PROGRESS TOWARDS TOP-UP OPERATION AT SSRF

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Abstract

The Shanghai Synchrotron Radiation Facility (SSRF) has been in operation for user experiments in decay mode since May 2009. In the meantime various activities to prepare top-up operation at SSRF, including safety analysis and simulation, dedicated instrumentations and interlocks, control software, radiation measurements, injection optimization and top-up operation tests, have been carried out. In this paper, the progress towards top-up operation at SSRF is described together with its achieved performance.

INTRODUCTION

The Shanghai Synchrotron Radiation Facility (SSRF) is a third generation light source. It consists of a 150 MeV electron linac, a full energy booster, a 3.5 GeV storage ring with circumference of 432m, and first seven beamlines (phase-I). Since the start of user experiment operation in May 2009, the SSRF has been operating in decay mode, where the beam is injected twice a day [1]. The top-up operation at SSRF was considered from its design phase, when the linac and booster performance was optimized to meet the specific requirements of the injector machines, including the high beam injection and transport efficiency from the linac, LTB transport line, booster and BTS transport line to the storage ring, the reasonable injector emittance and bunch charge. And the storage ring was also purposely optimized to meet its top up requirements by minimizing the orbit disturbance of the stored beam during beam injection. To obtain a high efficient injection, the 2998MHz linac with sub-harmonic buncher is employed for a harmonic frequency relation with the RF frequency of booster and storage ring, and the 12m long straight section was designed in the storage ring to accommodate all the injection elements.

The top-up injection with photon beam shutter closed was tested at SSRF during storage ring commissioning and machine studies [1, 2], storage ring performance including the injection efficiency and orbit disturbance of stored beam was investigated and optimized. With the interlocks, the radiation dose was measured at hutches and experimental hall when photon beam shutters are open, and the top-up operation was tested at SSRF with in-house user experiments simultaneously performing at all 7 beamlines. During the top-up test operation, the injection interval is set to 10 min, and 30 bunches with the smallest charges in 500 bunch train are refilled with about 0.08nC each in one injection cycle.

SAFETY ANALYSIS AND SIMULATION

One of the biggest differences between the decay mode and the top-up mode is the status of the photon shutters. In the former case, the shutters must be closed during the beam injection, on the contrary, it should be allowed to keep open for the top-up injection mode. In this case, safety problems, especially personal safety, becomes the first critical issue, i.e. how to prevent the users and the beamline staffs from an extra radiation dose or how to avoid electron beam escaping from the storage ring tunnel through photon beamline pipe.

It is obvious that if a bend magnet after a straight section is shorted, an injected beam will pass through the insertion device (ID) photon beam line and create a radiation hazard. The question is which case is dangerous and how to avoid it by the interlock system.

The simulation is done by using Accelerator Toolbox (AT) [3]. The combination of mis-steering of all the magnets can be enormous and could never be exhaustive. The forward-tracking method here is similar to SPEAR3[4]. The initial particles are starting from the straight section before the photon beam line. Any particles that could pass through the straight section are included as effective particles for the tracking. In this way, the mis-steering of the rest of the magnets can be ignored which strongly reduce the tracking time while covers all the combinations of the rest magnets faults. Figure 1 demonstrates beam line setting for the ID beam line safety simulation and Figure 2 is the tracking result for bend magnet short circuit. Summary of the tracking results for the safety region of the magnets is shown in Table 1 which will be used for the interlock setting. In all cases, the closed orbit does not exist when electrons reach safety shutters.

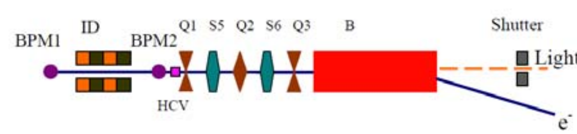

Figure 1: Beam line setting for ID beam line.

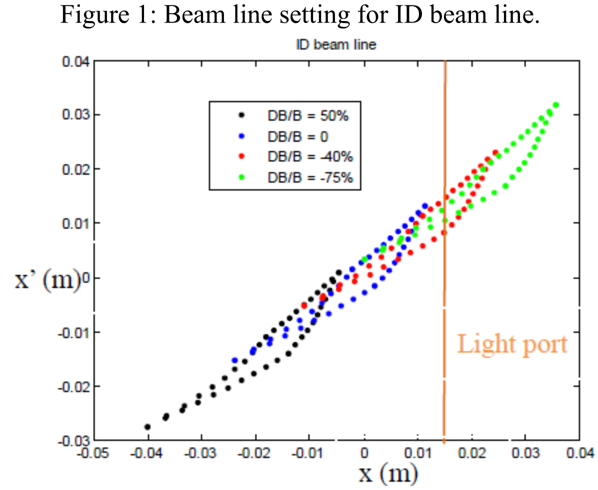

Figure 2: Track result for bend magnet short (Particles on the left side of the light port is considered as safety).

