The Realization of Top-up Injection

Top-up injection is an operation mode in which the beam current in the storage ring is maintained above certain level by frequent injections. The routine current stability is in the range of 10^{-3} to 10^{-4} for long period of operation. The top-up injection provides much more flexibility in operation, such as lower emittances, higher currents, smaller coupling, smaller ID gaps, exotic bunch filling patterns, and higher bunch charge. It compensates short lifetimes that result from small vacuum gaps for insertion devices or Touschek dominated high intensity or brightness beams. It also provides constant thermal loading on all components in the storage ring and the optics components of beamlines, as well a constant signal to the beam position monitors.

During top-up injection, the heavy metal shutter of every beamline in the storage ring is left open. Hence, special instrumentation and injection system such as kickers, septum and pulsers are required to operate with greater stability. Top-up injection also requires state-of-the-art systems and reliability for e-gun, modulators, linac, booster and beam transfer line. Depending on the lifetime, the injection disturbs the beam orbit during a certain time interval in every few minutes. Some users' experiments conducted at the beamline need a signal, typically of several msec, to gate out the disturbance during the injection time. To meet safety requirements, special interlocks shall be the installed to protect personnel and systems, e.g., no injection without a stored beam (a stored beam implies that the magnets are powered and therefore it is impossible to channel the injected beam down a beamline directly).

In recent years, both the Advanced Photon Source in the United States and the Swiss Light Source in Switzerland have demonstrated very successfully the top-up mode in partial- or full-time operation. Several top-up experimental tests were also carried out at various stages of Taiwan Light Source's (TLS) upgrade path. However, many obstacles prevent the realization of top-up injection in a routine fashion. Only in the last one and half years, a series of beam parameters measurement, subsystem checkout, installing of various sensors, control program modification, and hardware upgrade have made the top-up injection a feasible option in routine operation.

The requirement of lower emittance, small gap insertion device, and doubling of the stored beam current have made our machine physicists re-evaluate the feasibility of top-up operation at NSRRC. In normal operation before 2003, the injection working point was different from the user's working point at TLS. The cycling between injection and user's working points can ameliorate the magnets' hysteresis effect with very good and reproducible operation condition. A purifying process, which included re-establishing the ID operation tables, optimising the orbit, re-adjusting the injection parameters, and optimising chromaticity, of the injection working point was carried out to make sure that the injection working point qualified the user's operation condition without hitting any serious resonance lines. Fortunately, the injection working point can be optimised to satisfy the users' requirement with very good beam quality.

Two modes of top-up injection, fixed current bin and fixed time interval, were evaluated. The choice of stored beam current bin as the key parameter means that the system will trigger injection when the stored current is lower than a specified value. The injection will stop when the stored current is higher than a specified value. In order to reduce interference to the user's data acquisition process, the fixed time interval mode was chosen for the top-up injection. Figure 1 shows two user's shifts with decay mode and one top-up injection mode during machine-study. A zoom-in of

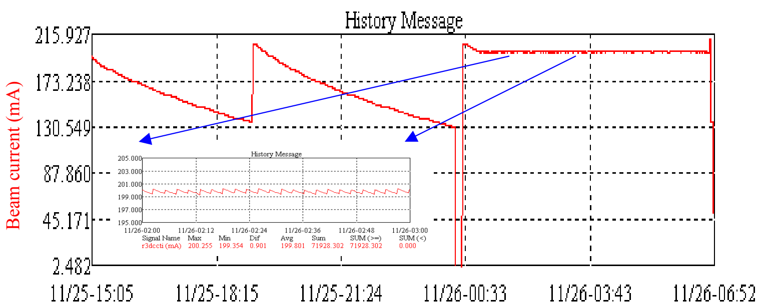

***Fig. 1:** Stored beam current in decay mode and top-up injection mode and zoom-in the beam current during the top-up injection.*

the stored beam current in top-up mode is shown also in Fig. 1. During the test, the time interval between two injections was set to 2 minutes. The maximum stored beam current was limited to 200 mA. The recorded current bin is ~0.6 mA. One of the key factors that affect the beam lifetime is the bunch distribution pattern or the filling pattern in a storage ring. From simulation, we understand that horizontal acceptance of the ring, launching position/angle, and timing jitters of injection components are the key parameters that affect the injection efficiency and filling pattern. The combination of a revised injection-buckets control-program, constant bunch pattern from booster, optimisation of injection parameters, and fine-tune of injection working point made the filling pattern very reproducible.

