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SEVEN YEARS STATISTICAL ANALYSIS OF THE SIAM PHOTON SOURCE OPERATION

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Abstract

The Siam Photon Source, a synchrotron light source in Thailand, has undergone multiple improvements in recent years, including the installation of up to four insertion devices in the storage ring. The machine has operated at maximum capacity for a significant period of time. This study presents a statistical analysis of the machine's operation over the past seven years, including the number of beam service hours, machine downtimes, and repair times. The paper also discusses critical incidents that occurred during this period, such as faults with a booster ring bending magnet power supply, superconducting magnet cool-down problems, and issues with a cryogenic plant's liquefaction process. Furthermore, this report highlights major upgrades and improvements made over the past seven years to enhance beam quality.

INTRODUCTION

The Siam Photon Source (SPS) is a reconstructed machine originally donated by the SORTEC Corporation, which was formerly installed at the Tsukuba Research Laboratory [1–5]. The storage ring of the SPS was modified and reconstructed to house four insertion devices in four long straight sections. Initially, the storage ring had an energy of 1.0 GeV, but it can potentially reach an ultimate beam energy of 1.2 GeV in future upgrades [6–10]. Building construction started in 1998, and the installation of machine components began in 2000. By the end of 2001, the first beam was able to circulate in the storage ring, and within a year, 100 mA of electron beam could be stored in the storage ring [11]. User beam service began in 2003 [12,13], and by 2005, the energy had been ramped up to 1.2 GeV [14,15]. The first insertion device, U60 undulator, was installed in 2008 [16,17].

In 2009, successful helium liquefaction for the superconducting insertion device was achieved by the cryogenic plant. Later, in the same year, the 6.4 T Superconducting Wavelength Shifter (SWLS) received from Lund University underwent conditioning and cold testing [18,19]. However, the He consumption rate was found to be high after operation, and the ID was replaced by the 6.5 T Superconducting Wavelength Shifter (SWLS) received from National Synchrotron Radiation Research Center (NSRRC), Taiwan. In 2013, the installation and commissioning of the ID and the 2.2 T Multipole Wiggler (MPW) received from Accelerator Science and Technology Centre (ASTeC), England, in the storage ring was successful [20].

The installation of three IDs resulted in increased energy loss, and hence, the second RF system was installed and commissioned in 2016 [21–23]. The full energy 1.2 GeV injection scheme from the booster ring was successfully upgraded in 2018. In 2018, the fourth ID, the 3.5T Superconducting Multipole Wiggler (SMPW), was installed in the storage ring through a collaboration with National Synchrotron Radiation Research Center (NSRRC), Taiwan [24,25]. In January 2020, the Thai cabinet approved the construction of a new 3 GeV synchrotron light source project after nearly 20 years of SPS operation since 2003 [26–29].

The SPS has been fully operational since 2018. Next section will present the statistical analysis of seven years of machine operation (2016-2022), followed by critical incidents and future improvements of the machine.

STATISTICAL ANALYSIS OF MACHINE OPERATION

The SPS had a user beam service hour plan exceeding 4,400 hours for the period from 2016 to 2020, but it decreased to 3,300 hours for the fiscal year 2021-2022. This reduction was attributed to the COVID-19 pandemic. Despite this, the delivered beam time of the SPS was well above 97% during the seven-year period, with the exception of 2020 when it was 95%. This decrease was due to unscheduled shutdowns and a limitation on machine operation hours due to the COVID-19 situation as in Fig. 1. The number of beam trips increased from 60 during the fiscal year 2016-2018 to approximately 80 incidents during 2019-2022, with the exception of 2021 which had 40 events, as illustrated in Fig. 2.

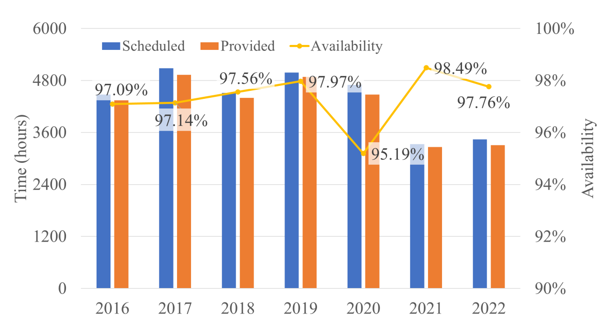

Figure 1: Machine availability statistics.

