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ASSESSMENT OF THE RATIOS OF RADIATION SOURCES AND TOTAL ELECTRON LOSS AT THE INJECTION SECTION OF THE TAIWAN PHOTON SOURCE FACILITY AND TOTAL ELECTRON LOSS BY USING NEUTRON MEASUREMENTS

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Abstract

Radiation in the injection section of a synchrotron radiation facility is primarily the result of injection beam loss, which occurs each time the current is replenished, and storage beam loss, which accounts for the lifetime during routine operations. This study conducted neutron measurements by using high-sensitivity neutron detectors and obtained the total electron loss during the unfolding process. With the known lifetime, the ratio of injection beam loss to storage beam loss and the total loss in the injection section of the Taiwan Photon Source facility during routine operations were determined. The total electron loss at the measurement site was approximately five millionths of the full load current. The ratio of injection beam loss to storage beam loss was 1.64. The total electron loss was 0.44 pC, with 0.27 pC being attributed to injection beam loss and 0.17 pC being attributed to storage beam loss.

INTRODUCTION

This study used a self-developed, high-sensitivity Bonner cylinder to measure neutron spectra in the Taiwan Photon Source (TPS) facility [1]. The system is highly sensitive because it has a large detection core. This makes the system particularly suitable for environments with low neutron fluxes, such as synchrotron radiation research facilities. High-sensitivity reference detectors were employed to mitigate the dynamic fluctuations associated with accelerator injection.

In 2023, we conducted a neutron measurement experiment under routine operating conditions at the TPS facility. Routine operating conditions may pose several more challenging measurement obstacles, including low neutron fluxes, uncertainties regarding detector measurability, and large detection errors. Additionally, the need for longer testing times, ensuring sufficient measurement windows provided by the accelerator, and maintaining long-term accelerator stability are all issues that must be addressed and overcome during measurements.

METHODOLOGY

Neutron Measurement

The present study conducted neutron measurements under routine operating conditions at the TPS facility with full load current (500 mA). To address the problem of neutron counts generally being lower during the neutron measurement process, we used a high-sensitivity Bonner cylinder measurement system. Additionally, dynamic fluctuations caused by the accelerator can be mitigated using high-sensitivity neutron detectors as measurement references.

Spectrum Unfolding

We used 16 sets of high-sensitivity neutron detectors for spectrum unfolding; however, this number was insufficient. The issue could be addressed by providing an appropriate initial spectrum to the unfolding program. An initial spectrum was generated by analyzing simulations of the radiation field. The response functions of each detector set were also derived from the analyses of these simulations [2]. With the initial spectrum, measurement results, and response functions, unfolding could be initiated using the MAXED deconvolution code [3] to obtain the neutron measurement spectrum and then determine the total electron loss at the measurement site.

Estimation of Electron Loss Ratio and Total Loss

At measurement site BP47, potential sources of electron loss included loss caused during the injection period in the injection section and loss resulting from normal operation considering electron lifetime. Throughout the experiment, the overall average lifetime was approximately 10 hours. The TPS facility has 48 sections, and on the day of the experiment, lifetime could cause measurement effects on section BP47 (Fig. 1).

RESULTS AND DISCUSSION

After the experiment was completed, the current of the TPS facility, the real-time gamma radiation dose rates of section BP47, and the neutron dose rate were plotted (Fig. 2). The experimental results are shown in Fig. 3. The TPS facility had an unstable current and exhibited a trip beam phenomenon (Fig. 2). Significant fluctuations in gamma and neutron dose rates were also observed in certain periods. Measurements during these periods required revaluation or exclusion to ensure the quality of the experiment.

The measured neutron counts (black line) and reference neutron counts (red line) are shown in Fig. 3. The reference results revealed that despite maintaining a stable full load current, a slight fluctuation in neutron counts was observed. This was mainly due to the dynamic nature of the accelerator itself, which included minute-by-minute injections, decay over time, and current variations. The stability and sensitivity of the detectors also affected the overall ex-

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perimental results, including neutron counts. The self-developed neutron detectors used in this study were sufficient to measure neutron counts under the routine operating conditions of the electron accelerator. The measurements were corrected by subtracting background values and normalizing the measured values to the reference values (Fig. 4).

