

THE EXPERIENCE OF TAIWAN PHOTON SOURCE COMMISSIONING AND OPERATION

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Abstract

TPS commissioning occurred between August 2014 and March 2016. The experience of phase I [1] (bare lattice 2014.8~2015.3) and phase II [2, 3] (SRF and insertion devices 2015.9~2016.3) commissioning will be discussed. The Taiwan Photon Source (TPS) started user operation in March 2016 and delivery of user time reached 3,211 hours in 2016. Continuous improvements of integrated accelerator performance and future developments are described and discussed.

INTRODUCTION

The TPS is a 3 GeV third generation light source. To diminish the difficulty and uncertainty from an extremely tight installation schedule, the TPS commissioning was divided into two phases, i.e., phase I and phase II. In phase I, the main commissioning goal was to store beam, measure beam parameters and pursue vacuum cleaning to become ready for installation of two SRF cavities and gain enough experiences for TPS phase II commissioning. In phase II, 10 insertion devices, two SRF cavities and seven beamlines were installed and commissioned for tests of their performance. In order to ready beamline hutches for experimentations, a liquid nitrogen pipe, as well as beamline end stations were installed, and the regulation radiation dose limit was set to $2\mu\text{Sv}$ per 4 hour interval to guarantee radiation safety for all people in the experimental hall during phase I and phase II beam commissioning.

The TPS started with 150 mA in top-up operation with a 1.3 % relative beam current stability on March 24, 2016. The stored beam was limited by a radiation hot spot in the area of the TPS-09 experimental hutch. After reinforcing radiation shielding in the beam collimator, radiation safety requirements of $2\mu\text{Sv}$ per 4 hours were met. Then the stored beam current was gradually raised to 300 mA on May 26, 2016 in 50 mA increments per week since May 12. In order to minimize the impact of injection transients, we chose 0.66% beam current stability and 4 to 4.5 minutes filling interval while the beam lifetime was 9 to 11 hours [4, 5]. The top-up refilling process is triggered whenever the stored beam current has decayed from 302 mA to 300 mA.

Due to radiation safety regulations, the stored beam current was raised eventually to 500 mA in three stages. The first stage occurred at 300 mA for meeting the existing operation license. Later, when a new operating licence was approved, the maximum current was raised to 400 mA and the final stage was 500 mA. Currently, the

maximum current is set to 400 mA in top-up operation for the time being in 2017.

TPS COMMISSIONING EXPERIENCE

Booster beam commissioning started on August 12, 2014, but got delayed for a week due to a fire in the dipole power supply during AC mode testing. The resistor of the leakage current detector in the booster dipole PS was designed for 100 Ohm without sufficient safety margin, such that it heated up to more than 1000°C and caused nearby circuits to burn during AC mode testing. The resistance of resistor was increased to 1 Mohm and extra cooling fans were added to carry the heat away from the dipole power supply cabinet.

In the first step of booster commissioning it took three months without getting a stored beam at 150 MeV. Several improvements were implemented, including modification of the injection kicker field uniformity and post pulse residual from 2% to 0.4%, re-alignment of the booster vacuum chamber from ± 6 mm to less than ± 1 mm in the vertical plane, improvement of the chamber alignment by installing fixtures at both sides of dipole magnets and quadrupoles to ensure an accurate gap between chamber and magnets. Roughly 30000 turns of injected electron beam could be achieved. Figure 1 shows the radiation dose distribution as measured at every booster dipole to possibly detect the most likely beam loss location.

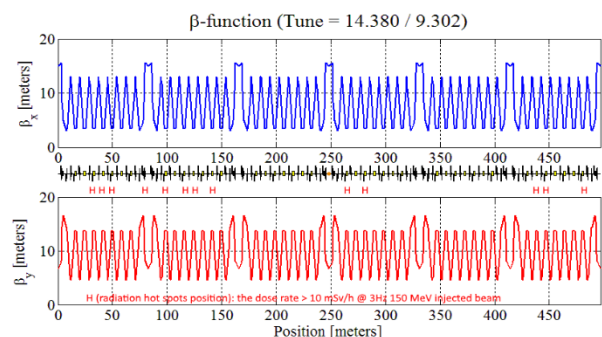


Figure 1: Booster beta functions in DC mode with the red H indicating the distribution of high radiation dose rates (> 10 mSv/h), large horizontal orbit (± 4 mm) was measured. Simulation with distorted magnetic fields indicated that linear optics were severely changed and dynamical aperture was very poor.