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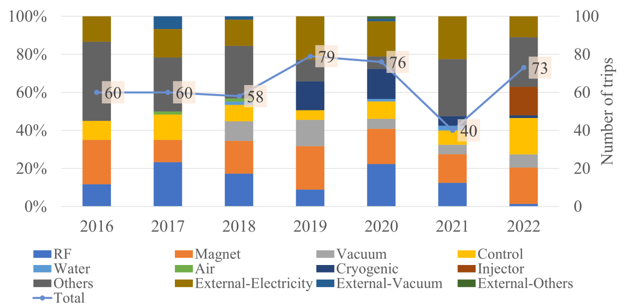

Figure 2: Number of trip statistic categorized by subsystem.

The beam trip events were classified into different subsystems of the machine and external factors, such as electricity instability. The most frequent cause of the trips were major subsystems. For example, the magnet power supplies were the dominant cause in 2016, 2018, 2019, and 2022, while the RF subsystem was the dominant cause in 2017 and 2020. In 2017, the contribution of the second RF system of the storage ring to the beam trip was from a learning experience with the new system [23]. Other unknown causes of internal factors were classified as "Others," and they still significantly contributed to the beam trip. The main external factor that caused beam trips was still electricity problems.

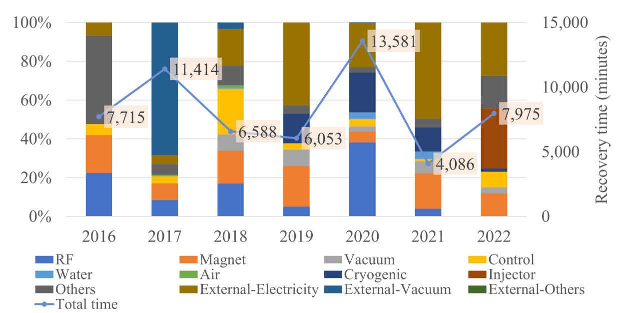

Figure 3: Recovery time statistic categorized by subsystem.

The time taken to recover from each beam trip was recorded and analyzed, as depicted in Fig. 3. Recovery time following a trip event of the magnet and RF subsystems were found to be the main contributing factors to the downtime of the machine operation among the internal factors. In addition, trip events caused by external factors such as electricity were also found to significantly impact the recovery time.

Figures 4 and 5 illustrate the mean time between failures (MTBF) and the mean time to repair (MTTR) of each subsystem. In the fiscal year 2017, the MTBF was approximately 80 hours, which was due to the subsystems' quick recovery time despite a few major trip events in the vacuum category. However, in 2021, there were fewer trip events, and the repair time was quick, resulting in a high MTBF.

MAJOR INCIDENTS

In September 2016, a vacuum leak occurred at the front-end of beamline BL1, resulting in a two-day recovery period.

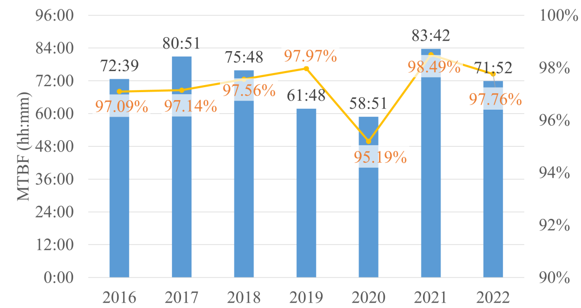

Figure 4: MTBF statistics.

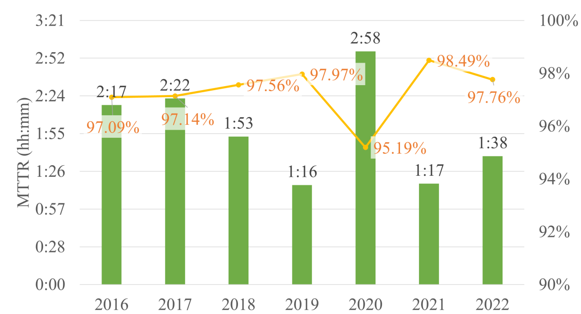

Figure 5: MTTR statistics.

The implementation of a new solid-state RF amplifier and digital low-level RF controller (LLRF) also contributed to the high recovery time in 2016. This event served as a valuable learning experience following the introduction of these technologies into the storage ring. Additionally, the storage ring bending magnet power supply experienced frequent tripping in 2016, likely due to its aging from continuous operation since 2005. As a result, plans were made to install a new power supply.

