

TWO YEAR OPERATIONAL EXPERIENCE WITH THE TPS VACUUM SYSTEM

Y-C Yang[#], C-K Chan, I-C Sheng, I-T Huang, J-Y Chung, and C-C Liang
 National Synchrotron Radiation Research Center (NSRRC), Hsinchu 30076, Taiwan

Abstract

The Taiwan Photon Source (TPS), a 3-GeV third generation synchrotron light source, was commissioned in 2014 December and is now currently operated in top-up mode at 300mA for users. During the past two years, the machine was completed to meet design goals with among others the installation of superconducting cavities (SRF), the installation of insertion devices (ID) and the correction of vacuum chamber structure downstream from the IDs. The design goal of 500mA beam current was achieved with a total accumulated beam dose of more than 1000Ah, resulting in three orders of magnitude reduction of out-gassing. As the beam current was increased, a few vacuum problems were encountered, including vacuum leaks, unexpected pressure bursts, etc. Vacuum related issues including high pressure events, lessons learned and operational experience will be presented and discussed in this paper.

INTRODUCTION

The TPS is a low-emittance, 3-GeV storage ring synchrotron light source with 518.4m circumference. After 3 years of civil construction, accelerator component installation started in October 2013 followed by the commissioning of the booster synchrotron by December 12th, 2014 to fill the first storage ring beam current on December 31 of the same year. During phase I machine commissioning, 100mA beam current was reached limited by the room temperature PETRA cavities and 35Ah of beam dose was accumulated by March 2015. The average base pressure of the storage ring was 2.8×10^{-8} Pa before commissioning and increased to 1.33×10^{-7} Pa with 100mA beam current. Through beam cleaning an out-gassing rate of 1.33×10^{-7} Pa/mA was reached with 35Ah beam dose [1].

Before phase II commissioning, the machine was shut down for a period of six month for machine upgrades, including the replacement of the PETRA cavities with superconducting cavities, SRF, installation of 10 IDs and associated Front End (FE) systems. The design goal of 500mA beam current was archived on December 12th, 2015 and a beam dose of 194Ah was accumulated by then. While commissioning IDs and Beam lines (BL), the TPS became available to users in 300mA top up mode in September 2016 and 1000Ah accumulated beam dose was reached in November 2016. Table 1 lists operational milestones of the TPS in its first two years. As to the vacuum system, few events like vacuum leakage, pressure bursts and malfunction of vacuum components, occurred while regular shut downs allowed efficiency upgrades as

well as correction and optimization of the interlock protection system to be described in more detail below.

Table 1: Milestones for the TPS in its First Two Years of Operation.

Date	milestone
2014.12	first beam stored
2015.03	100mA beam current archived
2015.12	500mA design goal archived
2016.09	open to user
2016.11	1000 Ah beam dose accumulated

VACUUM STATUS

The evolution of beam cleaning in the TPS storage ring is shown in Fig. 1 where the average pressure raise per beam current (dP-avg/I,) versus accumulated beam dose (Ah) is plotted and the logarithmic slope is -0.84. Totally, four vacuum incidences occurred, as shown in Fig. 1. The first incidence was the replacement of PETRA cavities with superconductivity cavities and the installation of ten insertion devices in straight sections. The second occurrence was due to the replacement of a bending chamber located in the 02 arc section, SR02B1, to correct an unexpected pressure raise. The third and last incidence was the upgrade of four bending chambers (SR05B1, SR13B1, SR21B1 and SR23B1) located downstream of insertion devices and of a straight section between two EPU's. The goal was to increase the aperture so that synchrotron light from IDs could pass without striking the chamber wall [2].

