Evaluation of a positron-beam-pulsing system in KUR reactor-based positron beam facility

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Abstract. The pulsing performance of the positron-beam-pulsing system of the slow positron beamline at Kyoto University research Reactor was tested using electron beams trimmed by 5-mm- or 15-mm-diameter apertures. Electron pulses with full width at half maximum of 143 ps were obtained with a 5-mm-diameter beam which corresponds to the diameter of the brightness-enhanced positron beam. This indicates the pulsing system has a sufficient pulsing performance for positron annihilation lifetime measurements.

1. Introduction

Recently, a reactor-based intense slow positron beamline has been newly constructed at Kyoto University research Reactor (KUR) which has a rated thermal power of 5 MW [1, 2]. The first positron beam extraction was achieved in 2014 with a slow positron beam intensity of $1.4 \times 10^6$ e⁻/s at a reactor thermal power of 1 MW [2].

Since the KUR slow positron beamline was constructed as a part of joint usage research facilities, typical size (~10 mm) samples should be measurable with positron annihilation lifetime measurements. Thus, the KUR slow positron beamline has been designed to pulse the beam after focusing the initial 30-mm-diameter positron beam [1, 2], and a positron-beam-pulsing system has been installed downstream of the brightness enhancement system [3]. From our test results using an electron beam, the initial positron beam is expected to be focused to a diameter of around 5 mm by the brightness enhancement system [4]. When a higher beam intensity is required compared with the brightness-enhanced beam, we are planning to introduce a brightness-unenhanced positron beam directly to the pulsing system. The positron beam diameter in this case was 15 mm, which is slightly smaller than the inner diameter, 20 mm, of the pulsing electrodes.

In this study, the pulsing performance of the positron-beam-pulsing system was tested using 5-mm- and 15-mm-diameter electron beams. The reactor operation was suspended for the last 2 years to comply with new safety criteria. Therefore, commissioning of the KUR slow positron beamline is performed using electrons instead of positrons at the moment.

2. Experimental method

A schematic diagram of the experimental setup of this study is shown in figure 1. A self-made electron source that consists of several magnesium (Mg) ribbons was installed upstream of the brightness...
enhancement system. The Mg ribbons emit photoelectrons by 254 nm (nominal) ultraviolet light irradiation. The emitted photoelectrons are extracted by a grid mesh having a 15-mm-diameter aperture, and transported to the pulsing system with an energy of 10 eV in a magnetic field of approximately 6 mT. The energy spread of the electron beam has been measured to be 1.2 eV full width at half maximum (FWHM). The electron beam was pulsed by the pulsing system which consists of reflection-type chopper, cylindrical-electrode-type sub-harmonic pre-buncher, and quarter-wave resonant-cavity-type buncher. The configuration of the pulsing system is similar to that used at the AIST LINAC-based slow positron beamline [5–8]. The resonance frequency $f$ of the buncher RF cavity has been confirmed to be $f = 122.694$ MHz. The chopper, pre-buncher, and buncher were driven at $f/4$, $f/4$, and $f$, respectively. The pulsed electrons were detected by a single-anode microchannel plate (MCP, Hamamatsu F4655-12) with an effective diameter of 14.5 mm at the sample position.

Since electrodes of the pulsing system have an inner diameter of 20 mm, we intend to introduce the 15-mm-diameter positron beam without brightness enhancement when a higher beam intensity is required. Apertures having diameters of 5 mm or 15 mm were installed about 350 mm upstream from the chopper to demonstrate electron beams corresponding to brightness-enhanced or brightness-unenhanced positron beams. The chopper driving signals and the electron detection signals were input to a constant fraction discriminator (CFD, Ortec 935), and the time differences between the two signals were accumulated with a time-to-amplitude converter (TAC, Ortec 566) and multichannel analyzer (MCA, Laboratory Equipment MCA-Lite/M) in order to obtain time structures of the electron pulses. The time structures were obtained using the 5-mm- or 15-mm-diameter apertures, with the driving-parameters of the pulsing system optimized in each case.