The measurement results (Fig. 4) were unfolded using MAXED deconvolution code. An isotropic response function was employed (Fig. 5), and the initial spectrum was derived from FLUKA calculations (Fig. 6). This process produced a new unfolded spectrum, with the final unfolding result yielding a best-fit value of 8.2503E+06. The total electron loss was equivalent to 1.32 pA. By normalizing both the experimental and computational results to 1.32 pA, Fig. 7 was generated, demonstrating that the trends of the experimental and computational results were consistent, with values closely aligned. This observation enhanced confidence in the measurement experiment.

The full load current of the TPS facility is 500 mA, which can be converted to 8.6333E+05 pC. The electron loss at the measurement site corresponded to the best-fit value of the unfolding result, which was 8.2503E+06 electrons (equivalent to 0.44 pC). The ratio between these two values was 5.10E-07, indicating that the electron loss at the measurement site was approximately five millionths of the full load current.

The overall average lifetime during the experiment was approximately 10 hours. The TPS has 48 sections, and on the day of the experiment, the lifetime was estimated to affect the measurements at section BP47 (Fig. 1). The lifetime of all 48 sections resulted in a loss of 150 million electrons per second. Considering that lifetime only affects one section, each section should have 3.125E+06 electrons.

According to the unfolding results, the electron loss per second was 8.2503E+06. The number of electrons lost due to storage beam loss was subtracted from the total number of electrons lost to obtain the number of electrons lost due to injection beam loss (5.1253E+06). The ratio of injection beam loss to storage beam loss was 1.64. The total electron loss was 0.44 pC. If the number of electrons was estimated on the basis of the aforementioned ratio, the injection beam loss and storage beam loss would be 0.27pC and 0.17pC, respectively.

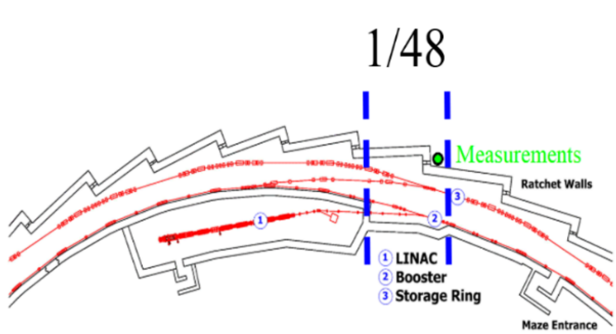

Figure 1: Taiwan Photon Source facility currently consists of 48 sections. Experiment was conducted at section BP47.

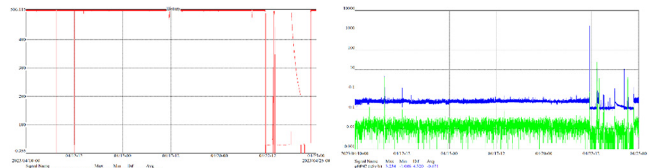

Figure 2: Storage ring current (red line), real-time gamma radiation at BP47 (blue line), and neutron dose rate (green line) recorded during experiment.

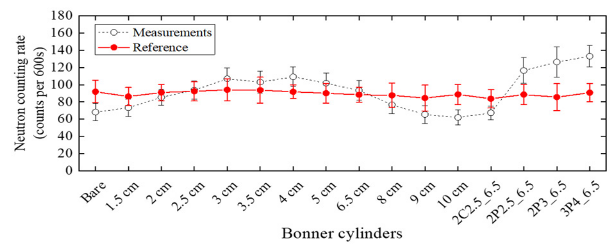

Figure 3: Measured neutron counts (black line) and reference neutron counts (red line).