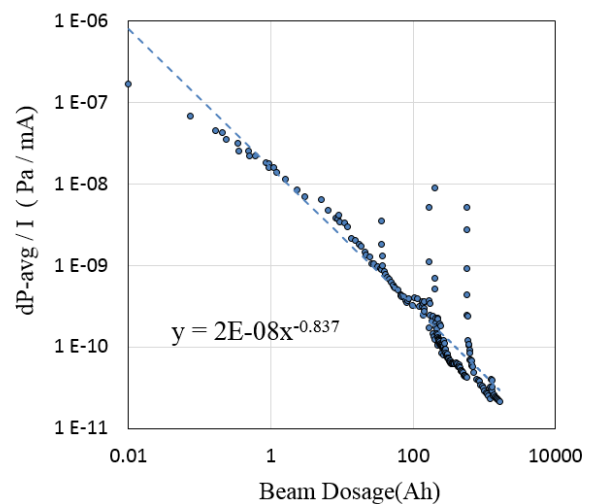


Figure 1: Evolution of beam cleaning.

Based on the design of the TPS vacuum system, more than 70% of synchrotron light was intercepted by crotch absorbers located downstream of bending chambers in the arc section. This explains why the out-gassing dP-avg/I

[#]jolas@nsrrc.org.tw

during the first machine shut down is smaller than later ones. The beam cleaning effect continuously decreased, reaching 2.84×10^{-11} Pa/mA after a beam dose of 1000Ah was reached.

VACUUM EVENTS

Several vacuum events occurred during machine commissioning. The two major ones were described below. On 10 February 2015, the vacuum pressure near the septum chamber in the injection section increased by more than 1×10^{-4} Pa. A leak was found near a welding joint between the vacuum tube and a flange in the septum 1 chamber as shown in Fig. 2. After in-situ repair, the vacuum pressure recovered quickly to less than 1×10^{-7} Pa. Yet, the pressure still increased during beam injection and after the tube was taken out no leak could be detected in the lab with a leakage detector. After re-installation and activating the septum the problem disappeared without a clear reason. We suspect that out-gassing from the gap between two flanges acted like a virtual leak leading to the rise of pressure.

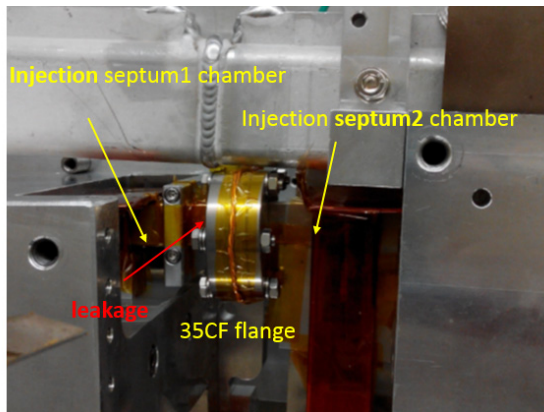


Figure 2: Position of a vacuum leak in the injection section.

After the RF system was upgraded to SRF cavities, the beam current could gradually be increased to meet the 500mA design goal. The first sudden pressure burst, close to 1×10^{-6} Pa, was observed near the SR02B1 region on October 4th, while the beam current was about 190mA. In fact, the normalized dynamic pressure, P/I , increased in the SR02B1 since September 20th, while starting phase II commissioning with more than 100mA beam current. It was not easy to notice, especially in the initial state of commissioning with generally unstable situations. After several leak and temperature checks, no causes were found, but the phenomenon persisted at high current and out-gassing from vacuum components was suspected. First, we replaced the crotch absorber inside the SR02B1 chamber and a photon stopper behind FE02 because they intercepted more than 70% synchrotron radiation from the upstream bending magnet. During the replacement process, the inner aperture of the B1 chamber was checked by endoscopy as well. After replacement, pressure burst still persisted at high beam current operation and the SR02B1 chamber was finally replaced.

A quick, in-situ replacement method was developed [2,3]. It took eight day to replace the chamber and recover to ultra-high vacuum. Inside the removed chamber, foreign matter on the surface along the beam orbit was found as shown in Fig. 3, which explains the pressure behaviour described above. Out-gassing from this matter was caused by image current heating at high beam intensity operation.

