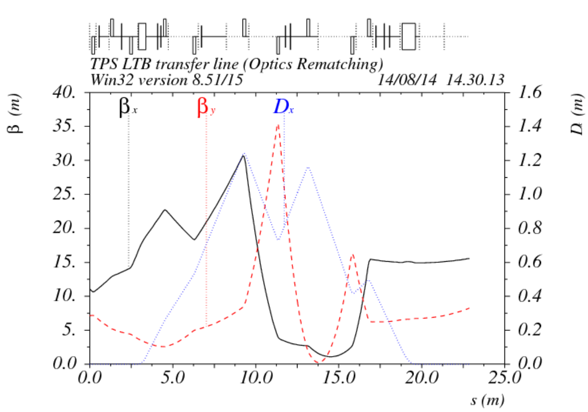

Figure 6: The beam optics of LTB with the launching conditions at the linac exit calculated by fitting the measured beam sizes.

Beam Test of Injection Septum and Kicker

The injection septum and kicker were active once the electron beam appeared at the LTB exit. With appropriate setting, the electron beam passed through both pulsed magnets and was observed at the exit of kick, as shown in Figure 7.

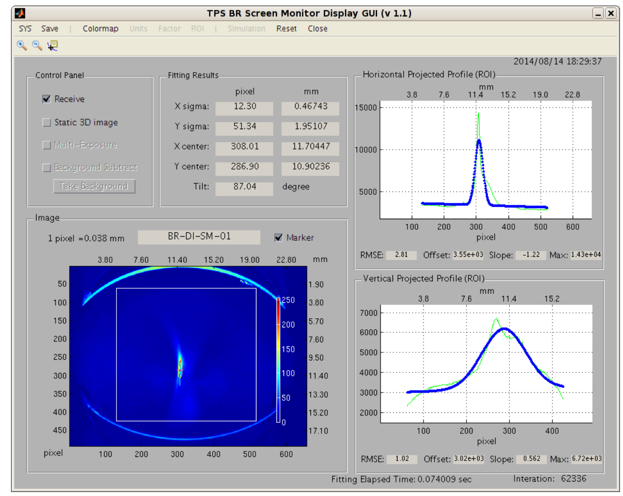

Figure 7: Electron beam appears at the first screen monitor of booster located at the exit of injection kicker.

SUMMARY

Relocation and installation of the TPS linac has been completed. The measured linac beam parameters are well accepted with its specifications. The LTB transfer line has been successfully commissioned with beam and the magnet settings agree with designed expectation. The overall LTB transfer efficiency may further be improved as soon as the required physical aperture is fulfilled.

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