The booster vacuum chamber was found to be magnetic by touching the vacuum chamber with strong magnets on November 12, 2014. It took one month to uninstall all

vacuum chambers, to anneal them at 1050 °C for demagnetisation, re-installation and final pump-down. The injected beam survived then 50 ms on December 11, and after turn-on of the RF system stored beam was achieved on December 12. The beam injected at 150 MeV was then successfully accelerated to 3 GeV on December 16 [6].

After replacing several silicon controlled pulser rectifiers for the injection septum, 3 GeV storage ring commissioning started on December 31, and a stored beam could be accumulated up to 5 mA only a few hours later.

In phase I commissioning, the maximum stored beam current reached 100 mA, limited by the maximum safe working power of the ceramic RF-windows for the two 5-cell PETRA cavities. A beam dose of 35 A·hr was accumulated and the vacuum conditions improved well enough to consider replacement of the PETRA cavities with two SRF cavities.

To protect IDs and vacuum chamber from upstream synchrotron radiation due to miss-steering of the electron beam, an orbit interlock is required [7]. Checking orbit interlock criteria, it became clear that the 9 mm internal height of the B1 chamber was too small. Some of the synchrotron radiation from an upstream EPU48 (Elliptical Polarized Undulators) in vertical polarization mode was hitting the chamber and deposited a very high heat load (2.4kW on each side) on the B1 vacuum chamber at 500 mA. Four B1 chambers needed to be modified, and the modifications call for the vertical aperture to be increased from 9 mm to 18 mm. The new chambers have been replaced in Jan. 2016 [8]. The impedance of TPS storage ring was investigated that found the threshold of microwave instability was about 3 mA bunch current [9].

A local abnormal vacuum pressure problem occurred on October 4, when in the storage ring cell 2 the pressure increased exponentially once the stored beam current exceeded 180 mA. A vacuum leak check had been carried out several times before, including a helium leak check even with stored beam and crotch absorber replacement. However, no vacuum leak was found. Following an innovative plan to replace the cell 2 B1 chamber in late November 2015, the chamber was cut and welded in-situ. A PVC pad and a small screw were found inside the B1 chamber. This in-situ replacement successfully demonstrated a well-controlled dust contamination and a state-of-the-art vacuum cleaning approach without requiring bake-out. The stored beam current was raised to 520 mA on December 12, proving the performance of the two RF cavities and two SRF modules fully satisfying fulfil the power expectations for 500 mA stored beam current operation. Meanwhile, we observed a limit for high current operation that was caused by vacuum bursts inside the horizontal stripline kicker due to its large loss factor and a re-designed kicker was installed in January 2017 [10]. We pushed high current operation during the early stages of commissioning to get early signs of problems and giving time to plan for their solutions.

To compensate for linear optics perturbations caused by insertion devices (IDs) we employed orbit feed-

forward tables for all IDs as well as tune and coupling feed-forward tables for three elliptical polarization undulator (EPU). The tune shifts introduced by EPUs are minimized by adjustment of local nearby quadrupole pairs, while the coupling introduced by EPUs is minimized by a pair of nearby skew quadrupoles. Figure 2 shows the horizontal and vertical orbit shifts due to gap changes of seven In-Vacuum Undulators (IVU) from 40 mm to 7 mm with and without feed-forward and FOFB.

