RF System of Linear Accelerator for Natural Rubber Research

J. Saisut [1,2*], M.W. Rhodes [2], E. Kongmon [1,2], S. Rimjeam[1,2] and C. Thongbai [1,2]

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

[*]E-mail: jatuporn.saisut@cmu.ac.th

Abstract. The natural rubber research is ongoing project at the Plasma and Beam Physics Research Facility, Chiang Mai University, Thailand. The project aims to use electron beam irradiation for high quality vulcanization process for natural rubber. The main accelerator system consists of a DC thermionic electron gun, 5-cell linear accelerator structure, control system, RF system and electron beam irradiation system. This accelerator system aims to generate adjustable electron beam energy range from 0.5 to 4.0 MeV with pulse current of 10 – 100 mA and pulse repetition rate of 20 – 200 Hz. The 4 MeV electron beam with current of 100 mA produced at pulse repetition rate of 200Hz is expected to achieve the maximum absorbed dose of 320 Gy. The control system is designed and built in-house to fit the accelerator system requirement. The RF system consists of Pulse Forming Network (PFN), trigger board and thyratron switch, pulse transformer and pulse magnetron. This RF system can achieve RF power of 0.9 to 2.0 MW with pulse width of 4 μs. The pulse repetition rate can be varied from 20 to 200 Hz to control RF average power. The performance of RF system as well as the results of RF commissioning will be present and discussed.

1. Introduction

A linear accelerator (linac) system for electron beam irradiation on natural rubber is developed at the Plasma and Beam Physics Research Facility, Chiang Mai University, Thailand. The system consists of a Pierce-type DC gun with a thermionic cathode, a 5-cell standing-wave linac structure equipped with a driven radio-frequency (RF) system, electron beam diagnostic instruments and an irradiation system. It is foreseen that the irradiation system composes of a beam sweeper (or beam scattering and flattening system) and a convayor for the sample container. The layout of the accelerator and irradiation system is shown in Figure 1. This accelerator system aims to generate adjustable electron beam energy range from 0.5 to 4.0 MeV with pulse current of 10 – 100 mA and pulse repetition rate of 20 – 200 Hz. The 4 MeV electron beam with current of 100 mA produced at pulse repetition rate of 200Hz is expected to achieve the maximum absorbed dose of 320 Gy [1]. In this paper, we present the RF system and the results of the RF commissioning.

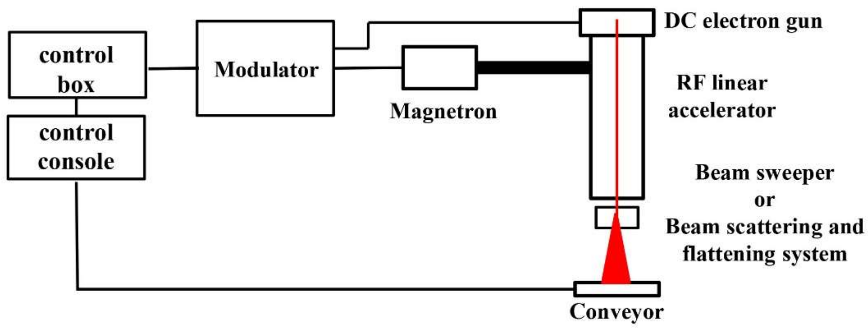


Figure 1. Layout of electron linear accelerator, a related RF power system and an irradiation apparatus.

2. RF system

The linac system can be used to accelerate electron beam to reach the average kinetic energy of 0.5 to 4 MeV depending on the supplied RF peak power. The high power RF can be generated form magnetrons and varied from 0.5 to 2 MW. The magnetron modulator at Chiang Mai University are line type modulator and have main components consisting of main power supply, a variac for voltage controlling (VAC), high voltage transformer, Pulse Forming Network (PFN), pulse transformer, trigger board and thyratron switch as shown in Figure 2. The system is controlled by control console though control box which is designed and built in-house to fit the accelerator system requirement. The control console also has capability to control electron beam sweeper and have display to show system status. In addition, the control system can deliver maximum pulse repletion rate of 200 Hz to trigger board for thyraton driving. The PFN is designed to achieve RF macro pulse of 4 μs using 6 LC sections and the capacitors have nominal capacitance of 32 nF. The characteristic impedance of the PFN is about 13.5 Ω. The high voltage pulse from the PFN is discharged through the thyratron switch to the pulse transformer for high voltage amplification and then is delivered to the magnetron.

