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# PRESENT STATUS OF LINEAR ACCELERATOR SYSTEM FOR NATURAL RUBBER VULCANIZATION AT CHIANG MAI UNIVERSITY

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*Abstract*

At the Plasma and Beam Physics (PBP) Research Facility, Chiang Mai University (CMU), an electron beam accelerator system for natural rubber irradiation has been under development and is currently under the commissioning. The research project is carried out with the aim to modify an old medical linac, retired from the clinical operation, for rubber latex vulcanization and materials irradiation using electron beams. The accelerator system consists of a DC-thermionic cathode electron gun, a standing-wave RF linear accelerator, an RF system, a control system, beam diagnostic systems, and an irradiation system. The components were completely assembled, and the RF system was tested. The RF processing has been performed and some of the electron beam properties have been measured. This contribution presents some experimental results while developing and testing the various sub-systems of this accelerator. The present status of development and some vulcanization results will also be reported in this contribution.

## INTRODUCTION

The radio-frequency (RF) linear accelerator (linac) system for natural rubber vulcanization has been developed and is currently under the commissioning at the Plasma and Beam Physics Research Facility, Chiang Mai University, Thailand [1]. The system aims to generate electron beams for induction of cross-linking in natural rubber latex at room temperature as an alternative to a conventional sulfur vulcanization. Not only does the sulfur vulcanization require high temperature, but it also needs some chemical for activation and acceleration of crosslink reaction [2,3]. Moreover, the rubber vulcanization using an electron beam has high potential to reduce extractable proteins which is possible to cause allergy to the consumers [4].

The accelerator system was constructed using parts from the 4 MeV medical electron linac system model Mitsubishi ML-4M [5], retired from clinical operation at Maharaj Nakorn Chiang Mai Hospital. The main components of the accelerator system are a DC gun, an RF linear accelerator, a magnetron with waveguide components, a modulator system, a control unit, and irradiation system as the diagram shown in Fig. 1. The layout of the system is illustrated in Fig. 2.

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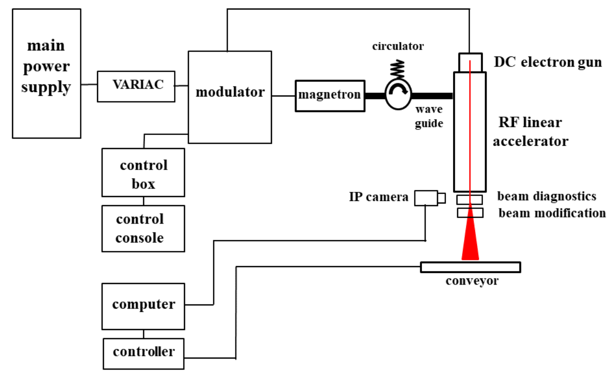


Figure 1: Diagram of the RF-linac system for natural rubber vulcanization at Chiang Mai University.

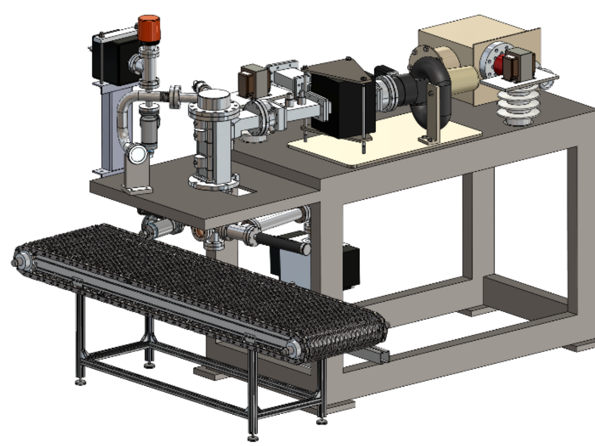

Figure 2: Layout of the accelerator system consisting of a DC-gun, a linac, a magnetron and a conveyor under the beamline.