Top-up injection helps orbit control and also stabilize the launching condition of photons from the source. Figure 2 shows the structure displacement of Beam Position Monitor (BPM) relative to the ground. In the decay mode, the stored beam current decayed from 200 mA to 130 mA in one user shift, the structure displacement of BPM can be as large as 15μm in the horizontal direction and 5μm in the vertical direction. In the top-up injection mode the displacement of the BPM relative to the ground can be reduced to within sub-micrometer range as shown in Fig. 2. Since the BPMs were used in the global orbit feedback system, their structure displacements will translate to beam movement. Hence, the source point will change with the thermal effect and beam current. In top-up injection, the quasi-constant beam current eliminates the thermal and current-dependent effects when reading the BPMs. The source point is locked to fixed position and angle, and this will improve the performance of those beamlines that place high demands on photon energy stability.

A pair of vertical scrapers was used to measure the minimum aperture available to the injection clearance and vacuum chamber of insertion devices. Two pairs of scrapers, one in horizontal and the other in vertical direction, were installed in the RF section. In Fig. 3, the black dots are the normalized beam lifetime as a function of the scraper position in vertical direction, and are fitted in Gaussian as shown by the red line. From the fitting curve, we found that the relative offset between scraper centre and beam centre was 0.88 mm, and the minimum gap of chamber should be made larger than 10.4 mm to avoid interfering with beam lifetime. The blue dots represent the normalized injection efficiency as a function of scraper position. The estimated injection clearance in the vertical direction should be 10~15% larger than the minimum clearance of beam lifetime in order not to jam the injection efficiency. The injection clearance will ensure minimum beam loss at the straight section during top-up mode.

A 140 keV E-Gun, 50 MeV Linac, and 1.5 GeV booster make up the injector at TLS. The injector injects the beam into storage ring at 10 Hz rate by a resonated white-circuit. If we run the injector continuously, the temperature of dipole magnets will raise at a rate of ~1.5 °C/hour due to the eddy current of rapid cycling. The temperature of in-vacuum extraction septum will also increase at a rate of ~2 °C/hour due to the cycling and the very limited cooling capability. In order to compensate the thermal effect, the current settings of dipoles magnets and septum need to be adjusted continuously. Otherwise, the available beam current to

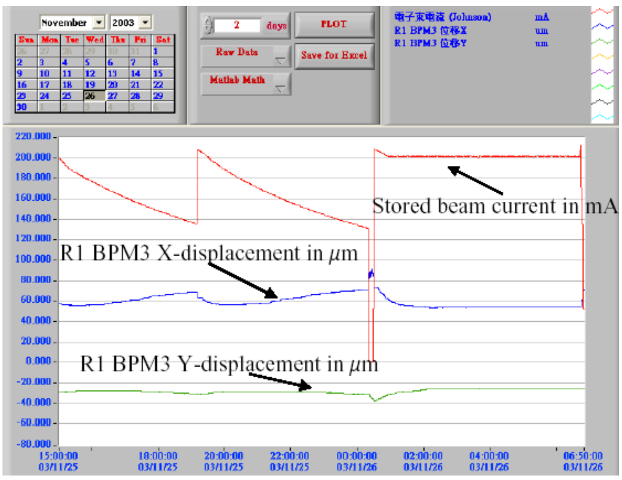

***Fig. 2:** Recorded structure displacement in vertical and horizontal direction of BPM during decay and top-up injection mode.*

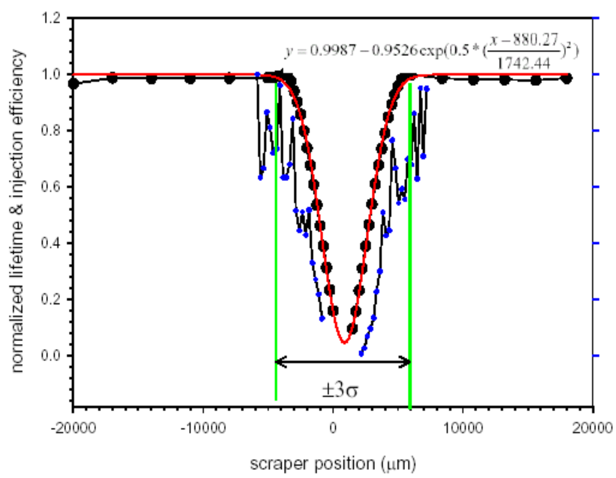

***Fig. 3:** Vertical scrapers were used to identify the minimum clearance of the ring without affecting the beam lifetime and the injection efficiency.*

storage ring will drop significantly at a fast rate. An intermittence operation mode, which will turn on the power supplies and pulsers 30 seconds before injection and turn them off after injection, was programmed. The intermittence operation mode of injector could stabilize the operation temperature of dipole magnets and extraction septum. The setting compensation of magnets' current, due to the thermal effect, thus can be avoided. Figure 4 shows the temperatures of dipole magnet and septum core under the new top-up control program applied to the injector. The temperatures of dipole magnet and septum core reached saturation after three hours operation of the injector.