3. Results and discussion

Before measuring the time structures of the beam pulses, the time resolution of the measurement circuit was confirmed by supplying the chopper driving signal through a power divider into the TAC start/stop connectors. An accumulation result of the detection-timing fluctuation of the same chopper driving signals indicated the time resolution of the measurement circuit was 44 ps FWHM which is comparable to a reported value in a similar experiment [9].

Measured time structures of electron pulses obtained using the 5-mm-diameter aperture are shown

![Figure 1. A schematic diagram of the electron beam pulsing test. A magnetic field of 6 mT is formed on the beamline by beam-guiding coils (not shown).](image-url)
in Figure 2. The result shows that the chopped electron pulses are bunched by passing through the pre-buncher and buncher. In this case, electron pulses with FWHM of 143 ps, which include the time resolution of the measurement circuit and the electron detector (MCP), are obtained. Similar electron/positron beam pulsing tests for positron annihilation lifetime measurements have been conducted using an MCP as an electron/positron detector by some other groups, and they obtained pulse widths in the range of 153–187 ps [10–12]. The pulse width in this study is sufficient for measuring positron annihilation lifetime spectra with a time resolution of a few hundred picoseconds. In our beamline, a 150-nm-thick Ni(100) single-crystal film is planned to be used as a positron remodulator at the brightness enhancement system [4]. The energy spread of positron beams emitted from Ni(100) film is reported to be 0.3 eV at FWHM [13], which is smaller than the energy spread of the electron beam used in this study (1.2 eV). When a positron beam emitted from the Ni remodulator is used, pulse widths are expected to be at least comparable or narrower than the results of this study. Therefore, our system has a sufficient pulsing performance for positron annihilation lifetime measurements at least using the brightness-enhanced positron beam.

Figure 3 shows measured time structures of electron pulses obtained using the 15-mm-diameter aperture. Even in this case, electron pulses with FWHM of 142 ps are obtained. It should be noted, however, that the actual beam diameter seems to be less than 15 mm (not uniform) in this case owing to insufficient optimization of beam trajectories. Thus, the actual beam diameter should be confirmed by an MCP phosphor screen in the future study, and the further pulsing performance tests for the trimmed 15-mm-diameter positron beam are necessary. At least, tail components of time structure curves in Figure 3 are slightly increased, suggesting that beam diameters larger than 5 mm influence the time structure of the electron pulses.

Beam chopping efficiencies calculated from the measured time structures were 5–7% in the present pulsing parameter settings. Such beam duty factors are largely dependent on driving parameters of the chopper, and the duty factor could be increased to 10% or more if a degradation of time resolution can be tolerated.

From the present results, we note that the performance of the pulsing system is determined as a consequence of the balance between the beam size and the intensity. For the brightness enhanced beam (~5 mm) with the 150-nm-thick Ni remodulator, the beam intensity will be decreased to 10–20% of the

![Figure 2](image1.png)

**Figure 2.** Time structures of electron pulses obtained with the 5-mm-diameter aperture. The dashed-dotted line (blue), dotted-line (green), and solid line (red) indicate spectra obtained with driving only the chopper, driving the chopper and pre-buncher, driving all units (chopper, pre-buncher, and buncher), respectively.

![Figure 3](image2.png)

**Figure 3.** Time structures of electron pulses obtained with the 15-mm-diameter aperture. The dashed-dotted line (blue), dotted-line (green), and solid line (red) indicate spectra obtained with driving only the chopper, driving the chopper and pre-buncher, driving all units (chopper, pre-buncher, and buncher), respectively.
initial intensity [14]. On the other hand, for the beam without the brightness enhancement, the intensity remains at 25% when the initial 30-mm-diameter beam is trimmed by the 15-mm-diameter aperture. If the large (15 mm) spot size can be tolerated, counting rates can be increased approximately by a factor of 2 with moderate pulsing performance.

4. Summary
In this study, we developed a beam-pulsing system for the KUR slow positron beamline with a brightness enhancement system, and beam-pulsing tests were conducted using an electron beam. Electron pulses with a FWHM of 143 ps were obtained from a 5-mm-diameter electron beam, which corresponds to the diameter of the brightness-enhanced positron beam. Our system was confirmed to have a sufficient pulsing performance to perform positron annihilation lifetime measurements.

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