DIAGNOSTIC AND TIMING SUPPORTS FOR TOP-UP INJECTION OPERATION FOR THE TLS

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Abstract

Routine top-up operation of Taiwan Light Source (TLS) was to commence from October 2005 after high efficiency multi-bunch instabilities suppression system put into service. Long-term 360 mA top-up operation has been tested and proven its successful and steady performance. Short-term 400 mA top-up run is also demonstrated. The TLS is current operated at 300 mA top-up mode to compromise various requirements of users at this moment. Higher current is possible in future. To support the top-up operation, various diagnostics and timing control are needed. These include diagnostics for injection efficiency, filling pattern of the storage ring, tune, instability, loss pattern measurement. Timing control of the injection process is also necessary. Further possible improvement will be also discussed.

INTRODUCTION

The accelerator system at the Taiwan Light Source (TLS) consists of a 140 keV thermionic gun, a 50 MeV linear accelerator (LINAC), a linac-to-booster (LTB) transport line, a 1.5 GeV booster synchrotron, a 70 m long booster-to-storage ring (BTS) transport line and a 1.5 GeV storage ring. The goals of the top-up mode operation are to provide high stability and highly integrated flux photon beam and to keep the heat load of the optical components constant. A complete diagnostics of the accelerator system is required for routine monitoring and machine debugging, to support the requirements of top-up mode operation. It includes charge, transmission of transport line, current, injection efficiency, orbit stability, electron loss, profiles, tune and instability and others. Table 1 summarizes these diagnostics. Timing control is also important for top-up injection to ensure better stored beam current stability.

DIAGNOSTICS FOR TOPUP OPERATION

LINAC and LTB Diagnostics

Diagnostic devices of the LINAC include several toroids, three fast gap monitors, and a screen monitor near the exit of LTB. These diagnostic devices can measure beam current, beam profile, energy and energy spread. A 60^{o} bending magnet is adopted to bend the output of LINAC. An energy defining slit is located just in front of the last toroid to define the energy. Integrating the current waveform of this toroid monitor obtain the beam charge of the LINAC output. The energy and energy spectrum can be measured by scanning the bending angle of the bending magnet. A screen monitor is added behind the bending magnet, to measure the emittance of the LINAC by the quad-scan method when this bending magnet is turned off.

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Table 1: Diagnostics to support top-up operation

Accelerator system	Parameters should be monitor	Descriptions
Linac	Transmission	Toroid, gap monitor, oscilloscope
	Charge	Toroid and charge integrator
Booster Synchrotron	Averaged beam current	MPCT
	Filling pattern	FCT, BPM with oscilloscope
BTS	Transmission	ICT and charge integrator
	Beam position	BPM
	Position, transverse profile	Screen monitor
Storage Ring	Averaged beam current	MPCT with 1 μA resolution
	Injection efficiency	$\Delta I_{avr,SR}*t_{rev,SR}/C_{ICT,BTS}$ per injection shot
	Filling pattern	BPM with oscilloscope
	Isolated bunch purity	Time Correlated Single Photon Counting system – in planning

Note: $\Delta I_{avr,sr}$ is increment of beam current per injection shot, $t_{rev,SR}$ is the revolution period of the storage ring, $C_{ICT,\ BTS}$ is the beam charge pass the BTS per injection shot.

Booster Synchrotron Diagnostics

The booster synchrotron diagnostic consists of seven sets of screen monitors, MPCT, FCT, BPMs, and a synchrotron radiation monitor. The measured parameters include beam current, closed orbit, tune and beam profile. The averaged beam current is measured by the MPCT. The filling pattern is measured by the FCT. The synchrotron radiation monitor is upgraded using an IEEE-1394 camera with an external trigger and exposure time control functions. Several approaches have been applied during the last decade for tune measurement. Figure 1 displays the sun signal and the Fourier analysis of the turn-by-turn beam position data captured by a Libera Electron.

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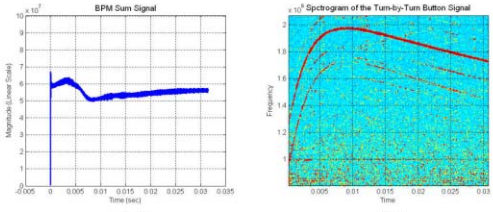


(a) (b)

Figure 1: (a) Beam intensity of the booster synchrotron; (b) tune variation during energy ramping.