## RF AND ACCELERATOR SYSTEMS

The RF system consists of a modulator unit, a magnetron, and waveguide components. Within the modulator unit, there are a pulse forming network (PFN), a pulse transformer, a trigger board, and a thyratron switch. The modulator provides high voltage pulses for the DC electron gun, and for the magnetron. A variac (VAR) was added to the RF system, as shown in the diagram in Fig.1, to control the charging voltage for the PFN. Having linear relation to the output RF power, the magnetron RF power can then be adjusted via the VAR adjustment. From the RF

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measurement, the magnetron can provide RF peak power of 0.6-1.6 MW with the VAR% of 60% to 85%. The magnetron can generate RF signals in the frequency range of 2988 MHz to 3002 MHz depending on tuner position. The RF pulses have the width around 4 μs pulse and the repetition rate can be adjusted within 10-200 pulse per second. More details of the RF system were reported in Refs [6, 7]. The RF wave from the magnetron is then transported to the linac via a WR-284 rectangular waveguide system filled by SF6 with a ceramic RF window.

The accelerator unit consists of a DC electron gun with a thermionic cathode, a 5-cell standing wave linear accelerator, and a beam diagnostics system. The RF characteristics of the linac structure were investigated and reported in Ref [1, 7]. At the operating temperature of 35 °C, the resonant frequency of the linac is 2996.82 MHz. The relative electric field distribution along the axis in the linac cavities was obtained from bead pull measurements. The measured field distribution was employed in beam dynamics simulation using the space-charge particle tracking code ASTRA [8]. The simulation results showed that the modified accelerator system can generate beam energy from 1 to 4 MeV depending on a given RF power [1, 7]. The cathode manufactured by Heat-Wave Labs, Inc. [8] was installed and the cathode processing was completed.

Beam diagnostic instruments: a faraday cup and phosphor screen, were installed after the linac structure to me asure the beam currents and to monitor the beam. The beam energy measurements were conducted with the system consisting of the phosphor screen, a steering magnet an IP camera. For the RF power of 0.8 MW - 1.60 MW, the electron beam energy range from 2.2 MeV to 3.2 MeV

## BEAM IRRADIATION SYSTEM

The results from beam dynamic studies were also used to define the initial beam conditions in Monte Carlo simulations with program GEANT4 [9]. Electron beam properties after exiting the Ti-window as well as the beam penetration depth and dose distribution in the natural rubber latex were studied. Moreover, some beam modification designs for the irradiation system were investigated, including beam sweeper [1], quadrupole magnet [10], and flattening filter [11]. However, the Monte Carlo simulation reported that after exiting the accelerator system through the titanium window, the beam scattered with large divergence angle and the beam size became large enough for irradiation without beam sweeping. [12]. During the commissioning, the irradiation experiments were conducted without any beam modification system. The irradiation system consists of a 50-μm thick titanium window an adjustable speed conveyer. The conveyor can be moved linearly by using a stepping motor, controlled with the in-house developed computer interface and software. The conveyer controller can specify moving direction, speed, and distance as well as pause time for irradiation.

An important specification for an irradiation system is the absorbed dose per unit time. The dose measurement was performed using B3 RisøScan Dosimetry System from GEX cooperation [13]. The B3 film is a radiochromic film, which its material turns from clear to deepening shades of pink or magenta color associated with exposure to sources of ionizing radiation.[14]. The optical scan images of B3 film dosimeters can then be analized by RisøScan software.

The accumulation doses on B3 films, placed at 5 cm below the titanium window were measured and the dose rate was 6 kGy per min, in the experiment. Dose distribution on the films showed that the dose cover uniformly over a circular area with 1.5 cm diameter. The penetration depth which is another important information for irradiation process was investigated and is reported in Ref [15]. For a larger volume, irradiation over a long rubber latex container can be done by moving the conveyor corresponding to the requirement.

## VULCANIZATION EXPERIMENTS

Natural rubber latex vulcanization by electron beam is done without heating and in the absence of vulcanization agents such as sulfur. [1-4] The absorbed dose that is required for cross-linking in polymer materials is in the range of 50-150 kGy [2-4]. To reduce electron beam dose for the rubber vulcanization process, radiation sensitizer such as N-butyl acrylate (n-BA) and 1,6-hexanediol-diacrylate (HDDA) can be added in the rubber latex prior the electron beam irradiation.[16]

Although, during the commissioning, there are only small number of electrons exiting the accelerator system, we did conduct some experiments on natural rubber vulcanization. Natural rubber sample containers were placed 5 cm under the titanium window. The samples are natural rubber, natural rubber added by 5 phr n-BA, and natural rubber added by 5 phr HDDA. The natural rubber used in the experiment is high ammonia concentrated natural rubber with 60% dry rubber content, purchased from a local company. As a reference, commercial (sulfur) prevulcanized natural rubber (PVNR) latex was also used in the experiment. The vulcanization experiments were carried out with the electron beam of 3 MeV average energy.

