CURRENT STATUS OF TPS VACUUM SYSTEM

Yi-Ch. Yang†, Ch.-K. Chan, Ch.-Ch. Chang, Bo-Y. Chen, Ch.-Mu Cheng, T.-W. Hsu, J.-H. Kang,
National Synchrotron Radiation Research Center, Hsinchu, Taiwan

Abstract

The TPS is currently operating at a beam current of 500 mA for users. Until now, 17 insertion devices have been installed in the straight vacuum sections, and the associated vacuum components have been upgraded. The average vacuum pressure of the storage ring is 8.5 nPa, and the beam lifetime under 500 mA operation is approximately 8 hours. The behavior of vacuum readings, the pressure distribution and the related interlock will be discussed in this paper.

INTRODUCTION

The Taiwan Photon Source (TPS) began operation for users in 2016 with a beam current 300mA. The beam current was raised to 400mA in December 2017, and regularly reached 450mA by the end of 2020. In 2021, the target storage beam current of 500mA was successfully archived. Until the end of 2025, a total accumulated beam dose of 24525Ah has been reached, with a beam lifetime of approximately 8 hours during 500 mA operation. Two operation modes, uniform filling and hybrid mode, are utilized periodically to meet the needs of user experiments.

The vacuum pressure distribution of the storage ring under 500mA operation is illustrate in Fig. 1, which shows a higher pressure spike in the SR24 section resulting from the machine upgrade in 2026. The dynamic average pressure is 8.9 nPa, compared to a static pressure of 6.8 nPa without beam. To date, 17 insertion devices (IDs), two superconductivity cavities, and one harmonic cavity (HC) have been installed in the straight sections of the storage ring. Corresponding vacuum components, including bending magnet chambers and front-end (FE) vacuum system, have also been upgraded [1, 2]. The lumped NEG-ion combination pumps used in EPU ID vacuum chamber was developed to improve and increase the effective pumping speed [3]. A vacuum gauge was installed at the center of each EPU chamber to measure local pressure accurately. The average pressure rise normalized to the beam current dP / I (Pa / mA), follows a downward trend proportional to $D^{-0.791}$, was shown as Fig. 2.

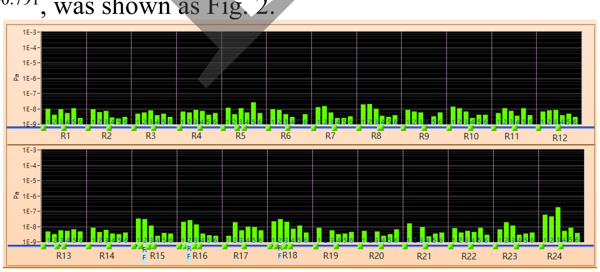

Figure 1: The vacuum pressure distribution of the storage ring.

† jolas@nsrrc.org.tw

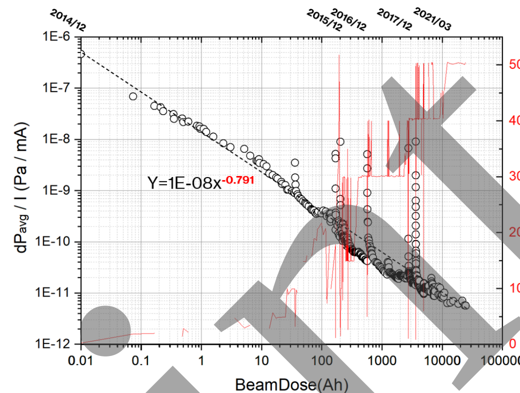

Figure 2: The average pressure rise normalized to the beam current.

BEAM TRIP EVENT

Over the past several years, seven beam trip events occurred during user time. The specific incidents and their causes are summarized.

- In 2017, two trip events were recorded. The first was caused by the temperature of the SR02S1 bellows exceeding its set-point. The second involved an ambiguous vacuum signal in the SR16 SRF section. It was difficult to determine whether the pressure spike originated from the storage ring or the SRF vacuum system. Consequently, Post-Mortem system was developed by I&C group to better identify abnormal signals across TPS subsystem.
- In 2018, a noisy signal from the cooling water flow meter triggered the machine protection system (MPS). The signal recovered immediately after the flow meter was reset.
- In 2019, An unready vacuum signal from FE07 vacuum system, combined with a burst signal (>1E-6 Pa) near the FE07, triggered a trip. This was classified as an unexpected incident.
- In 2020, a copper plate from the strip-line kicker in the SR14 section detached. While the vacuum remained stable, but the electron beam could not be stored, and high beam lose signal was detected in this section during injection. A dummy chamber and an additional NEG pump were installed to enhance pumping efficiency. The total downtime was 23.83 hours.
- In 2022, a cooling water interlock of the crotch absorber in SR21 section was triggered. The root cause was a failed of the DC power supply unit for flow meter, rather than an actual water flow issue.
- In 2024, an unexpected outage of vacuum gauges and pumps occurred in Control Instrument Area 24

(CIA24). The exact cause remains unconfirmed, though the UPS is the primary suspect.

