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THE BEAM CLEANING ANALYSIS FOR THE TPS VACUUM SYSTEM

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Abstract

Commissioning for the TPS, a low-emittance 3-GeV synchrotron ring, started in December 2014 and is now currently operating in top-up mode at 400mA for users. Until the last machine shut down in December 2018, a total beam dose of 4919 Ah was accumulated and the beam cleaning effect decreased the dynamic pressure to 1.5×10^{-11} Pa/mA. During past years operation, several vacuum chambers were replaced to improve vacuum performance and avoid exposure to synchrotron radiation from insertion devices. In this paper, the beam cleaning evolution of new vacuum sections will be discussed and compared with experience in the rest of the storage ring. A particular cleaning evolution could be predicted and can be referenced for machine shutdown planning in the future.

INTRODUCTION

The Taiwan Photon Source (TPS), a low-emittance 3-GeV synchrotron ring, was commissioned in December 2014 and is now currently operating in top-up mode at 400mA for users. During past years, two to three regular shut downs per year occurred to upgrade and improve machine performance. In the vacuum system, several problems occurred which can be classified in three groups. The first group includes emergency leakages found in the injection section and feedthroughs of ion pumps. The second group includes unexpected pressure bursts in SR02 and strip line kicker sections. The third group was caused by the replacement or installation of new vacuum components such as insertion devices and vacuum chambers. In total, 18 out of 48 vacuum sections have replaced in the past 4 years.

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 is showing a scaling with an exponent of -0.85. Until the last machine shut down in December 2018, a total beam dose of 4919 Ah was accumulated and the dynamic pressure, dP/I, decreased to 1.5×10^{-11} Pa/mA and to 1.63×10^{-8} Pa with a beam current of 500mA.

An in-situ technology to replace vacuum chambers was developed [1]. Seven bending vacuum chambers were replaced. Except for the vacuum chambers in section SR02 where unexpected pressure bursts occurred and foreign matter was found inside the vacuum chamber, other chambers were replaced to open the aperture to avoid irradiation from upstream insertion devices. After replacement of the vacuum chambers, it was interesting to find out how much bean cleaning time or how much accumulated beam dose was needed to recover original conditions before chamber replacements. In this paper, the vacuum beam cleaning process for new bending sections will be discussed together with beam loss counts near new vacuum chambers.

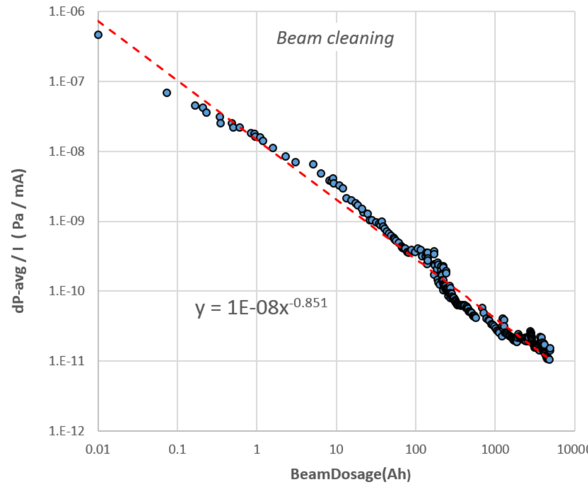

Figure 1: Evolution of the dynamic pressure in the TPS storage ring.

VACUUM PRESSURE ANALYSIS

The local dynamic pressure versus accumulated beam dose for six replaced vacuum sections with different beam commissioning periods are plotted and compared in Fig. 2. Each vacuum section corresponds to separate insertion devices with different power densities inducing different pressure readings. In general, the value of dP/I decreases continuously with accumulated beam dose. The goal of the beam cleaning process is to accumulate a high beam dose as fast as possible to get lower values for dP/I.

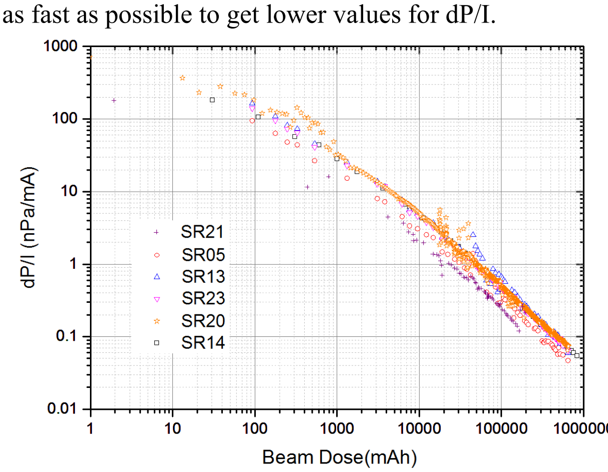

Figure 2: Beam cleaning process for six new vacuum sections.