BTS Diagnostics

Beam intensity, charge, trajectory and beam profile should be monitored routinely during top-up operation. The diagnostic devices of BTS consist of the FCT, ICT, BPMs and screen monitor. Bergoz's FCT and ICT are used to measure intensity and charge. Trajectory is measured using Bergoz's LR-BPM. Figure 2 plots the signal output of the Bergoz's charge integrator respective to the reference timing. In Fig. 3 shows the ICT located nearby the injection kicker suffered from kicker noise before the beam arrives during injection. This caused problem of the charge integrator needs further study to eliminate. The kicker fired noise from injection kickers interferes with the baseline of the ICT3 as shown in Fig. 2. The ICT2 is located in the middle of BTS and in the vertical bend. The charge measured by this monitor is accompanied with a current increment per injection at the storage ring measured by DCCT, enabling the injection efficiency of the storage ring to be computed.

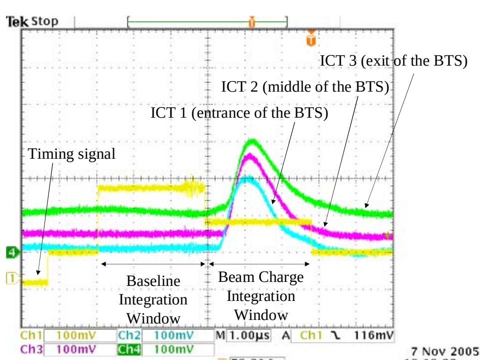


Figure 2: Signal output of the charge amplifier respectively to the timing signal of charge integrator.

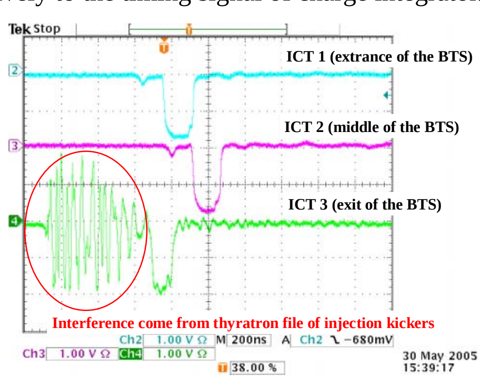


Figure 3: The ICT3 signal suffers the interference during injection kickers fired.

Storage Ring Diagnostics

The performance and functionality of the diagnostic system have been improved during the last decade. A part of the BPM electronics will be replaced by new generation of digital BPM electronics and are being in their final integration phase to enhance functionalities. The synchrotron radiation monitor has been upgraded to include an IEEE-1394 digital camera, which improves in the dynamic range and linearity of profile measurement. The measurement parameters of the storage ring diagnostic system include closed orbit, beam current, tune, filling pattern, bunch current, beam loss, beam profile, emittance and beam energy. Several diagnostics are particularly essential to the top-up operation and are addressed below.

The injection efficiency is relevant to the increase of beam charge, measured by the DCCT of the storage ring, divided by the charge measured by the ICT2 of the BTS at the same injection cycle. Figure 4 plots the typical injection efficiency during top-up injection. An injection efficiency of over 70% is routinely achieved.

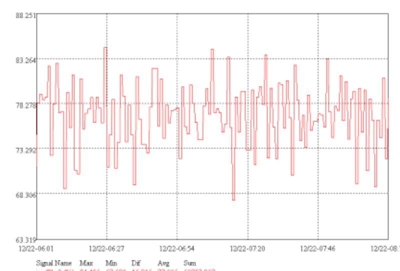
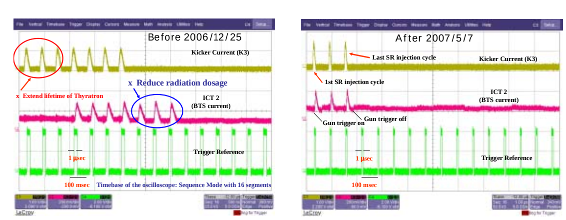


Figure 4: Injection efficiency during top-up mode operation.

