**Present status of 4 MeV electron beam accelerator system for natural rubber irradiation**

S Suphakul¹, M W Rhodes¹, J Saisut¹,², S Rimjaem¹,² and C Thongbai¹,²,*

¹ Thailand Centre of Excellence in Physics, Commission on Higher Education, Bangkok 10400, Thailand
² Plasma and Beam physics research facility, Department of Physics and Materials Science, Faculty of Science, Chiang Mai University, Chiang Mai 50200, Thailand

* Corresponding author's E-mail address: chitrlada.t@cmu.ac.th

**Abstract.** Electron beam accelerator system for natural rubber irradiation is under developing at the Plasma and Beam Physics (PBP) Research Facility, Chiang Mai University (CMU). The system aims to improve the natural rubber latex properties by using energetic electrons to induce cross-linking between polymer chain or called vulcanization process. Due to no chemical added as a conventional way (usually sulphur), the rubber product produced by this method has good mechanical properties with lower toxicity that is suitable for many applications. The system consists of a DC thermionic cathode electron gun, a 5-cell radio-frequency (RF) linear accelerator (linac), an RF modulator, an adjustable speed conveyer and a control system. The expected electron beam energy from the simulation is in the range from 0.5 to 4 MeV with a maximum pulse current of 100 mA and a pulse repetition rate is adjustable from 20 to 400 Hz. This beam condition provides a calculated average absorbed dose between 160 and 640 Gy. The system has been complete assembled and the RF modulator has been tested. The RF processing has been performed and some of electron beam properties has been measured. The present status of development and the results are reported in this contribution.

**1. Introduction**

Development of electron beam accelerator system for natural rubber irradiation at the Plasma and Beam Physics (PBP) Research Facility, Chiang Mai University is ongoing project. The system aims to generate electron beam using for natural rubber latex irradiation with the maximum energy around 4 MeV with the maximum pulse current of 100 mA and the adjustable repetition rate from 20 to 400 Hz [1]. The system consists of a Pierce-type DC thermionic cathode electron gun, a 5-cell radio-frequency (RF) linear accelerator (linac), an RF modulator, an adjustable speed conveyer and a control system. The 3-dimensional model of the system with the diagnostic chamber is shown in figure 1. The beamline had been assembled and the RF modulator had been commissioned [2]. Due to the late receiving of the cathode from the manufacturing company, the full system commissioning was performed in the begin of year 2018. This report presents the results of the beam extraction experiment, the radiation shielding design and the progress of the construction works.
Figure 1. 3-dimensional model of the accelerator system for natural rubber irradiation.

2. Electron beam extraction experiment
A Pierce-type DC thermionic cathode electron gun employ a specific design shape of cathode and anode to create electric fields for shaping electron beam. A misalignment or non-parallel plane between cathode and anode strongly effect to the beam shape and beam direction. To confirm about electron extraction from the gun, we applied a high voltage (HV) DC to between the cathode and anode. The HV DC power supply (BERTAN, 205B-20R) was used and its output could be adjusted from 0 to 19 kV with 1 kV increment. The extracted electrons were observed by a 45-deg tilted phosphor screen installed in the diagnostic chamber downstream the linac with distance 14.8 cm from the linac exit. The current for the cathode filament was supplied by a variac transformer through a high potential isolation transformer and a stepdown transformer. The circuit diagram and the setup of the experiment are shown in figure 2 and figure 3, respectively.

Figure 2. Circuit diagram of the electron beam extraction experiment.

Figure 3. Set up of the electron beam extraction experiment and the coordinate definition for the electron beam direction estimation.
As the result, the electrons could be extracted and accelerated by HV DC but the direction of the beam did not align to the linac center axis that might cause by the misalignment between the cathode and the anode. The beam image on the screen at the accelerating voltage of 15 kV and the cathode filament current of 15A is show in figure 4. The cathode image also reflected the screen and appeared around the center of the screen. The beam size was large and just the edge of the beam could be seen on the screen. The beam centre was out of the screen in the top right position and graphically estimated on the XZ plane at \( x = 23.7 \) mm and \( z = 13.8 \) mm. In the XY plane, the calculated beam centre was at \( x = 23.7 \) mm and \( y = 13.8 \) mm or at the distance of 27.4 mm from the linac center axis. The angle between X axis and the beam center plane A-A' (\( \Theta \)) was 30.2 degree and the misalignment direction between the cathode and anode was also in this plane. The system requires steering magnets to steer the beam to the center axis of the linac.

![Figure 4](image)

**Figure 4.** Electron beam on the screen at the accelerating voltage of 15 kV (a) and the estimated beam center on the XY plane (b).

3. Radiation shielding design

The radiation generated from the system has been survey by an ion chamber survey meter (LUDLUM, Model 9DP). At the RF power of 100% and the repetition rate of 220 Hz, we found that the system generated a high radiation dose rate up to 4.9 \( \mu \)Sv/hour in the roof direction. Therefore, the shielding made from 2-cm thick steel sheets was added to cover the linac and the conveyer as shown in figure 5. The shielding performance was calculated by monte-carlo simulation method using GEANT4 [3].

![Figure 5](image)

**Figure 5.** Radiation shield for the accelerator system (a) and the GEANT4 simulation result of electrons and photons generated by the accelerator system (b).
4. Construction works
The accelerator system and the RF modulator has been relocated and placed in the north side of the accelerator hall as shown in figure 6. The air-conditioning room was built covering both the systems to control the humidity and dissipate heat from the system.

![Figure 6. Relocation of the accelerator system (a) and the room that houses the accelerator system (b).](image)

5. Conclusion
The development of the electron beam accelerator system for natural rubber latex irradiation at the Plasma and Beam Physics (PBP) Research Facility, Chiang Mai University is ongoing project. The system has been relocated and all system facilities has been built. The steering magnets need to be added to the cathode and the linac to steer the beam to the linac center axis. The radiation shielding has been designed covering the linac and the conveyer with 2-cm thick steel sheets. For the next steps, we will test the beam acceleration by RF and measure the beam characteristics.

Acknowledgements
The authors would like to acknowledge the supports from the Department of Physics and Materials Science, the Faculty of Science, Chiang Mai University, the Thailand Center of Excellence in Physics (ThEP Center) and the Science and Technology Park Chiang Mai University (CMU STeP).

References
[1] Rimjaem S, Kongmon E, Rhodes M W, Saisut J and Thongbai C 2017 Electron linear accelerator system for natural rubber vulcanization Nucl. Instrum. Methods Phys. Res. B 406 223
[2] Saisut J, Rhodes M W, Kongmon E, Rimjaem S and Thongbai C 2018 RF system of linear accelerator for natural rubber research J. Phys.: Conf. Ser. 1144 012157
[3] Agostinelli S et al 2003 Geant4-a simulation toolkit Nucl. Instrum. Methods Phys. Res. A 506(3) 250