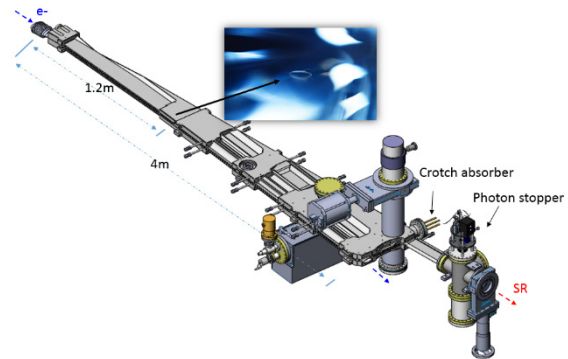


Figure 3: Foreign matter inside the chamber.

After solving this problem, increase of beam current was further pursued with 500mA being the design goal. A maximum of 520 mA was archived on December 12, only 12 days after replacement of the chamber. At 520mA, the average ring pressure increased to 8.6×10^{-8} Pa, whereas in the SR02B1 it was 3.5×10^{-7} Pa due to the new vacuum chamber. Figure 4 illustrates the comparison of normalized dynamic pressure raise in the SR02B1 section, P_{SR02B1} and rest of the storage ring, $P_{average}$. The timeline illustrates: (a) a pressure raise for more than 100mA beam current, (b) replacement of the crotch absorber and photon stopper, (c) replacement of the SR02B1 chamber and (d) operation at 520mA. The ratio P_{SR02B1}/I increased 1.5-15 times for more than 100mA of beam current before replacement of the SR02B1 chamber, whereas the ratio $P_{average}/I$ continued to decrease monotonically and was little affected by P_{SR02B1} .

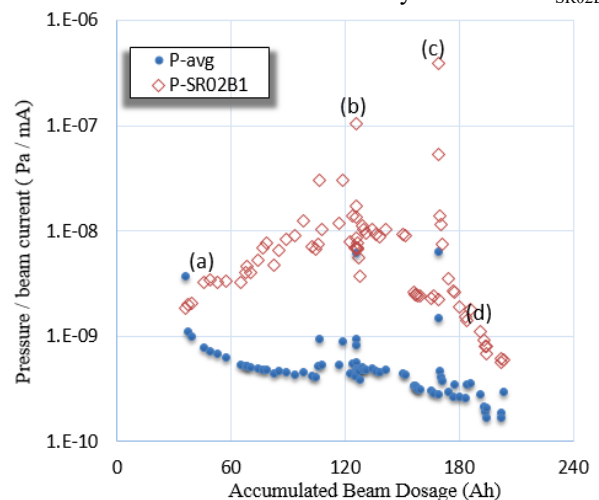


Figure 4: Comparison of the normalized dynamic pressure raise of the P_{SR02B1} and $P_{average}$.

VIBRATION ISSUES

Following design, exhaust pumping systems, including mechanical pumps and turbo molecular pumps (TMP), were used near crotch absorbers to maximize the pumping speed and extend the lifetime of non-evaporable getter pumps (NEG) and sputter ionized pumps (IP) during early commissioning. A 29 Hz vibration was observed in beam position monitors (BPM) and magnets. Turning pumping system on and off, the source of vibration was identified to come from the mechanical pumps [4]. As a consequence all exhaust pumping systems were turned off in March, 2015.

Another source of vibration came from the cooling water in vacuum chambers. The cooling system included two loops: An aluminium (Al) loop for the vacuum chambers and copper (Cu) loop for crotch absorbers and photon stoppers. Originally, the water flow was set to 10 LPM. Because less than 30% synchrotron light from the upstream bending magnet was distributed over the Al chamber wall, a test for cooling water vibrations was considered in arc section 13. From spectral analysis of BPM data, it was found that the power spectral density (PSD) of horizontal orbit oscillations improves 2-3 times under 100Hz when the Al water flow is reduced to 6 LPM, while the vertical orbit oscillations were almost completely eliminated in the range of 40-120Hz. Vacuum pressure and water temperature were not affected during those tests. As a result, the water flow setting of the Al system was reduced to 6 LPM in March 2015, whereas the Cu system retained the original setting to meet the high radiation heat load.

