BEAMLINE DESIGN AND BEAM MEASUREMENT FOR TPS LINAC

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Abstract

A beamline for examining the beam quality of TPS (Taiwan Photon Source) linac was designed and constructed in NSRRC. Beam parameters, such as energy, emittance and charge etc., are verified by using the equipments setup in the beamline for this purpose. The lattice design and its manipulation for the parameter measurements are presented in this report. Preliminary results and the tools in association with the measurement are briefly described.

INTRODUCTION

The TPS 150 MeV linac was procured as a single turn-key system, subject to a performance specification [1]. The scope of this work is to design, manufacture, install and commission in the NSRRC jobsite of this linac.

The contract of providing a 150 MeV turn-key linac was awarded to RI Research Instruments GmbH in 2008 [2]. All subsystems and components were shipped to NSRRC on time in 2010. The system installation started in January 2011 and completed in March. The performance test was taken place in May and reliability test was completed in June.

The specifications of the linac, for both operating at multi-bunch mode (MBM) and single-bunch mode (SBM), are listed in Table 1 and Table 2.

Table 1: Beam Parameters of MBM Operation

parameter	specification	measured
bunch train length (μs)	0.2 to 1	v
charge in bunch train (nC)	≥ 5	> 5
energy (MeV)	≥ 150	153
pulse to pulse energy variation (%)	≤ 0.25	0.07
relative energy spread (%)	≤ 0.5 (rms)	0.3
normalised emittance (1σ) (πmm mrad)	≤ 50 (both planes)	36 / 47
repetition rate (Hz)	1 to 5	v
pulse to pulse time jitter (ps)	≤ 100	26

Table 2: Beam Parameters of SBM Operation

parameter	specification	measured
pulse FWHM (ns)	< 1	0.7
charge in single bunch (nC)	≥ 1.5	2
energy (MeV)	≥ 150	153
pulse to pulse energy variation (%)	≤ 0.25	0.08
relative energy spread (%)	≤ 0.5 (rms)	0.2
normalised emittance (1σ) (πmm mrad)	≤ 50 (both planes)	41/36
single bunch purity (%)	better than 1	0.7
repetition rate (Hz)	1 to 5	v
pulse to pulse time jitter (ps)	≤ 100	29

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LINAC

The linac consists of various subsystems including: electron source, accelerating structures, high power amplifiers, beam focussing, vacuum system, beam diagnostics, and control.

Similar linac systems were installed and commissioned in SLS [3], Diamond [4], ASP [5]. This 150 MeV linac was particularly designed to fulfil TPS booster and storage ring injection requirements. In addition, it is capable of operating in rescue mode. The rescue mode is defined as whenever rf station-1 malfunctioned, the rf power of station-2 can be adjusted and re-configured via a waveguide switch system, such that the power from the rf station-2 can be fed into the bunching section, the first and the second accelerating structures. The switchover time needed for the rf power redistribution arrangement is expected to take no longer than 4 hours before restoring the linac for routine operation. The 150 MeV linac is shown in Fig. 1 and the rf stations are shown in Fig. 2.

Figure 1: The linac at test bunker.

DIAGNOSTIC BEAMLINE

A diagnostic beamline was constructed at NSRRC jobsite in order to verify the linac performance. Cases of linac-to-booster transfer line design have been discussed previously in order to cope with various practical considerations along the design phases [6]. A simplified version was adopted here for linac commissioning purpose. As shown in Figure 3, the beamline is equipped with appropriate elements for beam transport and beam diagnostics purpose, such as dipole (bending magnet), quadrupole (Q-1-2-3), current monitor (ICT, FCT-1-2), screen monitor (SM-1-2) etc. The beamline is separated into two regions, the dispersion free region between the linac and the bending magnet and the dispersion region after the bending magnet. Emittance measurement was done in the dispersion free region by observing the beam size variation while tuning the triplet Q-1-2-3. In the dispersion region, the beam energy spread was determined by using bending magnet for beam energy and SM-2 for beam size measurements [7].

Figure 2: The linac rf stations.