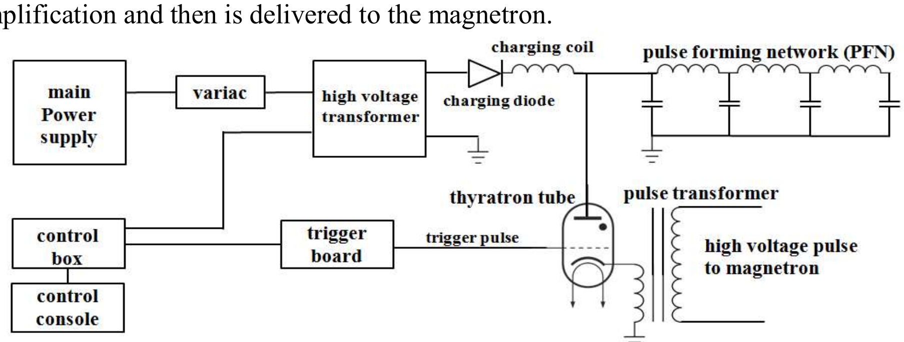


Figure 2. Schematic diagram of the magnetron modulator at Chiang Mai University.

3. RF measurement

3.1. RF power measurement

The high power RF is generated by a magnetron to reach the MW level. Then, the RF wave is transported from the magnetron to the dummy load via a WR-284 rectangular waveguide system for Power measurement. A diagram of the RF generator and measurement systems is shown in Figure3(a) and the magnetron test setup is shown in Figure3(b). A forward and reflected RF powers are measured at a directional coupler. The forward and reflected RF ports of the directional coupler have the attenuation values of -60 dB. The forward and reflected RF power ports are connected to the cables and the attenuators with total attenuation values of -96.66 dB and -97.89 dB, respectively. The RF signals are converted to analog signals by using crystal detectors, which can be measured with a digital oscilloscope.

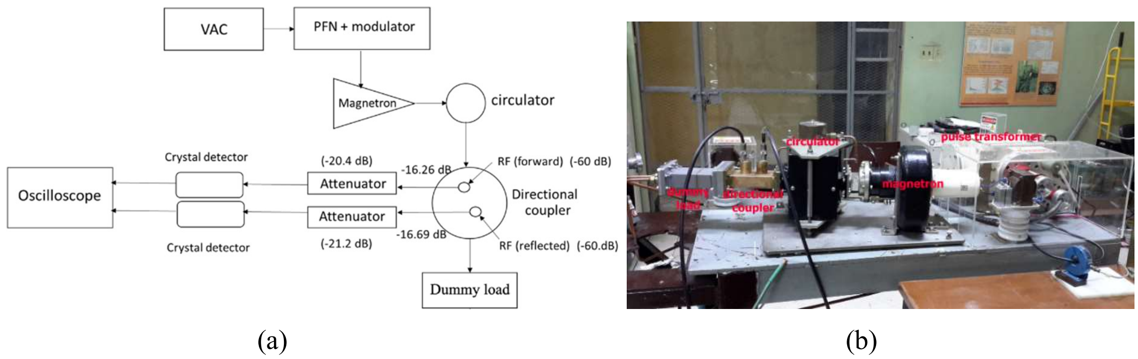


Figure 3. (a) Schematic diagram of the RF measurement and (b) the magnetron test setup at Chiang Mai University.

The variac (VAC) is adjusted in order to control the charging voltage for the PFN which has linear relation to the RF peak power. In this experiment, the high voltage is varied from 5 kV to 6.9 kV which correspond to the RF peak power of 0.9 MW to 2 MW, respectively, as shown in Figure 4.