Based on these experiences, two main strategies were adopted to enhance the reliability of safety interlock system and reduce the frequency of trip event.

- Modified the interlock logic of temperature. Temperature signals were removed from the vacuum protection system in 2020, while the temperature readings continued to be monitored. When the readings exceed the set-point value, an alarm message is issued instead of immediately interrupting machine operation.
- Implementation of redundancy mechanisms. A second flow sensor and meter were installed in each cooling loop. A beam trip is triggered only if both signals indicate a failure (AND logic). This prevents trips cause by noise or a single sensor failure. Additionally, commercial redundant power modules were implemented to ensure power quality, specifically for critical DC power units.

ABNORMAL OF VACUUM GAUGE

In addition to the trip events, several abnormal phenomena were observed.

- Certain vacuum pressure readings are influenced by the operating current of nearby magnets. Fig. 3 illustrates an example where the SR24IG3 gauge reading fluctuated during the magnet degaussing process. Once degaussing was complete and the Q1 magnet was set to its nominal current of 165A, a slight drop in the gauge reading was observed. Despite the symmetric configuration of vacuum gauges and magnets throughout the TPS, such interference affects only a limited number of gauges. Attempts to shield the gauge heads with Mu-metal proved ineffective. We are currently investigating potential crosstalk between the vacuum gauge signal cables and the magnet power cables as a possible root cause.

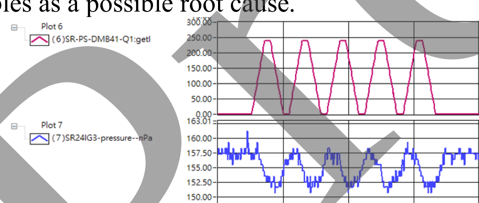

Figure 3: SR24IG3 fluctuated during magnet degaussing.

- During the beam injection process, high pressure fluctuations have been observed in a few specific gauges. These fluctuations do not occur during every injection cycle. There is a strong suspicion that these signals are highly correlated with the firing of the injection kickers, possibly due to electromagnetic interference (EMI).
- A few gauges were damaged. The trend of gauge readings variation is compared with the beam current trend to assess whether this gauge is functioning property. A specific case is SR20IG2, which is located at the center of the EPU vacuum chamber and positioned at the same elevation as the electron beam, as shown as Fig. 4. After long term operation, this gauge began to fluctuate randomly, showing no correlation with the beam current. Although lead shielding was installed around the gauge head to prevent radiation damage when the EPU chamber was first commissioned, the effectiveness of this shielding appears to have degraded. This gauge functioned correctly initially but began to show signals of failure after approximately one year operation.

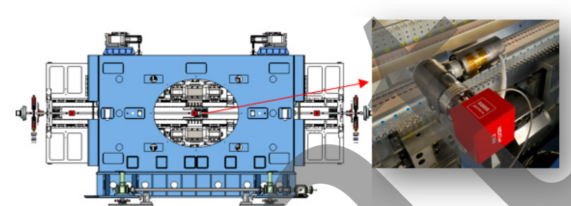

Figure 4: SR20IG2 is located at the center of the EPU chamber.

In all cases mentioned above, the pressure fluctuations are small or transient, meaning they do not disrupt machine operations. However, their intermittent nature makes them easy to overlook and difficult to solve. Research and monitoring are ongoing to further clarify these mechanisms and implement permanent solutions.

EBPM ISSUE

The temperatures of the electron beam position monitor (eBPM) blocks and bellows, with no cooling water, are monitored. As the beam current rises, the temperature of the eBPM blocks increases gradually, with the most significant rise observed in the straight sections. In straight sections, the aperture height of the eBPM blocks is 16mm, relative to 38mm in the arc sections. The eBPM blocks in the straight sections are constructed from stainless steel, whereas those in the arc sections are made of aluminum. To mitigate this heat accumulation, cooling fans have been installed in all straight sections to reduce temperature rise. The temperature of air cooling in the SR04S2 section and natural cooling in the SR02S2 section is compared in Fig. 5. A temperature increase of 20 ℃ with natural cooling was observed at 300mA beam current, while only 5℃ increase with air cooling. At 500mA beam current, the temperature of eBPM block in straight section stabilized at approximately 45 ℃ with air cooling, compared to 32 ℃ in the arc section under natural cooling.

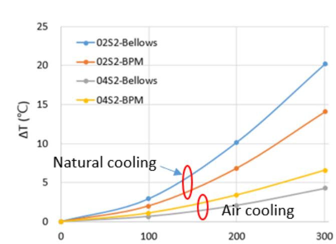

Figure 5: Temperature comparison between air cooling and natural cooling.

