STUDY ON ELECTRON BEAM TRANSVERSE EMITTANCE AT THE LINAC-BASED THz LABORATORY IN THAILAND

K. Kosaentor, S. Rimjeam#, Plasma and Beam Physics Research Facility, Department of Physics and Materials Science, Faculty of Science, Chiang Mai University, Chiang Mai 50200, Thailand

Abstract

This research focuses on simulations of transverse emittance of electron beams, which are produced from a linac-based THz source at the Plasma and Beam Physics (PBP) Research Facility, Chiang Mai University (CMU), Thailand. The accelerator system consists of a thermionic RF-gun, an alpha magnet, a linear accelerator, beam focusing and steering elements and various beam diagnostic instruments. The quadrupole scan technique is utilized to measure the transverse beam emittance at three main locations, which are downstream the RF-gun, the alpha magnet and the linac. The experimental setup consists of quadrupole magnets with a maximum gradient of 7.01 T/m, a drift tube, and a movable fluorescent screen station. Beam dynamic simulations by using the computer codes ELEGANT are performed to track electrons from the cathode to the experimental stations. In this contribution, the simulation results for the transverse emittance at various positions of the accelerator are reported and discussed.

INTRODUCTION

The electron linear accelerator at the Plasma and Beam Physics (PBP) research facility, Chiang Mai University, consists of a thermionic cathode RF-gun, an alpha magnet for magnetic bunch compressor, a traveling-wave linear accelerator, quadrupole and steering magnets and a 60^{o} dipole magnet for beam dump and energy measurements. There are several beam diagnostic components are installed along the beam transport line. The drawing layout of the PBP CMU linac system is shown in Fig. 1 The RF electron gun can produce electron beams with a bunch charge of ~0.2 nC and the maximum kinetic energy of 2.5-3 MeV with large energy spread. Some fraction of low energy electrons is filtered out by using energy slits in the alpha magnet vacuum chamber. The beam with a bunch charge of 64.8 pC and an average energy of 2.6 MeV exits the alpha magnet and is further accelerated in the linac structure. After exiting the linac, the coherent THz transition radiation is generated at the experimental station of about 186.2 cm downstram the linac exit.

This research aims to investigate the electron beam emittance at various locations in the of PBP CMU Linac system. Beam dynamic simulations from the RF-gun exit to the experimental screen stations were performed by using the computer program PARMELA and ELEGANT [1, 2]. Simulation results will be used as the support information to design and develop the emittance measurement setup and procedures.

METHODOLOGY

In this research, the transverse emittance measurement using the quadrupole scan technique is studied. The technique is used to evaluate the beam emittance by measuring the electron transverse beam size as a function of the quadrupole gradient. The quadrupole magnets used in this study have a maximum gradient of 7.09 T/m. As shown in Fig. 2, double quadrupole magnets are used in the emittance measurement. The gradient of one quadrupole is varied to obtain a relation between the transverse beam size and the quadrupole focal length (f_1). Another quadrupole is used to control the beam size of the defocus plane by keeping the focal length (f_2) constant during the measurement. The distances between the two quadrupole magnets and the view screen station for each emittance measurement location are listed in Table 1. Here L_1 is the distance between the two quadrupole magnets and L_2 is the distance between the second quadrupole magnet and the screen position. The beam matrix elements and beam emittance can be obtained from the following equation:

$$
\begin{aligned}
(\sigma_s)_{11} = {} & (L_1L_2)^2\left(\frac{1}{f_2^2 f_1}\right)\sigma_{12} + \left(L_2^2\right)\left(\frac{1}{f_2^2}\right)\sigma_{11} \\
& + \left(L_1L_2\sigma_{11} + (2L_1^2L_2 - 2L_2^2L_1)\sigma_{12}\right)\left(\frac{1}{f_1f_2}\right) \\
& + \left(-(L_1+L_2)\sigma_{11} - (L_1^2L_2)\sigma_{12}\right)\left(\frac{1}{f_1}\right) \\
& + \left((L_2+(L_1L_2))\sigma_{22} - (L_1)^2\sigma_{12}\right)\left(\frac{1}{f_2}\right) \\
& + \left(\sigma_{11} - (L_1+L2)\sigma_{12} + L_1\sigma_{22}\right)
\end{aligned} \tag{1}
$$

The transverse beam size including the energy spread can be calculates as [3]:

$$
\begin{aligned}
\sigma_L^2 = {} & \sigma_{L,\delta=0}^2 + \{K_1^2L_{12}^2 + 2K_1L_{12}(K_1+2K_2-3K_1K_2L_{12})L \\
& + [(K_1+K_2)^2 - 6K_1K_2(K_1+K_2)L_{12} \\
& + 6K_1^2K_2^2L_{12}^2]L^2\}\sigma_\gamma^2\sigma_x^2 + (K_2L_{12}L)^2\sigma_\gamma^2\sigma_{x'}^2 \\
& + (2K_2L_{12}L\{K_2L + K_1[2L + L_{12}(2-3K_2L)]\})\sigma_\gamma^2\sigma_{xx'}
\end{aligned} \tag{2}
$$

where L is the distances between the last quadrupole and the measurement screen, L_{12} is the distance between the two quadrupoles and σ_γ^2 is the energy spread of the beam.