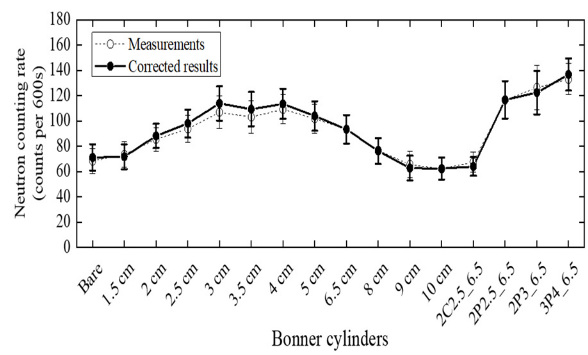

Figure 4: Corrected neutron measurement results.

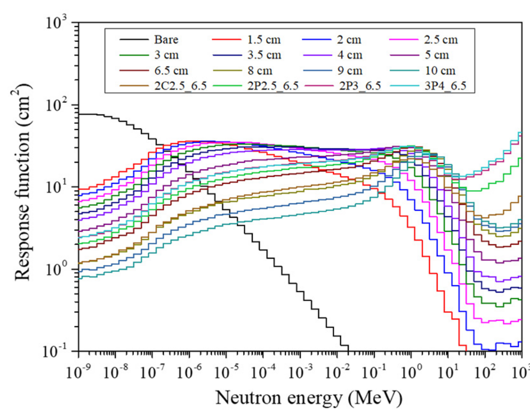

Figure 5: Response function of high-sensitivity Bonner cylinder (isotropic).

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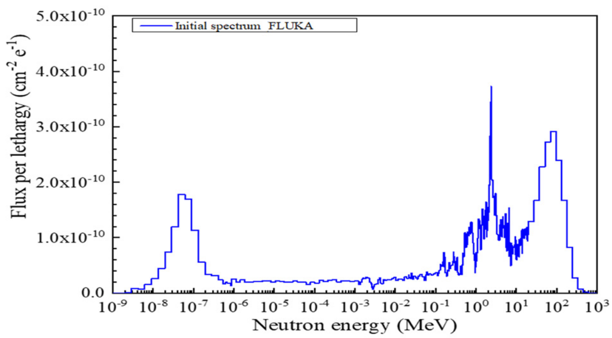

Figure 6: Initial spectrum calculated through FLUKA computational program.

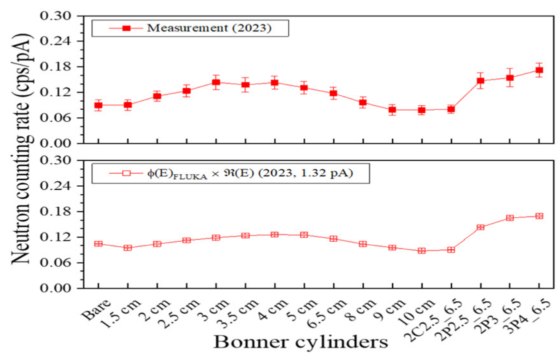

Figure 7: Experimental and computational results separately normalized to 1.32 pA.

CONCLUSIONS

This study employed a high-sensitivity Bonner cylinder measurement system and high-sensitivity neutron detectors as measurement references to mitigate the dynamic fluctuations caused by the accelerator. The experiment was conducted when the TPS facility was operated at a full load current of 500 mA. The overall average lifetime was approximately 10 hours. With the initial spectrum, measurement results, and response functions, unfolding was performed using the MAXED deconvolution code. Subsequently, on the basis of the unfolding results, the total electron loss was estimated to be approximately five millionths of the full load current.

Most of the radiation in the injection section of the TPS facility was attributed to injection beam loss, which occurred each time the current was replenished, and storage beam loss, which accounted for the lifetime during routine operation. The ratio of injection beam loss to storage beam loss was 1.64. The total electron loss was 0.44 pC, with 0.27 pC being attributed to injection beam loss and 0.17 pC being attributed to storage beam loss.

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