After irradiation to the required dose, the latex samples were tested for vulcanization state by chloroform test. The chloroform-coagulation test or chloroform test provides a very simple and fast method for assessing state or degree of vulcanization in natural rubber latex [17]. Four stages of vulcanization are usually distinguished by this test, and are assigned chloroform numbers as 1: unvulcanized, 2: lightly vulcanized, 3: moderately vulcanized , and 4: fully vulcanized. The vulcanization results from the experiment described above are listed in Table 1.

Table 1: Stage of Vulcanization by Chloroform No. (#) from the Vulcanization Experiments

| sample + dose | # | sample + dose | # |
|---|---|---|---|
| NR+0 kGy | 1 | NR+nBA+10kGy | 2 |
| NR+20 kGy | 1 | NR+nBA+20kGy | 4 |
| NR+50 kGy | 4 | NR+HDDA+10kGy | 3 |
| NR+50 kGy | 4 | NR+HDDA+10kGy | 3 |

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From the experiments, natural rubber vulcanization using electron beams from our accelerator system occurred at the radiation dose of 50 kGy. The mixture of rubber latex and HDDA as well as the mixture with n-BA were fully vulcanized after electron beam irradiation at the radiation dose of 20 kGy.

## RADIATION SHIELDING

The RF and accelerator system are located inside the underground radiation shielding hall. Moreover, the extra steel shielding box to prevent the leakage of radiation when the accelerator system is under operation was designed by using the Monte Carlo simulation software GEANT4. The layout of the shielding box is shown in Fig. 3(a). The accelerator hall, however, has just been added with a steel plate at the height of 2.4 m from the floor, as shown in Fig. 3(b) Thus, the steel shielding box over the accelerator system might not be necessary. The GEANT4 was used to evaluate radiation leakage for this new scenario. The results shows that a 3-cm-thick steel roof can maintain the radiation level within the regulation limit.

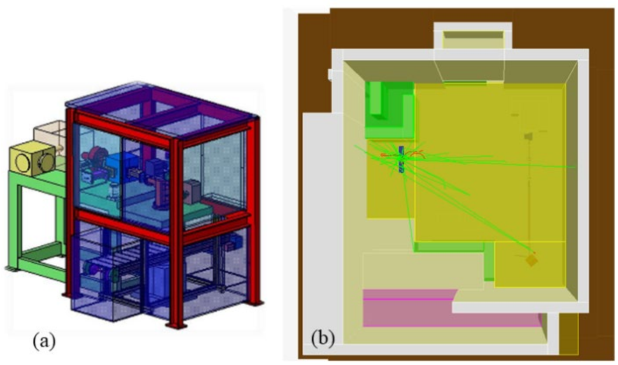


Figure 3: Two scenarios for radiation shielding: (a) extra steel shielding box and (b) layout of steel plate covering the accelerator hall.

## CONCLUSION

The RF-linear accelerator system and irradiation system for natural rubber vulcanization has been developed and is currently under the commissioning. The accelerator system can generate the electron beam with average energies of 2.2 MeV- 3.2 MeV for the given RF power of 0.8 MW - 1.60 MW. Natural rubber vulcanization experiments were carried out with the electron beam of 3 MeV average energy. The preliminary experimental results show that the natural rubber vulcanization occurred at the radiation dose of 50 kGy. Moreover, the rubber latex was fully vulcanized at the radiation dose of 20 kGy if the radiation sensitizers (HDDA or nBA) were added to the rubber latex prior to the irradiation. The radiation shielding has been investigated considering full machine operation. More vulcanization experiments will be conducted after the electron beam optimization to get higher beam currents.

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