#Corresponding author: sakhorn.rimjaem@cmu.ac.th

ISBN 978-3-95450-147-2

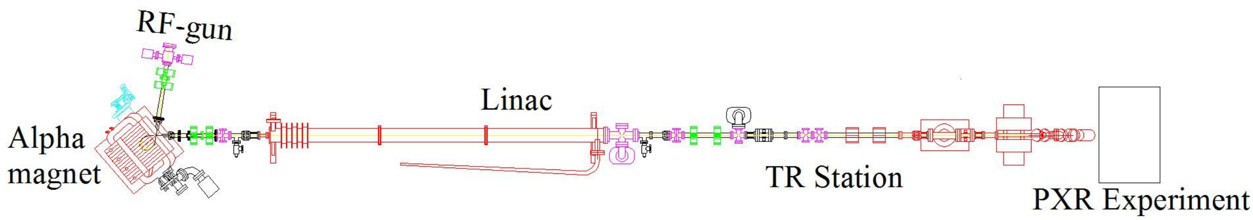

Figure 1: Layout of the PBP CMU Linac system.

In the emittance measurement, the quadrupole magnet gradient is varied and the beam transverse distribution is monitored on a fluorescent view screen, which illuminates linearly to the electron density colliding on it. A schematic layout of the transverse beam distribution measurement at the PBP-CMU linac facility is shown in Fig. 3.

Table 1: Distances between the Quadrupole Magnets and the View Screen Station for each Emittance Measurement Location. Screen Stations SC1, SC2 and SC3 Refer to the Screen Stations for the Emittance Measurement Downstream the RF-gun Exit, the Alpha Magnet Exit and the Linac Exit.

Station	L_1	L_2	f_2
SC1	5.3 cm	16.75 cm	5 cm
SC2	4.3 cm	2.3 cm	5 cm
SC3	7.8 cm	68.2 cm	5 cm

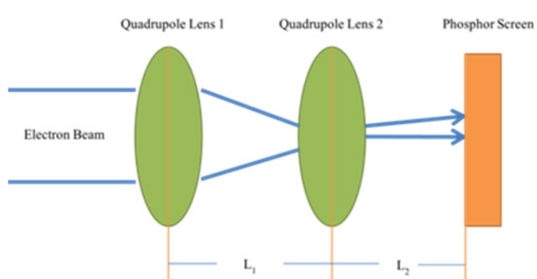

Figure 2: Emittance measurement setup.

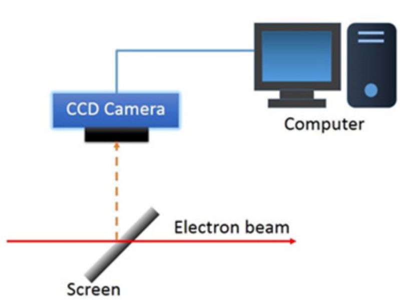

Figure 3: Schematic layout of the beam image measurement system [4].

RESULTS AND DISCUSSION

Electron beam dynamic simulations for the RF-gun was performed by using the cylindrical symmetric and 3D-electromagnetic (EM) field distribution from the code SUPERFISH [5] and CST Microwave Studio 2012 [6], respectively. The particle tracking code PARMELA was utilized to investigate the motion of electrons through the electromagnetic fields inside the gun.

The program ELEGANT [2] was then used to study the electron properties along the rest of the accelerator system. In simulations, the quadrupole focal length was varied and the beam transverse distributions for both symmetric and asymmetric cases were monitored at the screen position. Then, the RMS beam transverse sizes were calculated. Simulated horizontal and vertical RMS beam size squared as a function of the quadrupole focal length for the symetric and asymetric beams monitored at the screen stations SC1, SC2 and SC3 are shown in Fig. 4 and Fig. 5. The simulation results for the horizontal and vertical emittances are concluded in Table 2 and Table 3.

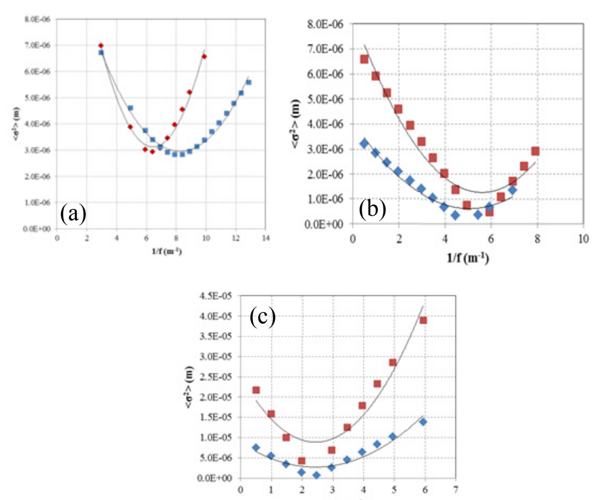

Figure 4: Simulated horizontal RMS beam size squared as a function of the quadrupole focal length for symetric and asymetric beams monitored at the screen stations (a) SC1, (b) SC2 and (c) SC3. The red and blue plots are for the symmetric and asymmetric beam distributions

By includinng the chromatic effect as shown in Eq. 2 the transverse beam size and the emittance values compared with the results from ELEGANT simulations are shown in Fig. 6 and Fig.7. The results after including chromatic effect show that the emittance values increase from 19.6 mm-mrad to 22.3 mm-mrad and 20.6 mm-mrad to 37.1 mm-mrad for asymmetric beam in x and y dimension, respectively.