Table 1: Interlock specification for injected beam energy and magnet current. (- means no restriction)

	ID beamline		*Bend beamline*	
	Max	Min	Max	Min
Energy	+5%	-	+5%	-1%
Bend	+5%	-8%	+5%	-3%
Q1	-	-15%	+30%	-5%
Q2	+3%	-15%	+3%	-12%
Q3	-	-15%	+15%	-15%
Q4	-	-	-	-30%
Q5	-	-	+5%	-
S5	-	-40%	+50%	-
S6	+50%	-	-	-40%
SD	-	-	+30%	-
SF	-	-	-	-20%
HVC	1.5mrad	-	1.5mrad	-1.5mrad

INTERLOCK AND CONTROL SOFTWARE

The Top-up interlock system includes power supply interlocks on specific storage ring and BTS power supplies, stored current interlock, storage ring injection efficiency interlock, beam lifetime interlock, radiation doses interlock etc. All interlock functions carry out within existed MPS (Machine Protection System). A special control rack is used to control operation mode conversion. If the conditions for top-up mode are not met, logical control system consists of a PLC controller will convert the operation mode from top-up to decay.

The interlock logic diagram is shown in figure 3.

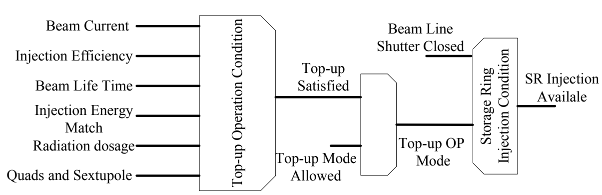

Figure 3: Top-up operation interlock logic diagram.

At present, the injection is controlled by the software written in MATLAB. The program continually monitors the progress of top-up from MPS, and will terminate top-up injection by interrupting the trigger to the linac electron gun if top-up conditions are not satisfied. Top-up injection condition includes the following aspects: (1) The top-up key has been inserted in the key panel. (2) The stored beam current in storage ring should be in excess of 100mA. (3) The BTS dipoles are at the nominal current ±5%. (4) The storage ring dipoles are at nominal current ±3%. (5) The beam life time of storage ring should be larger than 10 hours. (6) The transfer efficiency from BTS to storage ring should be better than 80%. (7) The storage ring quadrupoles are at nominal current ±3% for Q2 and ±5% for others respectively. (8) The storage ring sextupoles are at nominal current ±20%. (9) The radiation doses detected by any of the monitors are less than pre-determined value. The top-up injection control panel interface is shown in Figure 4.

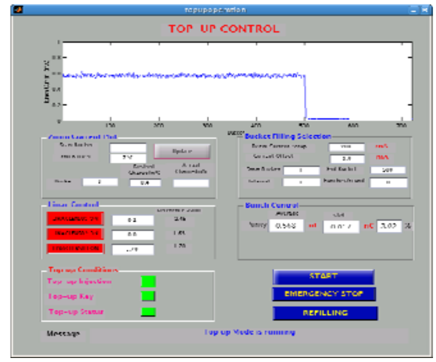

Figure 4: Top-up injection control interface.

TOP-UP COMMISSIONING

The top up injection beam commissioning began in early 2008. Recently, some optimization works have been done. Perturbation of the stored beam by the inject kickers is optimized by scanning the kickers' current and kicker tilt mechanical adjustment. The perturbation amplitude in both planes is reduced to about 50μm. Figure 5 shows the turn-by-turn data recorded by a BPM 12 meters downstream of the kicker after inject.

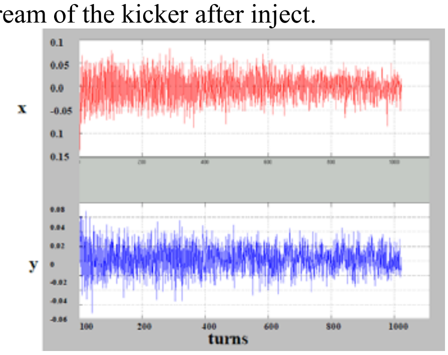

Figure 5: BPM turn-by-turn data after injection.

The beam lifetime is limited by a vertical collimator downstream of the injection kicker with the gap of 4.6mm to protect the in-vacuum undulators from the injected beams[5]. The beam lifetime is typically about 20 hours@200mA for the top-up mode. Injection occurs once every 10 minute at 200mA for a 500 bunch train, which means refilling current is 1.7mA. It is assigned to 30 shoots. Figure 6 shows beam current of the top-up operation. Figure 7 shows bunch filling status from begin to about 3 hours later top-up injection, bunch uniformity reaches about 5%.

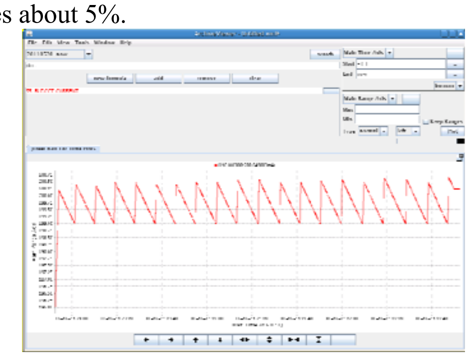

Figure 6: Beam current for top-up injection.