It is utmost important to keep the experimental area as a non-radiation working environment. The shielding wall will be enhanced along the storage ring, especially at the injection section. The basic parameters of shielding wall were designed according to the design handbook at 1.3 GeV and 400 mA stored beam current in storage ring. Now the shielding wall will be upgraded for the operation of 1.5 GeV and 500 mA. The measurement results of the radiation dosage along the wall of bending magnet beamline and injection straight section beamline are shown in Fig. 5. As seen in the measured data, the beamline port from bending magnet has adequate shielding. However, due to smaller gap and higher integration vacuum pressure in the straight section, the exclusion zone of beamline ports from insertion device will be extended outward and become closer to the end station in order to keep the radiation dosage in the controllable range. Additional radiation safety interlock system will be implemented, and will abort the injection if accumulated dosage or injection period exceeds specified value.

In summary, to improve the thermal relaxing problem during the energy ramping era at TLS, the injector was upgraded to have the capability of full energy injection to the storage ring. This provides a chance to evaluate the feasibility of top-up injection at TLS. The installation of SRF cavity enables the ring to provide more photon flux with better beam quality to the users. In order to reach the ultimate goal of third generation light source, TLS has prepared all the necessary steps to provide top-up operation mode to the users. The top-up injection mode will provide the best solution to the thermal effects of beamlines' optical components, and locked the launching condition of the synchrotron light to users. This will greatly benefits those superconducting wiggler x-ray beamlines which have large thermal load on the optical components and take relatively long time to reach thermal equilibrium. In addition, these beamlines generally have high demands on the photon energy stability after the monochromator, and top-up injection mode offers the best solution to the limited beam lifetime of a storage ring. Top-up injection also opens new opportunities in probing better operation conditions, for example, the lower emittance, the lower gap of insertion device, and the increase of bunch current without the need to worry the impact of beam lifetime.

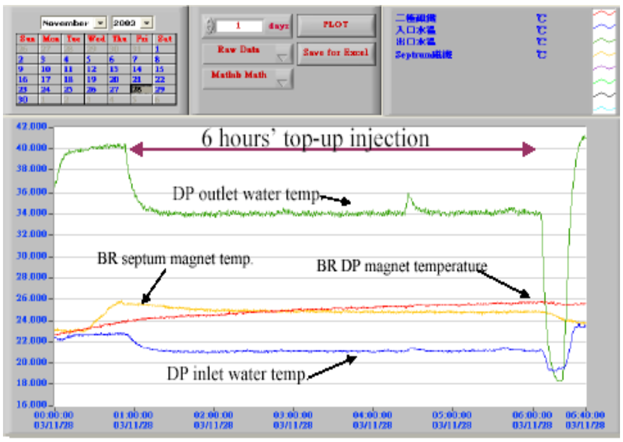

Fig. 4: The temperature readings of dipole magnet and septum core under intermittence operation mode of injector at TLS.

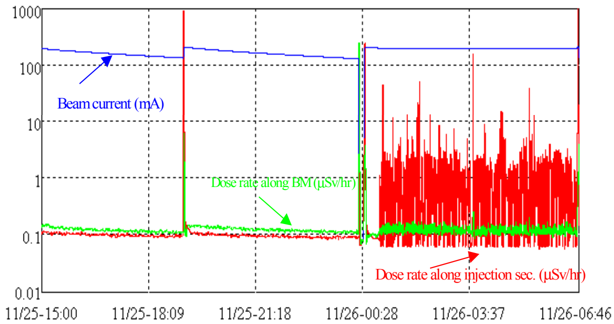

Fig. 5: Stored beam current and dose rate at shielding walls outside of injection section and bending magnet during decay and top-up injection modes.

AUTHOR
G.-H. Luo
National Synchrotron Radiation Research Center, Hsinchu, Taiwan

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CONTACT E-MAIL
luo@nsrrc.org.tw