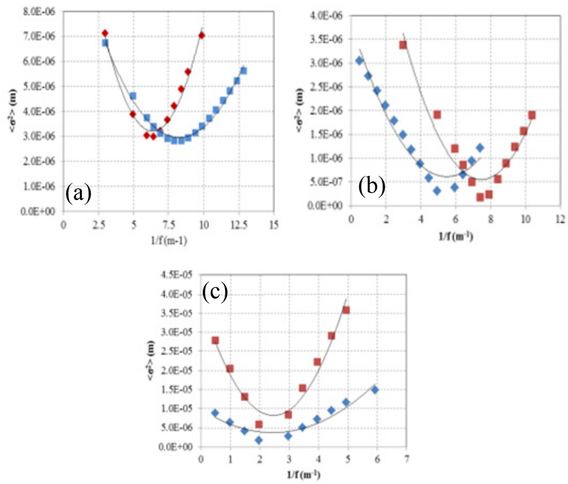

Figure 5: Simulated vertical RMS beam size squared as a function of the quadrupole focal length for symetric and asymetric beams monitored at the screen stations (a) SC1, (b) SC2 and (c) SC3. The red and blue plots are for the symmetric and asymmetric beams.

Table 2: Horizontal Emittance Values in Cases of Simulations by Using Multi-quadrupole Scan.

Station	**Symmetric x** (mm-mrad)	**Asymmetric x** (mm-mrad)
SC1	12.4	19.6
SC2	5.4	10.6
SC3	32.8	81.1

Table 3: Vertical Emittance Values in Cases of Simulations by Using Multi-quadrupole Scan.

Station	**Symmetric y** (mm-mrad)	**Asymmetric y** (mm-mrad)
SC1	12.6	20.6
SC2	4.95	5.5
SC3	38	119

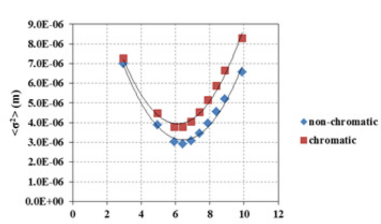

Figure 6 : Simulated vertical RMS beam size squared as a function of the quadrupole focal length including chromatic effect at SC 1

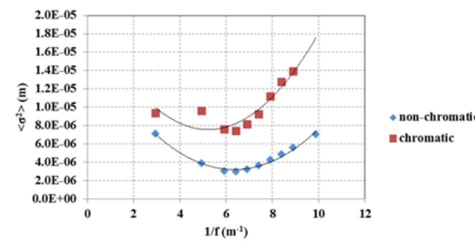

Figure 7: Simulated vertical RMS beam size squared as a function of the quadrupole focal length including chromatic effect at SC 1

CONCLUSION

This study concludes the trend of emittance along the beamline of PBP-CMU by using ELEGANT simulations. The results show that emittance after alpha magnet emittance in y axis is smallest because in the alpha magnet we filter the energy which lower than 2.5 MeV out so beam is smaller with high intensity. The emittance value at 68.2 cm from the linac is large due to large beam size. This study also includes the chromatic effect, which is the effect from the energy spread of electron beam. This to higher beam emittance of about 3%. This can be used so this can be predicted the result which should be close to the real measurement in the future.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support by the CMU Junior Research Fellowship Program, the Department of Physics and Materials Science, Faculty of Science, Chiang Mai University, and the Science Achievement Scholarship of Thailand (SAST).

REFERENCES

[1] L.M. Young, J. H. Billen, “PARMELA”, Los Alamos, New Mexico, USA, Los Alamos National Laboratory Technical Note LA-UR-96-1835, 2002.
[2] ELEGANT, http://www.aps.anl.gov.
[3] A. Mostacci, M. Bellaveglia, et al., “Chromatic effects in quadrupole scan emittance measurements”, American Physical Society, 23 August 2012.
[4] S. Chumkong and S. Rimjaem, "Development of Analysis Program for Beam Emittance Measurements.", in proceedings of the 7th National Science Research Conference, Phitsanulok, Thailand, March 2015, paper PY-P-047.
[5] L.M. Young, J. H. Billen, “POISSON/SUPERFISH”, Los Alamos, New Mexico, USA, Los Alamos National Laboratory Technical Note LA-UR-96-1834, Revised January 13, 2006.
[6] Microwave Studio, Computer Simulation Technology, http://www.cst.com

ISBN 978-3-95450-147-2