

GENERATION OF LOW-ENERGY ELECTRON BEAM USING KURRI-LINAC

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Abstract

At KURRI-LINAC, electrons can be accelerated in two accelerator tubes up to 46 MeV. The peak electron energy was reduced to 5.2 MeV by decreasing the microwave power to avoid electron acceleration and by eliminating the high-energy component using several regulation methods. Although the electron beam current was decreased to 39% of that in normal operation, the machine could operate stably for at least five successive days.

INTRODUCTION

In our normal operation, electrons with an energy of around 30 MeV have been used for various researches [1-4]. We improved regulation methods to generate low-energy electrons, which did not induce radioactivity, for the development of an irradiation facility without adding any extra equipment.

First, we regulated the introduction of microwaves into the accelerator tubes [5]. The peak energy of the electron beam was reduced by introducing microwave power into only the first accelerator (Figure 1). In addition, that power was decreased by decreasing the PFN charging voltage from the 27 kV used in normal operation to 20 kV. The emission of electrons from the electron gun just before the microwave filling time (2 μ s) of the first accelerator tube caused insufficient acceleration of the electrons because of the lack of microwave power in the accelerator tube (Figure 2). Attempts to reduce the peak energy of the electron beam by shifting the microwave phase in the second accelerator tube showed no effect (Figure 1). In the case of introducing microwave power into only the second accelerator tube, electron diffusion occurred during the acceleration, with the result that there was no electron beam at the end of the accelerator tube.

We next regulated the electron beam bunching and electron emission [6]. The peak energy of the electron beam was reduced by 1.3 MeV with a beam bunching phase difference of +72° relative to normal operation (Figure 3), while the beam current increased by 10%. The increase in electron emissions from the electron gun affected the decrease in electron energy. This is because when the microwave power introduced into an accelerator tube is divided between a greater number of electrons, it yields a lower average energy.

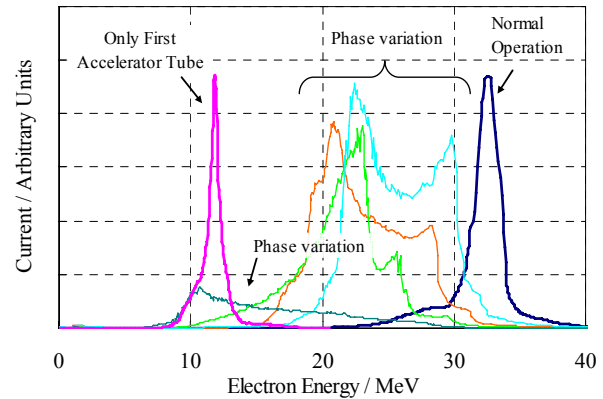


Figure 1: Effect of changing introduction of microwaves into acceleration tubes.

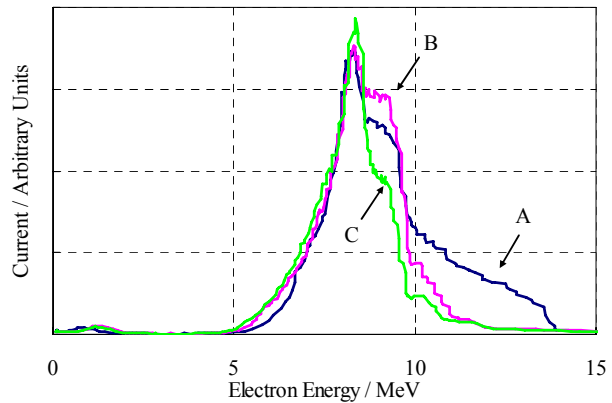


Figure 2: Effect of electron emission timing. (A): Normal emission. (B) and (C): 200 ns and 400 ns faster than normal emission, respectively.