VACUUM INTERLOCK

The basic vacuum interlock design was described earlier [5]. The vacuum pressure protection function, isolating poor vacuum regions by closing up- and downstream sector gate valves (SGV), worked well during commissioning. After the in-vacuum ID installation, the interlock logic was updated to include also the ID vacuum components. The principle is to ensure three ionization gauges between two SGVs used in the pressure protection logic. The storage ring interlock protection logic also monitors vacuum signals from FE. Several times during commissioning, false FE vacuum signals caused interrupts from faulty evaluation of signals from FEs and BLs. Another vacuum signal in the storage ring adjacent to the FE system was added and a trip signal is given only when these two signals fault simultaneously.

The temperature monitoring and interlock system were also optimized, since several times during commissioning a trip signal was sent by malfunction of temperature sensors. Originally, plastic covers for the temperature signal cables were used and the sensor readings were affected by radiation. A few sensors were even damaged as shown in Fig. 5, especially downstream of IDs. These covers were gradually replaced by metal ones.



Figure 5: Temperature sensor cable damage by radiation.

The temperature of bellows and BPM blocks with no cooling water channels in straight sections were affected by image current heating while the beam current gradually increased. In straight sections, the aperture height of BPM blocks is 16mm, relative to 20mm elsewhere and 38mm in the arc. Cooling fans were installed in all straight sections to reduce the effect of heating. The temperature of air cooling in the SR04S2 section and natural cooling in the SR02S2 section of equal design is compared in Fig. 6. A 20°C increase in the SR02S2 bellows with natural cooling was observed at 300mA beam current operation together with a 15% increase in local vacuum pressure.

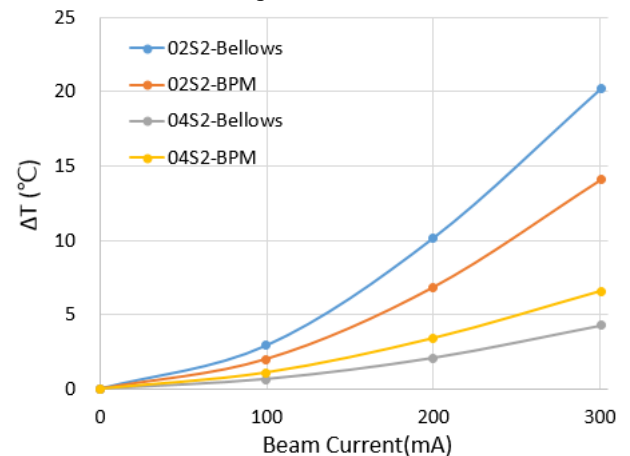


Figure 6: Temperature comparison between air cooling and natural cooling.

CONCLUSIONS

Two years of vacuum operation experience in the TPS has been presented. Good beam cleaning was obtained with continuing decrease as more beam dose is accumulated. Through machine commissioning, the ability of vacuum diagnostics and recovery was established. Interlock protection and monitoring systems were optimized and expanded to meet machine protection requirements.

REFERENCES

- [1] Y. C. Yang, *et al.*, "Behaviour of vacuum pressure in TPS vacuum system", in *Proc. IPAC'15*, Richmond, Virginia, USA, May3-8, 2015, pp. 3222-3224.

- [2] I. C. Sheng, *et al.*, “Chamber upgrade for EPU48 in TPS”, in *Proc. IPAC’16*, Busan, Korea, May 8-13, 2016, pp. 3676-3678.
- [3] C. K. Chan, *et al.*, “Conditioning of the vacuum system of the TPS storage ring with baking in situ”, *Nuclear Instruments and Methods in Physical Research A*, vol. 851, pp. 57-61, 2017.
- [4] C. H. Huang, *et al.*, “Integrating the measuring system of vibration and beam position monitor to study the beam stability”, in *Proc. ICALEPCS2015*, Melbourne, Australia, October 17-23, 2015, pp. 277-280.
- [5] Y. C. Yang, *et al.*, “Development of the TPS Vacuum Interlock and Monitor System”, in *Proc. IPAC’14*, Dresden, Germany, June 15-20, 2014, pp. 2387-2389.