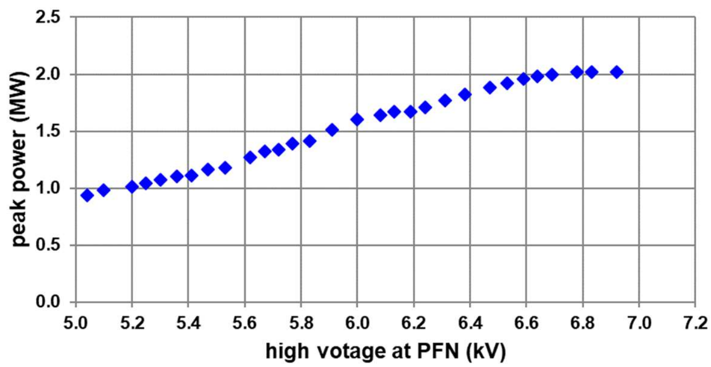


Figure 4. Relationship between the high voltage value and the peak power of the forward RF signal

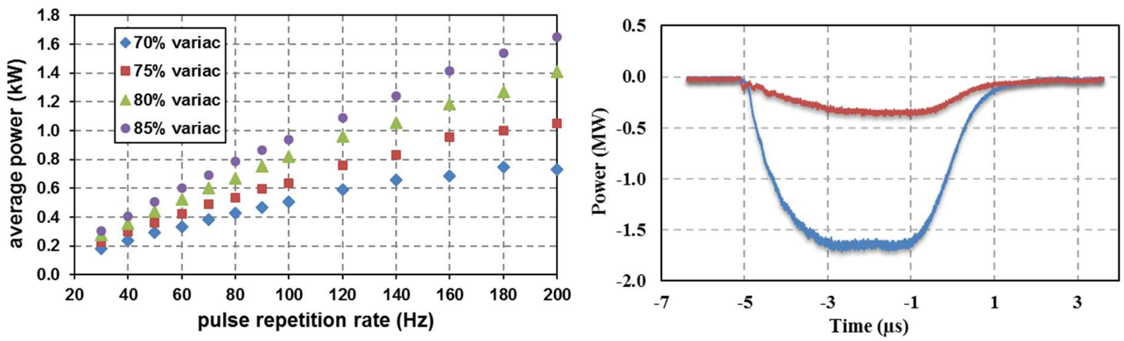
The average power of the RF wave can be calculated by using the following equation

$$P_{average} = (\tau)(pps)(P_{peak}), \quad (1)$$

where τ is the RF pulse width, which is equal to 4 μs. Here, pps is the pulse repetition rate, which is adjusted from 10 to 200 Hz in this experiment and P_{peak} is the RF peak power. The variac is adjusted from 70% to 85% with 5% step. The relationship between the pulse repetition rate and the average power for each variac level is shown in Figure 5(a). An example of the measurement result of forward and reflected RF signals at the pulse repetition rate of 200 Hz are shown in Fig 5(b). In this measurement, the forward peak power is 1.65 MW and the reflected RF power is 0.38 MW.

3.2. RF frequency measurement

The magnetron has tuner which can be adjusted for resonance frequency tuning. The resonance frequency was measured by the Signal Hound USB-SA124B spectrum analyzer[2]. The magnetron frequency tuner is able to rotate about 5 turns. The reflected RF signal from the directional coupler was connected to the spectrum analyzer. The magnetron resonance frequency measurement result is shown in Figure6. At 85% of VAC, the magnetron is able to generate RF signal which have the frequency range from 2988 MHz to 3002 MHz depending on tuner position. The result also shows that the frequency is not change much when the pulse repetition rate is changed.



(a) (b)

Figure 5. (a) Relationship between the pulse repetition rate and the average power and (b) forward (blue-line) and reflected (red-line) RF signals of 85% VAC at the pulse repetition rate of 200 Hz.