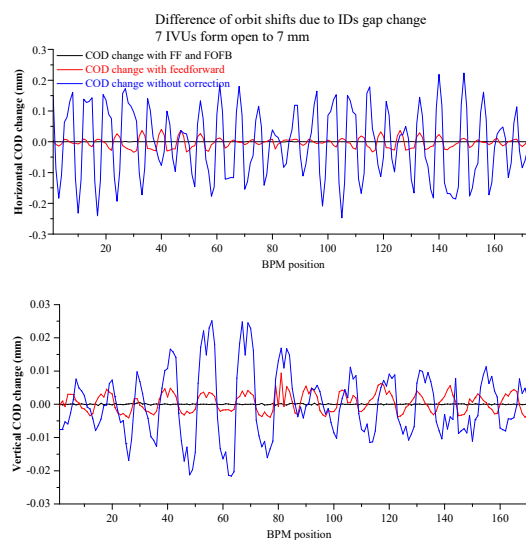


Figure 2: Difference of the orbit shift for 40 mm and 7 mm gaps of seven IVUs with and without feed forward and FOFB.

TPS USER OPERATION

Optimization of the TPS was pursued toward good reliability and high performance for both experimental use and beamline commissioning on March 24, 2016, just seven months after installation of the two SRF cavities and ten insertion devices.

Four standard 7-meter and three 12-meter long straight sections have been assigned to ten insertion devices reducing the six-fold symmetry to a three-fold symmetric lattice. A double minimum β_y (DMB) lattice could preserve the original low emittance design to provide extremely high brilliance and high flux beamlines. The seven IVUs will allow a magnetic gap as small as 7 mm (3 IVUs located in 7-meter straight section have the potential to allow a magnetic gap of only 5 mm), while the two EPUs with 48 mm period length and one EPU with 46 mm period length have variable magnetic gaps down to 13 mm and 14 mm, respectively. The optical functions and horizontal emittance of the electron beam at the insertion device positions determine photon beam sizes and divergences. Lower horizontal emittance can, for example, provide a smaller source size, especially suited for nano-focusing applications.

To achieve top-up operations with sub-micron electron orbit stability (1/10 beam size criteria), requirements of radiation safety must be fulfilled first, followed by completeness of the machine protection system, accelerator

system capabilities and related reliability and finally integrated performance of the accelerator complex.

The electron orbit interlock has been merged with the machine protection system to protect IDs and vacuum chambers from radiation damage caused by miss-steered electron beams, at the cost of a reduction in accelerator availability. Any BPM failure can lead to a false action of the orbit feedback, or faulty BPMs close to IDs can activate the orbit interlock and dump the beam. It is crucial to mitigate false signals from critical components such as SRF modules, in-vacuum undulators and BPMs, by delaying the response time or by reduction of the EMI noise. In this respect, the reliability of accelerator components have been tested and improved during beam commissioning.

There are two filling modes in top-up operation, 650 bucket (75 %) filling and 75 % filling with a 2 mA isolated single bunch in the centre of the beam gap (hybrid mode). In hybrid mode, the bunch current of the single bunch is over 4 times higher than multibunch currents depending on the vertical chromaticity.

The injection efficiency is defined as the ratio of charge increase in the storage ring to the delivered charge from the booster. The injection efficiency gradually improved by matching optics of the transfer line to its design values at the storage ring entrance, fine-tuning of launch conditions and 45 seconds running of the booster extraction pulser power supplies. With these efforts, the injection efficiency is between 80 % and 100 % due to small losses within a bunch train into different buckets.

A number of procedures are now in use or under test to ensure reliable performance of beamlines. A diagnostic beamline, including a visible light synchrotron radiation interferometer and an X-ray pinhole camera, is used to measure the beam size from a bending magnet. The electron beam emittance can be determined from optical functions at the source point and measured beam sizes. The horizontal and vertical emittances are measured to be 1.64 nm·rad and 15.7 pm·rad, respectively, while the emittance coupling ratio is measured to be 0.96 %. This result is in good agreement with the expected natural emittance of 1.6 nm·rad and 1 % coupling ratio. The linear optics of the storage ring is corrected by the widely used algorithm LOCO, “linear optics from closed orbit”.