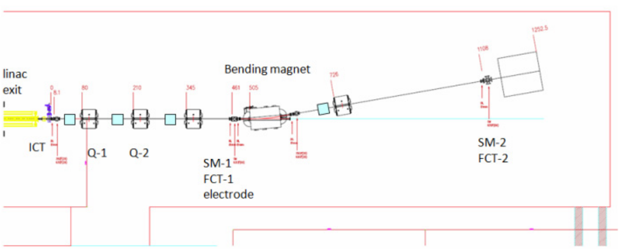

Figure 3: The layout of diagnostic beamline.

ICT: integrated charge transformer; Q: quadrupole; SM: screen monitor; FCT: fast current transformer; electrode: pickup electrode of BPM; BPM: beam position monitor.

The evolution of the beta function by the transfer matrix M from the linac exit to the screen is:

$$\beta_m = \beta_0 M_{11}^2 - 2\alpha_0 M_{11} M_{12} + \gamma_0 M_{12}^2$$

where

$$\gamma_0 = \left(1+\alpha_0^2\right)/\beta_0$$

$$M = M\left(s_m \mid s_0\right)$$

The beam size measured at the screen monitor before the bending magnet is:

$$\sigma_m = \sqrt{\varepsilon\beta_m}$$

The transfer matrix M can be determined and adjusted by tuning the triplet quadrupoles. With N sets of the M matrices and beam size measurements, one can determine the α_0, β_0 and ε by using the fitting method statistically. Concerning the energy spread determination, one could also install another screen monitor located at the dispersion region for this purpose. The beam energy spread δ can be calculated by the measured horizontal beam size:

$$\sigma = \sqrt{\varepsilon\beta + D^2\delta^2}$$

where β and D are the beta and dispersion functions located at the screen. In this beamline design, D = 1 m at SM-2.

MEASUREMENT RESULTS

There are two types of operation modes of TPS linac, multi-bunch mode (MBM) and single-bunch mode (SBM). Beam property measurement procedures for both cases were similar. Typical measurement results are given in this section for discussion and illustration purpose.

Beam Energy, Energy Spread, and Pulse-to-Pulse Stability

Beam energy was determined by the field strength of the bending magnet. During the beam measurement process, the dipole current was set at 46 A. This corresponds to a beam energy of 153 MeV. Also, beam energy spread was deduced from the measured beam size at SM-2. Since the dispersion at SM-2 is 1 m, i.e. D = 1 m, such that a width of 1 mm equals an energy spread of 0.1%. The pulse-to-pulse energy variation of the electron beam was measured by observing the beam behind the 10° bending magnet at the center of the SM-2. The horizontal position of 100 beam pulses were measured and analyzed. Similarly, a position variation of 1 mm equals an energy variation of 0.1%. Typical examples of the beam size and beam center position readouts at SM-2 for MBM operation are illustrated in Figure 4 and its 100 pulses histogram is given in Figure 5.

Emittance

The normalized emittance of the electron beam was measured by observing the beam behind the quadrupole magnet Q-1, Q-2, and Q-3. The width of the horizontal and vertical profile was measured and analyzed during quadrupole scans of Q-1 and Q-2 (variation of quadrupole strength k). The emittance values were calculated from a parabolic fit to the function • $^2(k)$. Typical example of the measurement is shown in figure-6 for SBM horizontal beam profile fitting.

Single-Bunch Pulse and SPB

The single bunch pulse was observed at the exit of the linac with one pickup electrode of the beam position monitor in the beamline. The signals were analyzed with the oscilloscope LeCroy-WaveMaster-808Zi. A comparison of the measurement results between without and with turning-on the 500 MHz sub-harmonic pre-buncher (SPB) is shown in Figure 7a and Figure 7b. This SPB located at the downstream of electron gun is required for subsequent injection consideration into the booster of

500 MHz rf system. Notice that the actual single-bunch pulse length achieved in this measurement was probably limited by the bandwidth of the instrument.