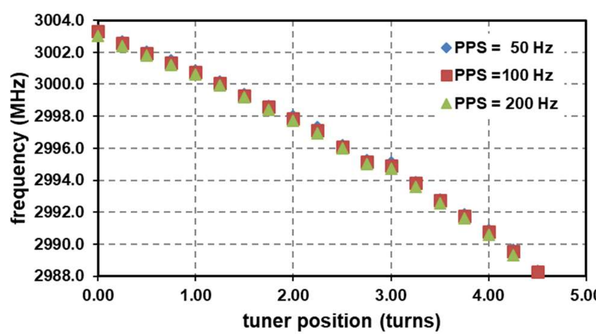


Figure 6. Relationship between the magnetron frequency and the tuner position at variac of 85%.

4. RF commissioning

The RF window and linac were installed into the system for RF processing and RF measurement. In the high power RF measurement, the resonant frequency of the linac structure was measured to be 2997.103 MHz, while the measured value for the low-power RF measurement with the S-parameter network analyzer was 2996.816 MHz [3]. The frequency difference of 187 kHz is probably due to the resolution of the frequency measurement with the spectrum analyzer in the high power measurement. The RF commissioning results are summarized in table 1. The examples of the RF power with 85% of VAC and 200 Hz pulse repetition rate are shown in Figure 7. The average forward peak power is about 1.78 MW and reflected peak power is about 0.38 MW. The average forward and reflected peak power can be used to estimate the electron beam energy generated from the accelerator system [3] as shown in Figure8 for pulse repetition rate of 200 Hz. According to Figure8, the minimum beam energy of 0.2 MeV and the maximum beam energy of 4.0 MeV will be generated from our linear accelerator system.

table 1. Summary of RF commissioning results.

Parameter	Value
Resonant frequency	2997.103 MHz
Operating temperature	35°C
RF peak power	0.3 - 2 MW
Maximum pulse duration	4 μs
Pulse repetition rate	10-200 Hz

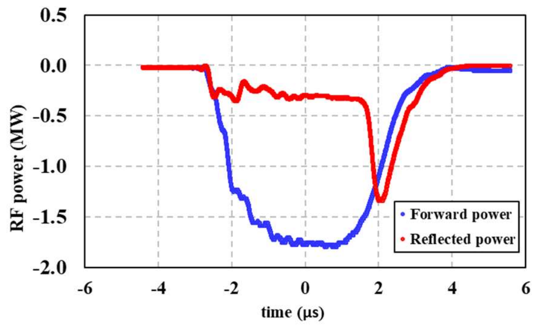


Figure 7. Forward (blue-line) and reflected (red-line) power of linac for 85% VAC and the pulse repetition rate of 200 Hz.

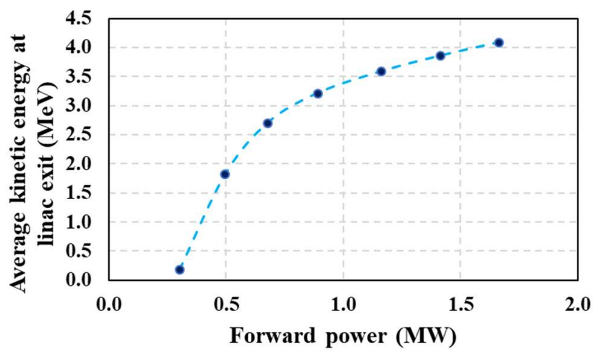


Figure 8. Electron beam energy as a function of forward power at pulse repetition rate of 200 Hz.

5. Conclusion

In this paper, we present the RF system and the RF commissioning progress of the electron linear accelerator system for natural rubber researches. The control console and control box was designed and built in-house. The RF system was tested and commissioned. The high power RF commissioning results show that the system is able to deliver RF peak power from 0.3 to 2.0 MW with RF pulse duration of 4 μs. At the moment, the system is able to achieve maximum average power of 1.65 kW at pulse repetition rate of 200 Hz. The resonant frequency of the linac structure is 2997.103 MHz. the minimum beam energy of 0.2 MeV and the maximum beam energy of 4.0 MeV will be generated from our linear accelerator system at pulse repetition rate of 200 Hz. The electron beam generation is ongoing process.

6. Acknowledgements

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

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