Timing for the top-up injection is important. Control system delay and timing scheme causing extra operation cycle of electron gun and injection kicker of the storage ring is shown in Fig. 5 (a). Extra radiation and shorter lifetime of the thyratron tube of the pulser for injection kicker are the undesirable results. After upgrade of the linear accelerator control system in May 2007, precision control of the top-up injection was achieved as shown in Fig. 5 (b). These waveforms were captured by the segmented trigger mode of the oscilloscope, segmented trigger provide an elegant tool to observe a short pulser with low repetition rate. High time resolution and long observation time are essential in this case.



(a) Before upgrade (b) After upgrade

Figure 5: Typical injection timing before and after upgrade of control system an timing of the linear accelerator during the top-up mode operation.

The filling pattern of the storage ring drastically affects the operation performance [1-4]. Moderate control of the filling pattern is desirable. A dedicated filling pattern measurement system was set up to satisfy the bunch current measurement requirements and possible filling pattern control in the future. The sum signal of BPM buttons is digitized by an Agilent 54832D 1 GHz oscilloscope, operated in equivalent sampling mode. The filling pattern server computer is connected to this oscilloscope via an Agilent E5810A IEEE-488 to LAN server. The ring clock triggers the oscilloscope. Analysis of the captured waveform can extract the relative bunch intensities of all bunches. The raw bunch intensity data normalized by the precision averaged beam current reading from DCCT is then obtained to calculate bunch-by-bunch current.

Figure 6 show the measured filling pattern with a stored beam current of 302 mA in a snapshot taken during top-up operation. This bunch current measurement has an accuracy better than one percent. The 16 nsec structure and bunch current variation are associated with the present injection scheme. A short bunch train of about 30 bunches is used to fill the storage ring at this moment, and the bucket jumps 8 bunched for each injection. This process is repeated during the top-up operation scenario, which results in bunch current variation per 16 nsec. Despite this fact, the filling pattern can be maintained within 5% during several days of continued top-up operation. Consecutive bunch current in decay mode operation as shown in Fig. 7. It can be used to study lifetime related effect of individual bunches.

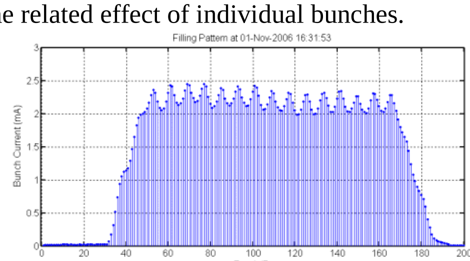


Figure 6: Measured bunch current of a snapshot during top-up operation. Total beam current is 302 mA.

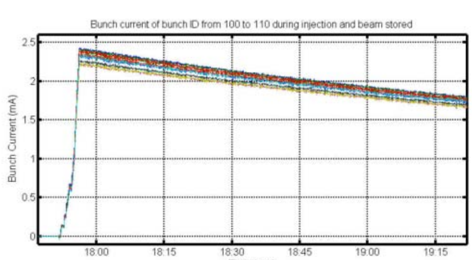


Figure 7: Ten consecutive bunch current of in decay mode operation.

The beam is perturbed in a fixed interval for top-up injection. This beam position oscillation caused by injection perturbation, can be captured by the Libera Electron. The Fourier analysis of the turn-by-turn data can extract the tune at instance of injection. Bergoz's type PIN diode beam loss monitors can acquire the radiation distribution. Several high counting rate scintillator type beam loss monitors are also installed to support various studies. Besides, a tune monitor and a beam loss monitor can support various studies and monitor routine operation.

TIMING SUPPORT FOR TOPUP OPERATION

To coordinate the injection process and to measure charge and current at the booster synchrotron, BTS and the storage ring, timing of the software process have been designed, very carefully to ensure all measured done at the same machine cycle. Control system of the linear accelerator has been renew recently to make system delay removed fully [5]. Precise control of the injection process in one machine cycle is possible. Better stored beam current control is possible overshot of upper threshold of the top-up injection. An injection synchronization signal is available in all experimental stations, to deal with the beam perturbation caused by non-ideal injection local bump and the perturbation from field leakage of the injection septum. This signal can help users to gate out the data related to the unstable beam during instance of injection, guaranteeing the quality of experimental data.

SUMMARY

Diagnostics to support top-up operations of the TLS have been gradually improved over the last two years. Experiences accumulated during the last two years of top-up operation will be helpful for further improvement of various diagnostics. Operation of the storage ring with camshaft filling pattern is possible in the future and requested by some users. Bunch purity diagnostics for this isolated bunch with time correlated single photon counting technique is in planning.

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