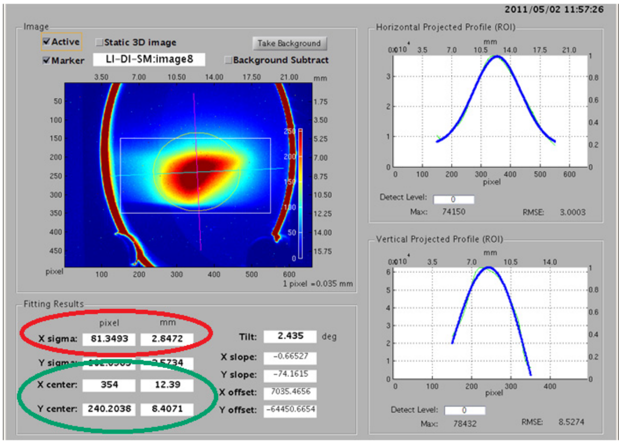

Figure 4: The measured beam size is given in (red circle). Energy spread information can be deduced from the calculated beam size and dispersion relation. The beam center locations (green circle) for each shoot were recorded for stability analysis.

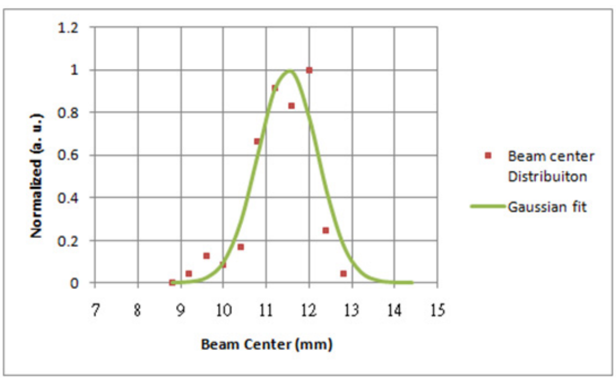

Figure 5: Pulse-to-pulse energy variation: histogram of 100 pulses. The standard deviation of the beam center position is 0.7 mm which equals to a rms pulse-to-pulse energy variation of 0.07%. The peak-to-peak energy variation is ±0.2%.

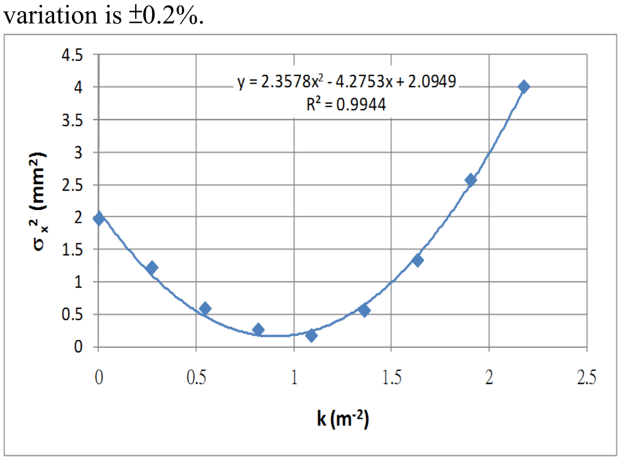

Figure 6: SBM – beam size variation verse Q-1 strength.

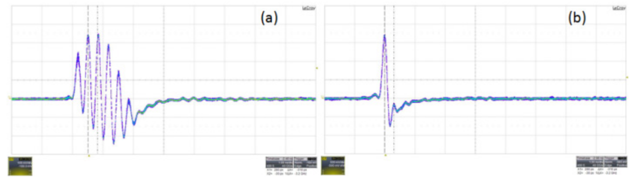

Figure 7: A single bunch beam measured with pickup electrode. (a) The bunch contains six buckets at 0.33 ns distance with similar charge when the SPB is off; (b) The bunch contains one main bucket and only two small neighbour buckets at ±0.33 ns (with SPB operating).

Summary

The acceptance test was performed at Jobsite after completion of the system installation, and subsequent commissioning. This demonstrated that the requested beam parameters as highlighted in section 1 are met. The acceptance test with beam was performed using the diagnostic instruments of the beamline. The site acceptance test included measurement of the linac system performance of MBM, SBM operations and a 10 days reliability test with up-time of 98%.

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