NEW INJECTION CONTROLS ENVIRONMENT FOR THE TAIWAN LIGHT SOURCE

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Abstract

Taiwan Light Source (TLS) has been service for user service since 1993. Several legacy systems have recently been updated in order to remove obsolescent parts and provide higher operating efficiency. Proprietary designed timing modules were recently replaced by an event based timing system. The magnets of the booster synchrotron were configured as three White circuits and driven by resonance excitation. The original control of the White circuits, which included an analogue amplitude loop and digital phase loop for regulation, has been replaced by full digital regulation loops. The successful upgrade of both systems has led to easy and smooth injection control with enhanced functionality and flexibility. The injection control includes foreground and background processes that coordinate the operation of e-gun, linear accelerator, booster synchrotron, and storage ring with the help of timing system. The injection control GUI provides an intuitive operation interface that includes parameter setting and all necessary information displays, such as various timing value, stored beam current/lifetime, injection efficiency, filling pattern, kickers waveform and so on. Energy saving mode of White circuits operation are supported and embedded into injection control to save electricity. Lifetime calculation of the storage ring is also synchronized with the injection process. Implementation details and operation experience will be presented.

INTRODUCTION

The Taiwan Light Source (TLS) is a third generation of synchrotron light source that has been dedicated for user service since 1993. TLS consists of a 50 MeV electron linear accelerator (linac), a 1.5 GeV booster synchrotron, and a storage ring that operates at 360 mA top-up injection mode. The facility initially operated at 1.3 GeV and was upgraded to 1.5 GeV in 1999 to enhance x-ray brightness to meet requirements of x-ray users. The upgrade replace the booster original BITBUS based control environment with a VME crates based control environment. The booster dipole and two family quadrupole configured as three White circuits driven by resonance excitation, and their control was also convert into VME system [1-3]. VME based timing generator and dedicated timing link were deployed. The injection control convert was converted in an automatic way. The design relied on several analogue sample and hold amplitude and zero-crossing phase detector to detect the 10 Hz current amplitude and phase. The implementation utilized analog regulation for amplitude control and digital regulation for the relative phase between magnet families. An injection control application with top-up functionality was deployed starting from 2004. Fixed 60 sec time interval injections was chosen to crop with lifetime limitation and user requirements, which are synchronized with UTC time. Beamlines could use hardware gating signal provided by timing system or UTC time stamp to exclude data contamination due to beam transient during the injection process. Beam current drops around 1 mA per 60 seconds at the storage ring, it takes one to a few shots (0.1 sec/shot) to refill the stored beam current back to 362 mA.

After more than 20 years of service, the previous VME crates based control system is being considered for redesign due to the aging and maintenance difficulties. In 2021-2022, new event based timing [4] and new White circuits controls [5] were implemented and deployed to avoid obsolescence of components in the existing system and to share the same hardware as TPS to minimize maintenance overhead. The new environment supports the EPICS control environment. The newly upgraded system adopt digital regulation for amplitude and phase regulation loops of the White circuits. The newly deployed injection control takes advantage of the new timing and new White circuit control, resulting in performance and efficiency improvements.

INJECTION RELATED SUBSYSTEMS

The injection process need coordinate among several sub-systems, including the electron gun, linac, booster White circuits, injection and extraction pulse magnets of the booster synchrotron, and injection septum and kickers of the storage ring. All these subsystems need to work together seamlessly to ensure a successful injection process.

Injector

The TLS injector comprises the electron gun, linac and booster synchrotron, and their operation requires the proper setting of working points and trigger functionality of various subsystems. The operation of the injector is monitored through waveform signals, include klystron voltage/current, RF, booster main magnets current waveform, pulse magnet current waveform and beam signals. These signals are essential for monitoring the performance of the subsystems and ensuring a successful operation of the injector.

Pulse Magnets

The pulse magnets are responsible for supporting the injection/extraction processes in the booster and storage ring. The booster has one injection septum, one injection kicker, three extraction bumpers, one extraction septum, and one
extraction kicker. The storage ring has one injection septum and four injection kickers. Coordination between the pulse power supplies of these magnets is necessary for successful injection into the storage ring. However, all pulse magnets' current suffers from slightly different amplitude between the first trigger after longer charging times that reach a steady state and 10 Hz continues trigger that still in the transient state of the charging power supplies. The difference is due to the overshoot characteristics of the charging power supplies. The only exception is the injection kicker of the booster synchrotron, which doesn’t use capacitor charging scheme. The charging power supplies are still in regime of settling time at the time scale of 100 msec when trigger repetitively.

The warm-up triggers for pulse magnets are used before injection in the booster synchrotron, but not for the storage ring injection septum/kickers due to the need to avoid sacrificing user beam-time. The solution is to use special circuit that sets a lower charging voltage for the longer charging time, ensuring the same amplitude for longer charging times, ensuring the same amplitude as for regular 100 msec charging for the injection septum. The setting return to normal when a continue trigger is applied. Injection kickers of the storage ring can keep pulse current amplitude less than 1% with continue charging as well as longer charging times, meeting injection requirement without further compensation.