Table 1 displays a summary of the beam cleaning process in each new vacuum section, including the time duration for the beam cleaning process, accumulated beam

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dose, the value of dP/I at the end of commissioning and the scaling of the fitting curve. The time duration for each commissioning was determined in advance and vacuum cleaning was not the only issue for each commissioning process. The value of dP/I is inversely proportional to the accumulated beam dose and the scaling among all vacuum sections was similar and also similar to the overall pressure evolution in the TPS.

Table 1: Summary of Beam Cleaning for Each New Vacuum Section

Section	Time Duration (hrs)	Beam Dose (mAh)	dP/I (Pa/mA)	Slope
SR21	600	49.15	5.48E-10	-0.75
SR05	667	102.9	3.91E-10	-0.8
SR13	667	102.9	5.99E-10	-0.82
SR23	667	102.9	4.46E-10	-0.84
SR20	635	74.3	7.0E-10	-0.87
SR14	350	75.3	6.5E-10	-0.77

A high accumulated beam dose to get lower values of dP/I during beam commissioning was hoped for, but actual time durations and schedules were irregular. High beam currents were used to accelerate beam cleaning by keeping the highest vacuum pressure below 1×10^{-5} Pa in the new vacuum sections and raise the operational current gradually while setting the interlock to 1×10^{-4} Pa. Higher operational beam currents would accelerate accumulated beam dose to get lower dP/I value.

Another way to decrease dP/I values is to increase the pumping speed. One extra pump was installed near crotch absorbers downstream of the bending chamber in section SR05 to increase the pumping speed. An additional non-evaporable getter (NEG) pump was added to replace the turbo pump originally installed here. The evolution of dP/I of SR14 and SR05 are compared in Fig. 3. Two trend lines in section SR05 were found, which come from bending magnet contributions and a combination of bending and insertion device power. Compared with the same condition for only bending magnet power, the value of dP/I in section SR05 with higher pumping speed, reaches a value of 0.4 nPa/mA after only 75321 mAh beam dose whereas a beam dose of 123506 mAh was needed to get the same value in section SR14. The 48485 mAh beam dose difference was due to the NEG pump, which was equivalent to 120hrs at a beam current of 400mA.

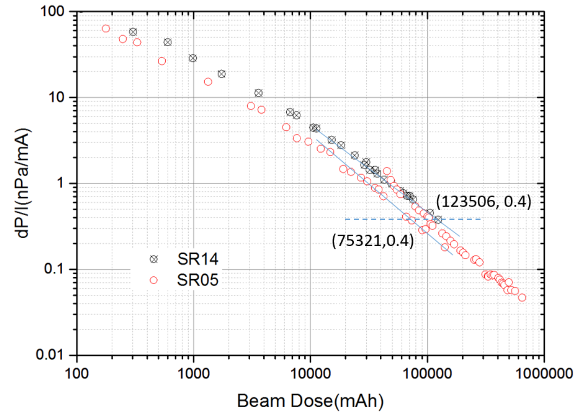

Figure 3: Comparison of dP/I with different pumping speeds.

BEAM LOSS ANALYSIS

We expect that a higher vacuum pressure produces a higher beam loss or higher radiation dose rate. Two types of detectors were used to observe the beam loss distribution and mechanisms during SR14 beam cleaning commissioning. The locations of the beam loss detectors are marked in Fig. 4, where two straight vacuum ducts (S3, S4) and one bending chamber (B1) were replaced, while the B2 chamber stayed the same during the chamber upgrade. Opti-chromic dosimeters (OCDs) and PIN-Diode beam loss monitors (MLMs) are standard detectors used in the TPS machine and in many other facilities.

In section SR14, the vacuum pressure readings with 400mA beam current were 5.46 nPa in S3, 6.20 nPa in B1 and 7.77 nPa in B2 before machine shut down in June 2018. After chamber replacement, the pressures rise to 1684.3 nPa, 7161.6 nPa and 1251.1 nPa with only 60mA beam current at the beginning of beam cleaning and dropped to 151.6 nPa, 371.8 nPa and 61.4 nPa with 400mA beam current at the end of commissioning, which is still 8-60 times larger than under the last normal operation conditions. Until December 2018, before the next machine shutdown, these pressures were recovered to original level with 1225 Ah accumulated beam dose. The whole pressure evolution during beam commissioning is displayed in Fig. 5.

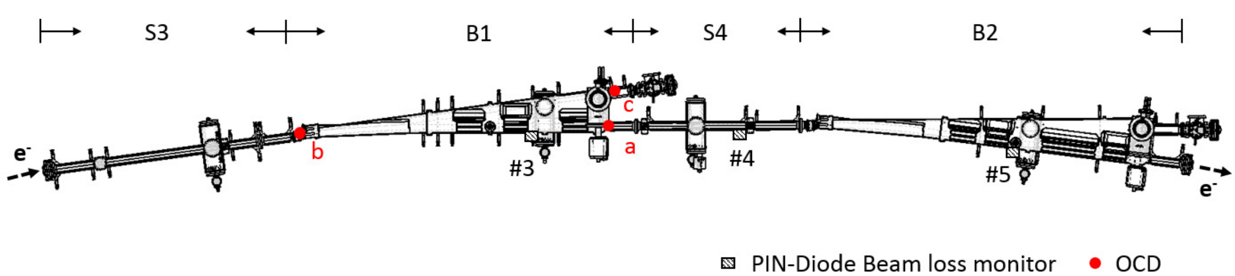

Figure 4: Distribution of beam loss monitors and radiation dosimeters in section SR14.