Based on CST studio simulation [4], the loss factor k of the eBPM block in the straight section is 4.68 mV/pC, with an estimated power loss of 3.37 W under current operating parameters and a bunch length of 16.6 ps. The thermal conditions improved significantly following the installation of the HC in early 2026, as the bunch length increased by approximately 1.8 times to 30 ps. The temperature of eBPM blocks in the straight section decreased to below 35°C. Additionally, a 10% reduction in vacuum pressure was observed, attributed to the mitigation of resistive wall heating.

Abnormal eBPM signals have been observed in both straight and arc sections. Most of these anomalies occur intermittently or randomly. If a signal exhibits excessive instability, it is excluded from the orbit feedback system. Using eBPM050 as an example, its abnormal behavior has been found to be highly correlated with the switching of the upstream ID. Interestingly, these anomalies are not caused by the same electrode (button) every time. Furthermore, the duration of these events varies significantly; some are transient, while others persist until the next ID operation, sometimes lasting over 12 hours. As shown in Fig. 6, an ID gap adjustment resulted in position fluctuations of approximately 8 μm along the X-axis and 6 μm along the Y-axis, lasting for about three hours. Despite the Instrumentation and Control (I&C) team replacing cables, electronics, and even the electrodes, the issue persists, and the exact root cause remains unclear.

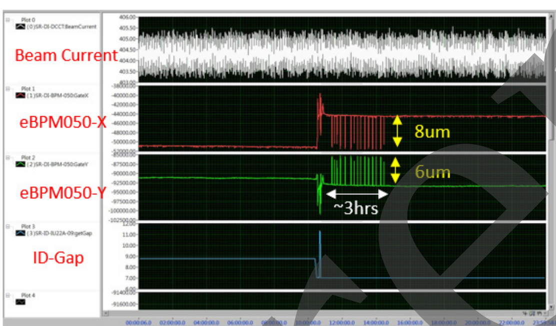

Figure 6: Abnormal signal of eBPM050 is correlated with the switching of the upstream ID.

To investigate this issue, a vacuum test section will be installed downstream of the SR05 section. An additional eBPM will be positioned as close as possible to BPM050 to determine whether the anomalies occur simultaneously across both units, which will help clarify the source of the interference.

Additionally, this test section will serve as a R&D platform for next generation accelerator components, including eBPMs with various button and insulator designs. Molybdenum button will be prioritized for testing to replace the current stainless-steel button, owing to its superior electrical and thermal conductivity.

NEXT GENERATION RESEARCH

Beyond the research and development of next generation eBPM electrodes, technical advancements for future light source vacuum systems continue to progress, including NEG coating, nonlinear in-vacuum kicker (NIK) [5], and eBPM electrode welding. An in-house NEG coating system has been successfully established, capable of coating vacuum tubes up to 2 meters in length. The NEG-coated chamber will first be installed in the TPS front-end vacuum section to evaluate its vacuum performance. Meanwhile, the second version of the NIK chamber is currently being optimized, with primary improvements focused on its pumping speed and thermal conductivity. Furthermore, a photon stimulated desorption (PSD) beamline has been completed, as shown as Fig. 7, which will be utilized to verify NEG film performance and conduct outgassing research on various vacuum materials.

Figure 7: The PSD beamline.

CONCLUSION

After nearly a decade of operation, the vacuum system has stabilized, with vacuum pressure decreasing as expected in correlation with the accumulated beam dose. The protection logic has also been upgraded. In particular, the implementation of redundancy mechanisms has effectively mitigated the impact of component aging, reduced abnormal trip events, and maintained stable machine operation. Issues such as signal interference and anomalies are being addressed through continuous monitoring and research, with the intergration of machine learning and AI technologies planned to accelerate these studies. Meanwhile, research and development for next generation light source technologies are ongoing to prepare for future construction.

REFERENCES

[1] C.K. Chan, *et al.*, "Replacement of the TPS bending chamber with an on-site cutting method," *Bull. Soc. Vac. Coaters*, vol. 143, pp. 229–235, Sep. 2017. doi:10.1016/j.vacuum.2017.06.019

[2] B. Y. Chen, *et al.*, "Modification of TPS arc-cell vacuum system for installation of EPU66", in *Proc. IPAC'24*, Nashville, TN, USA, May 2024, pp. 1572-1574. doi:10.18429/JACoW-IPAC2024-TUPR61

[3] C.K. Chan, *et al.*, "Development of an EPU vacuum system using lumped NEG-ion combination pumps," *Bull. Soc. Vac. Coaters*, vol. 195, p. 110693, Jan. 2022. doi:10.1016/j.vacuum.2021.110693

[4] CST STUDIO SUITE, http://www. cst.com

[5] Chin-Chun Chang, *et al.*, "Development of the nonlinear in-vacuum kicker at Taiwan photon source," *Bull. Soc. Vac. Coaters*, vol. 239, p. 114356, Sep. 2025. doi:10.1016/j.vacuum.2025.114356