Event Based Timing System

The previous timing system used in the facility was based on VME modules and had been in operation since 1992. However, it was replaced by an event-based timing system in July 2022 to provide better control of time response and avoid the obsolescence of legacy hardware. The old system involved enabling and disabling various timing channels at different VME crates over control network, which caused control jitter of several tens of milliseconds delay.

The storage ring total beam current is read by digital multi-meter with integration time of two power line cycles (32 msec), so there are only 15 msec left to make a decision and send control to disable related trigger channels after the beam injection and current reading increase. Therefore, the booster injection cycle runs an extra cycle after storage ring current reaches the desired setting, as the booster cannot stop in time.

The new event-based timing system consists of an event generator (EVG), event receivers (EVRs) and a timing distribution fiber network [4] as shown in Fig. 1. Machine clocks, such as the repetition rate, revolution clock of BR and SR, and coincident clock, are available. Trigger events for the injection are managed at the timing master and distributed to hardware related to timing without delay, allowing for precise control of the injection cycle. The RF frequency is divided by four as event clock of the timing system, providing 8 nsec coarse timing resolution, which meets the timing requirements of the TLS. The injection sequence is initiated by the magnet field of dipole in the booster synchrotron when it reach 50 MeV injection energy.

This injection trigger event is derived from the booster dipole White circuit current, which serves as injection trigger input of the EVG. Several EVR outputs provide feedback to the EVG external trigger input to define important timing, such as bucket addressing, injection, and extraction, instead of using the sequence RAM of EVG as typical implementation of an event-based timing system.

Booster Power Supply Controls

The booster synchrotron has dipole and two families of quadrupole magnets configured as three independent White circuits that are resonance excited at 10 Hz. The previous generation controls were implemented using three proprietary VME 10 Hz waveform generators based on numerical controller oscillator (NCO) with phase and amplitude control functionality in 1999. Phasing control was performed by digital PI controller running at VME host, and amplitude regulation was performed by an analogue PI regulator on the module.

An upgrade of the White circuits control was done in 2021 using direct digital synthesis (DDS) based waveform generators to drive power suppliers of the White circuits and digital control of amplitude and phase [5] running in EPICS IOC. There are three amplitude regulated loops and three phase regulation loops to maintain amplitudes and phases of the magnet current in White circuits constant. Six independent digital regulators provide flexible and stable control of the White circuits and diagnostic functionalities when problem occur.

Energy saving operation of the booster White circuits was implemented in 2017 to save electricity [6] and new injection control environment also supports energy-saving functionality and better process monitoring.

Filling Pattern Measurement

The filling pattern is an important factor that can affect the performance of the storage ring, such as its lifetime and stability. It is crucial to maintain the desired filling pattern for user operation. Therefore, the filling pattern should be continuously monitored. The acquired waveform from BPM button signal is captured by a dedicated 500 MS/s
digitizer triggered by revolution clock to extract bunch current with high resolution. The filling pattern analysis code extracts relative bunch intensity along with the total beam current measured by DCCT to calculate individual bunch current.

**Rich Waveforms Supports**

To provide an clear view of various waveforms information to assistance the TLS operation, integrated waveforms fare gathered from a variety sources, include klystron current/voltage, RF and beam waveform from the linac, injection and extraction pulse magnet current, injection pulse magnet waveforms from the storage ring, beam signal from the booster and transport line, and filling pattern data from the storage ring. By gathering and integrating this information, the TLS operation team can gain a clearer view of the operation conditions, and can more quickly identify and address any problems that may arise.

**INJECTION CONTROL**

The EPICS EDM page shown in Fig. 2 is a convenient interface for beam injection into the storage ring. It provides information on injection-related configuration, delays, and trend/waveforms, as well as presenting the operation conditions of the accelerator system. The injection control EPICS sequencer program manages modes and sequences by enabling/disabling external triggered events arranged at the rate of 10 times per second, according to the injection cycle. The injection control sequence is coded in state notation language (SNL) and executed by the EPICS sequencer running at the timing master EPICS IOC [7]. The injection sequence program is a state machine that communicates with the injection interface via process variables to control the injection process. Injection state machine control the injection process. Figure 3 illustrates the relationship between various components involved in injection control.

The e-gun generate near 50 nsec bunch-train (25 bunches) for injection. The injection bucket address in the storage ring increase four buckets after every shot, and this process repeats back and forth within the defined range until the desired storage beam current reached. It’s interesting to note that the filling pattern can be kept in trapezoidal shape without requiring active filling pattern feedback. The filling pattern is display on the injection control GUI, which also includes various configuration settings and support for trend/waveforms.

**SUMMARY**

New injection control system was developed and deployed for the TLS in 2022, along with upgrades to the booster White circuits and timing system. These upgrades provided better performance than the previous generation and helped to avoid obsolescence of hardware and software. The injection control functionality support automatic decay mode as well as top-up mode injection and provide rich information for the injection process diagnostics. This new system has significantly reduced the working load requires to operate the TLS.
REFERENCES


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