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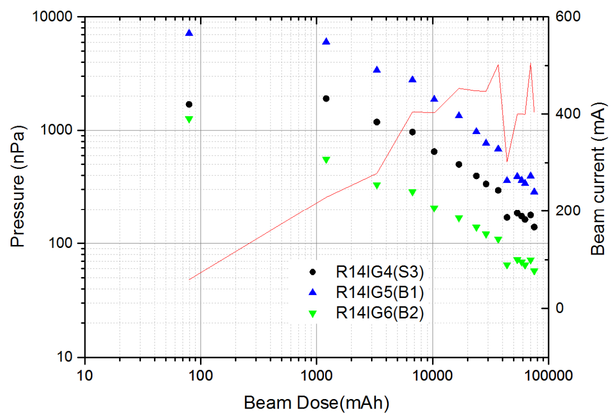

Figure 5: Pressure evolution during beam commissioning in section SR14.

The OCD (FWT-70-40M) is a small dye made of aminotripheny-methane, which has good linearity in the range of 10 Gy to 10 kGy [2]. Three OCDs, mark (b) located upstream and mark (a) and (c) downstream of the B1 chamber, were compared between normal operation and beam commissioning. The distribution of the radiation dose during normal operational conditions shows a higher radiation dose downstream of the bending chamber produced by bending magnet radiation. During beam commissioning, no big differences were found compared to normal operation even though the vacuum pressure was 2-3 orders of magnitude higher. Monthly data were compared and are shown in Fig. 6, where beam commissioning started from July.

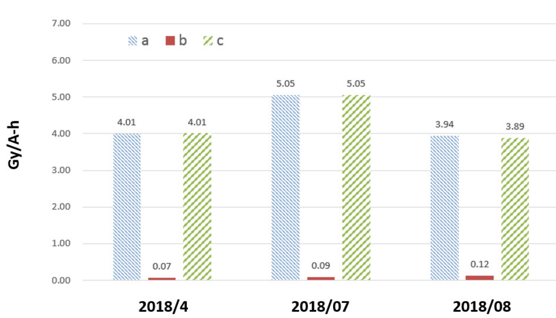

Figure 6: Comparison of OCD dose rates for normal operation and beam commissioning.

Bergoz's PIN-diode beam loss monitors (BLMs), located on inner vacuum chamber walls are also shown Fig. 4. Three monitors, BLM#3 in B1, BLM#4 in S4 and BLM#5 in B2, were compared during beam cleaning. Higher BLM counting rates during machine commissioning was observed, especially in new chambers with elevated vacuum pressures [3]. The high counting rate is due to inelastic Coulomb scattering of electrons with residual gas atoms as detected downstream of the new vacuum sections. This is why the counting rate of the BLM#5 was higher than that of BLM#3 even through the pressure in the B1 vacuum chamber was higher than in the B2 chamber. From the data shown in Fig. 7, the normalized counting rates of BLM #3 and #5 decreased as a result of the vacuum pressure improvement whereas the BLM#4 was saturated due to exposure to bending magnet radiation which was solved by lead shielding.

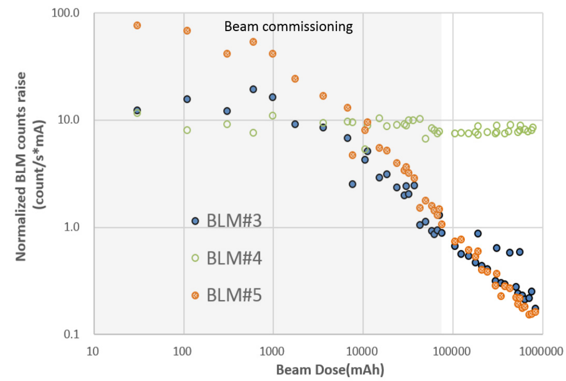

Figure 7: Normalized counting rates of the BLM decreased due to the vacuum pressure improvement.

CONCLUSION

An in-situ chamber replacement technology was developed and implemented. Good repeatability of beam cleaning was obtained especially after 10000 mAh accumulated beam dose. In addition to high beam currents to accelerate beam dose accumulation, adding extra pumps to increase pumping speed can be used to reduce the dynamic pressure. Beam loss monitors were used to study and verify vacuum cleaning. No big difference was found in radiation dosimeters. More data will be collected and compared in the future.

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