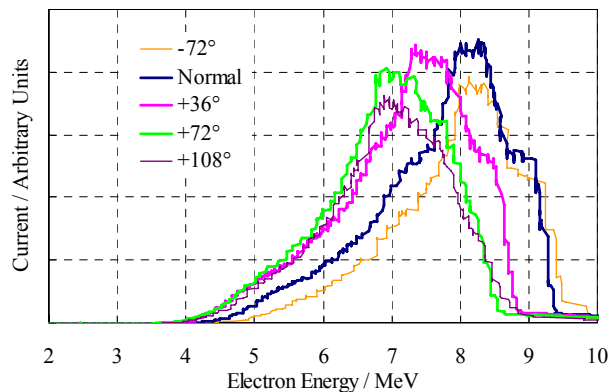


Figure 3: Effect of regulation of beam bunching phase.

In this study, we regulated the generation of a lower-energy electron beam by measuring the microwave power at the termination resistance (water load) connected to an accelerator tube and measuring the time spectra of an electron beam, which showed the time when the high energy component arrived in an electron pulse.

REGULATION METHODS

A lower-energy electron beam was generated by increasing the radiation emission from accelerated electrons and discriminating the high-energy component in the electron beam, as well as by decreasing the microwave power using the method described above.

The radiation emission from accelerated electrons can be detected as microwaves at the termination resistance of the second acceleration tube. Without electron emissions from the electron gun, no significant microwave power arrived at the termination resistance because no microwave power was introduced into the second accelerator tube, even though the first accelerator tube was filled with microwave power. The electron emission caused the detection of microwaves at the termination resistance, which was attributed to the energy loss of electrons in the accelerator tubes. We made adjustments to maximize the microwave power measured at the termination resistance and to reduce the peak energy of the electron beam.

The energy and current of the electron beam was measured using the magnetic field at KURRI-LINAC. The electron pulse emission was used as a trigger to obtain the time spectra at each electron energy. We made adjustments to ensure that the arrival of the higher-energy component was delayed and electrons in the first part of the pulse were converted to a lower-energy component, in order to eliminate the high-energy component by shortening the electron pulse.

RESULTS AND DISCUSSION

The detection of the microwaves at the termination resistances of both accelerator tubes is shown in Figure 4. Without electron emissions, the microwave power was measured on the basis of the introduction of microwaves into each accelerator tube. Electron emissions caused the consumption of microwave power in the first accelerator tube, which resulted in a decrease in that reaching the termination resistance. In addition, a trapezoidal waveform signal was seen at the termination resistance of the second acceleration tube. The amplitude of this signal was effectively maximized by regulating the current of the magnetic lens coil arrayed between the electron gun and the pre-buncher in front of the first accelerator tube. At the peak amplitude, which represented a 41% increase relative to the normal setting, the peak energy of the electron beam decreased by 2.8 MeV and the beam current decreased by 13% (Figure 5).

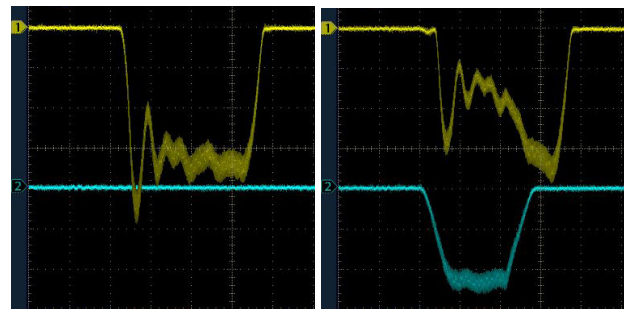


Figure 4: Detection of microwaves at termination resistances connected to acceleration tubes. (Upper) First acceleration tube, (lower) second acceleration tube. (Left) Without electron emission, (right) with electron emission.

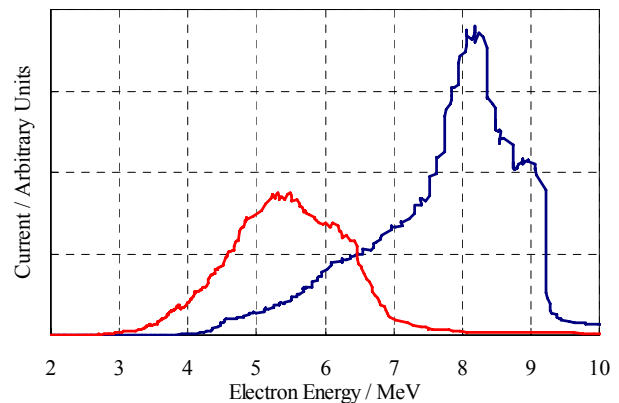


Figure 5: Effect of losing energy from accelerated electrons in second accelerator tube. (Blue line) Normal setting. (Red line) Setting for maximum energy loss.