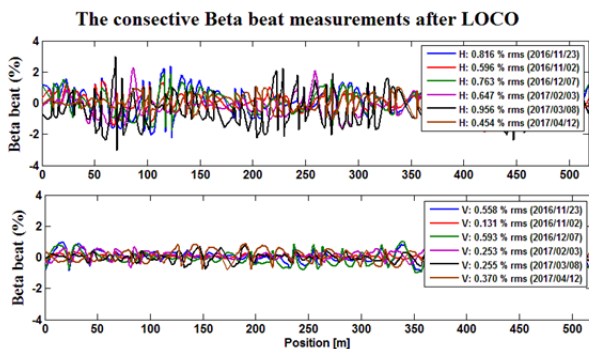


Figure 3: The consecutive beta beat measurements show that the LOCO procedure should be performed every month.

LOCO is used to calibrate the linear optics and to maintain the symmetry of the lattice and working tunes. Figure 3 shows that the LOCO procedure should be performed every month to maintain reliable daily operation.

To understand the performance of the accelerator facility, it is essential to measure three key parameters of machine operation, like user beam availability, Mean Time between Failures (MTBF) and Mean Time to Recovery (MTTR). The scheduled user beam time for TPS was 3351 hours in 2016, and the delivered beam time was 3211 hours resulting in 95.82 % beam availability for the first year of user operation, which just meets a typically expected user beam availability. The MTBF is 52.35 hours, based on a total of 64 faults and 2.15 hours MTTR. Monthly statistics of user operation are shown in Fig. 4.

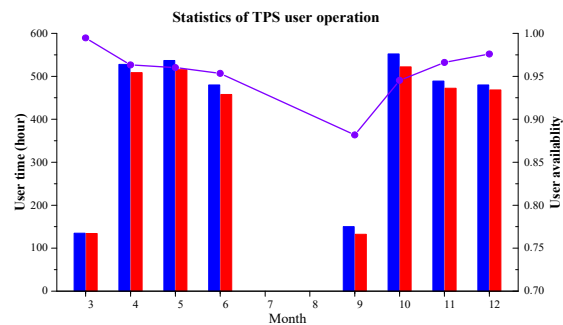


Figure 4: Statistics of monthly user beam availability.

The goal of a failure analysis is to develop an effective preventive maintenance program and to improve subsystem reliability. Any FOFB errors have been counted as downtime during the user period from March 24 to June 28, 2016. There are 17 faults attributed to the RF system, of which four faults were caused by a too tight interlock level in the LLRF which were adjusted during machine studies in September (see Fig. 4). The machine protection system triggered 15 times, telling us that there are still many improvements possible. The six trips, attributed to the I&C system, were caused by malfunctioning of the BPM051 electronics and there are eight trips attributed to other systems, including two earthquakes, two voltage dips, and the four EMI-induced kicker miss-fire events.

DISCUSSION

Incomplete system integration can cause many other problems. For example, a missing demagnetization step in the production of the booster vacuum chamber, foil damage incident of IU22B-09, synchrotron light from a miss-steered electron beam in the upstream IU22A-09, located in the 12-meter long DBM straight section. Many damage incidents can be prevented by more sophisticated quality control. After the foil damage event, we modified the operating procedures from floating target to fixed orbit interlock target, and activate first the orbit interlock before turning on the FOFB. Reducing the injection transients by Mu-metal shielding in the upstream vacuum chamber of the kicker magnet 2 and breaking the circuit for induced eddy currents in the injection section vacuum

chambers, the horizontal and vertical injection transient oscillations could be reduced to 0.5 mm/0.1 mm from 5 mm/0.7 mm peak to peak value, respectively [11]. Every problem that we found during TPS commissioning and operation drives us to improve the performance of TPS, and it can provide higher availability and better beam quality to user operation.

ACKNOWLEDGEMENT

It is a pleasure to thank Professor S. Y. Lee for useful discussions, and Dr. Hitoshi Tanaka and the SPring-8 expert team for useful technical suggestions to reduce injection transients.

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