Figure 6: Installation of a refurbished board.

In 2017, there were significant incidents involving vacuum leaks at the front-end of beamlines BL2, BL5, and BL6, resulting in extended recovery periods. In 2018, there was a failure of both the multipole wiggler motor driver and the digital interface board of the second LLRF system. Addi-

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tionally, instability of the electricity was a major incident in 2019.

In 2020, there was an unscheduled one-month shutdown of the machine due to the COVID-19 pandemic, followed by a one-month period of daytime service only. The most significant incident that year was a water leak inside the klystron focusing coil (KFC) of the linac RF system, which required four days for recovery. The KFC is an outdated model, and a spare part order was placed with a Japanese company. RIKEN/SACLA provided assistance in coordinating communication, monitoring fabrication, and performance testing. The spare part was shipped and arrived in January 2022, with plans for installation during the machine shutdown period in fiscal year 2023.

During the 2021 fiscal year, there was a significant incident that impacted the machine service time. Specifically, the booster ring bending magnet power supply failed in November 2020 during the process of preparing the machine for user service following the shutdown period. Fortunately, the old bending power supply was still operational and could be used in the 1.0 GeV ring injection. However, the COVID-19 situation and worldwide semiconductor shortage posed challenges in obtaining spare parts, which resulted in the long procurement process. A refurbished board by our staff was installed and tested with the guidance of company experts in August 2022 as shown in Fig. 6. New spare boards were delivered in October 2022, and the power supply was put back into operation for the fiscal year 2023. Additionally, during the machine shutdown period in August 2021, the old RF system of the storage ring was dismantled and removed.

In November 2020, a significant incident occurred with the cryogenic system involving the 3.5 T superconducting multipole wiggler (SMPW). Specifically, there was an issue with the cooling process, as it was not possible to fill the SMPW cryostat with liquid helium to reach a temperature of 4 K. Several investigative actions were taken to identify the problem, and the latest investigation revealed that there was contact between the temperature shielding parts inside the transfer line. As a result, the transfer line is currently undergoing repairs.

Figure 7: Investigation of cryogenic plant.

In September 2021, another significant incident occurred with the cryogenic system, specifically with the liquefaction of helium. The helium expansion turbine of the plant failed during operation, and attempts to solve the problem remotely through consultations with the company were unsuccessful. Consequently, a technical expert was dispatched to fix the issue in March 2022 as shown in Fig. 7.

FUTURE IMPROVEMENTS

During the shutdown activities of fiscal year 2021, a new storage ring bending magnet power supply was planned and installed to enhance the stability of electron beam energy and minimize the impact of electromagnetic interference from power cables. To achieve this, the new power supply was installed outside of the storage ring, with the power cable not connected directly to the ring. Furthermore, the old bending power supply was relocated and installed adjacent to the new one, providing redundancy in the operation of the power supply.

A plan was devised to test an optical fiber-based beam loss monitor in the storage ring during energy ramping and injection [30]. Analysis of the data gathered from this beam loss system will be utilized to enhance injection efficiency and beam orbit control. Additionally, a screen monitor system is planned to be installed at the injection septum of the storage ring as a diagnostic tool to further improve injection efficiency.

Improving instability in the infrared beamline is a primary area of focus for machine improvement. Ongoing activities involve investigating noise figures in the IR spectra. There are also plans to investigate the RF system signal, and a new low-phase noise master RF frequency has been acquired and is scheduled for installation during the shutdown period in fiscal year 2023.

Efforts are currently being made to enhance the diagnostic capabilities of the injector linac in order to improve injection efficiency [31]. Additional diagnostic components will be incorporated to gather beam information for optimizing the linac and beam transport system. In the future, machine learning and artificial intelligence will be utilized to optimize the injector.

CONCLUSION

The statistical analysis of SPS operations revealed that the main causes of beam trip events were related to magnet and RF subsystems, as well as an electricity stability. Although several trip events have yet to be identified and require further investigation, major machine incidents such as vacuum and water leakage, as well as problems with the cryogenic plant and booster ring bending magnet power supply, have been explained. Efforts to improve beam stability and injection efficiency have been the primary focus of these activities over the past seven years, leading to the development of a skilled workforce for the upcoming new light source project scheduled to begin serving users in 2033.

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