Time spectra of the electron beam at various energy levels are shown in Figure 6. The current signals were detected within a time of 4 μ s, corresponding to the pulse width of the electrons emitted from the electron gun. The lack of a current signal for 8.0 MeV shows the electron beam without the energy component of 8.0 MeV. The current signal for 7.0 MeV is seen between 2.1 and 2.9 μ s and between 3.8 and 4.0 μ s. In contrast, the current signal for 6.0 MeV is seen across the entire emission period, except between 0.3 and 0.6 μ s. Below 5.1 MeV, current signals are seen for the entire emission period, although the amplitudes of the waveforms are smaller than the others, with one or two peaks at around 0.5 μ s. The time spectra suggest that an electron emission pulse shorter than 2 μ s can yield a lower-energy electron beam by eliminating electrons of 7.0 MeV. The energy spectra resulting from three pulse widths are shown in Figure 7. The energy spectrum with the pulse width of 2 μ s has no energy component higher than 7.0 MeV, showing the effect of a narrow pulse width. As inferred from the time spectra, shortening the pulse width to 1 μ s had no effect on eliminating the highest part of the energy spectra.

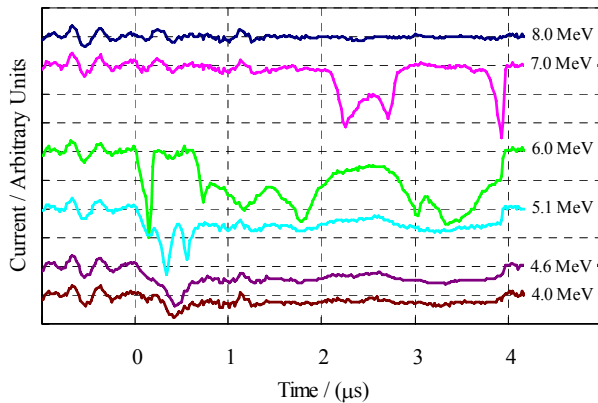


Figure 6: Time spectra of electron beam.

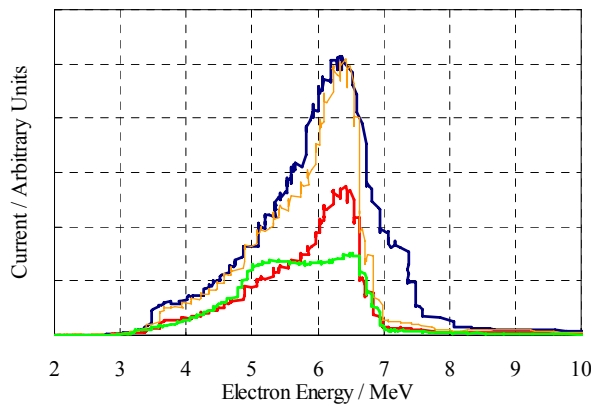


Figure 7: Effect of electron pulse width (Blue) Pulse width of 4 μ s. (Red) 2 μ s. (Green) 1 μ s. The orange line was drawn by expanding the red one for easier comparison.

In conclusion, a low-energy electron beam, for example, one with a peak energy of 5.2 MeV and an average current that was 39% of that of the normal operation, was generated by the following methods. Low-power microwaves were introduced into only the first accelerator tube. The number of emitted electrons was increased, and the emission timing was advanced to fill the accelerator tube with microwaves. The power remaining in the microwaves at the termination resistance of the second accelerator tube was maximized. The phase of the pre-buncher in front of the first accelerator tube was regulated. The width of the electron pulse, if effective, was regulated by using the time spectra of the electron beam.

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