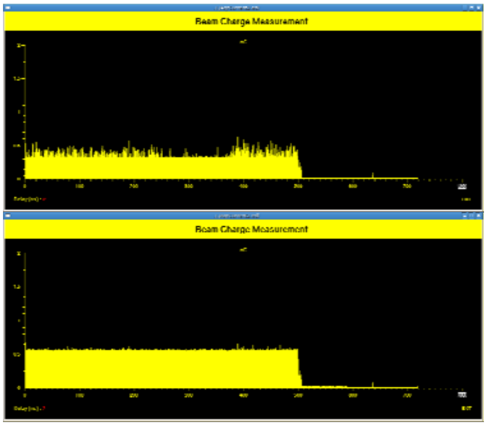

Figure 7: Bunch filling status (up, at the beginning, below, 3 hours later top-up injection).

Increase injection efficiency from the booster to the storage ring is important to the radiation dose control. The optimize work has been done for the booster to storage ring (BTS) transfer line and injection septum and kicker. The inject efficiency is beyond 95% measured by the DCCT in the booster and storage ring.

The orbit stability is improved from 10microns to 2microns in horizontal plane and 2microns to 1micron in vertical plane (Data from 10 BPMs at the ends of IDs in 60hours test). The improvement is majorly from relaxation of BPM current dependency. Figure 8 shows the horizontal orbit drift during the test running while slow orbit feedback system is in operation.

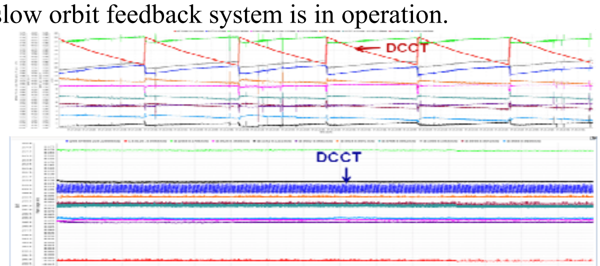

Figure 8: BPM records horizontal orbit drift for decay (up) and top-up (below) operation.

Dose measurements have been done with the beam lines shutters open. The results show that 4-hour period integrated dose is about 0.4μSv which is well under dose limitation. And instantaneous dose rate has also been detected continuously for the alarm and interlock system. The top-up operation mode will be interrupted if any of dose monitors exceed pre-determined value.

TOP-UP OPERATION

In July 2011, SSRF was operated top-up injection mode with existed 7 beam lines experiments. All the 7 beam lines experiment reported that the influence of injection process on experiment can be neglected or be acceptable. And all of the merits of top-up injection have been represented.

For examples, BL08U is a soft X-ray micro-spectroscopy beamline with EPU insert device. The intensity fluctuation measured at the experimental station reduced to 0.8% from 3% of the first top-up operation model. The quality of picture scanning became better with the improvement of the top-up model operation, as shown in Figure 9.

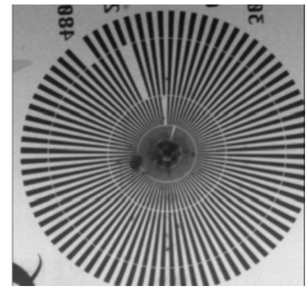

Figure 9: The image result of BL08U.

BL13W is a hard X-ray medical imaging beamline from the Wiggler insert device light source. The experimental results shown that the imaging quality of SR-μCT of the same sample are not different from top-up and normal injection operations. The imaging time is decreased greatly because of the high constant beam intensity.

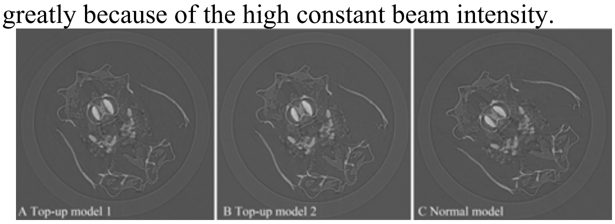

Figure 10: The reconstruction results of SR-Mct.

The experimental results from the other five beamlines all showed the experimental feasibility of the Top-up operations. In summary under the current condition the 7 beamlines can all be carried out for the normally data collecting of the experiments.

CONCLUSION

Safety simulation and beam commissioning studies on top-up operation at SSRF have been done in order to guarantee any cases electrons cannot transmitted down to an open photon beam line while stored electron beam is existed. All interlock functions work properly for top-up injection. Reports from the test experiment show that the disturbance on photon beam from injection process can be accepted. SSRF will commence the top-up operation for user experiments officially when the safety license is obtained from governmental agency.

REFERENCES

[1] Z.T. Zhao H.J. Xu and H.Ding, "Commissioning of the Shanghai Light Source", PAC09, Vancouver, May. 4-8, 2009.
[2] H.H. Li, M.Z. Zhang, and et al, "Study of Top-up Operation at SSRF", IPAC10, Kyoto, May. 23-28, 2010.
[3] A. Terebilo, SLAC-PUB-8732, May 2001
[4] A. Terebilo, et al. SSRL-ACC-PHYS NOTE-009
[5] Z.T. Zhao, H.J. Xu, Proceedings of IPAC'10, Kyoto, Japan. 2421-2423.