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STATUS OF THE TPS CONTROL SYSTEM

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Abstract

Control system for the Taiwan Photon Source (TPS) has been delivered in mid-2014 to support commissioning and routine operation of the accelerator system. The TPS control system adopts EPICS toolkits as its frameworks. Various subsystems interface to the control system according its specific requirements. Operation experiences accumulated during last four years confirmed the system working well. Minor revisions were made to improve the system performance. Current status of the control system and ongoing developments will be summarized in the report.

INTRODUCTION

The TPS [1] is a latest generation of high brightness synchrotron light source which is located at the National Synchrotron Radiation Research Center (NSRRC) in Taiwan. TPS consists of a 150 MeV electron linac, a booster synchrotron, a 3 GeV storage ring, and experimental beam lines. The control system environment was ready in mid-2014 to support subsystem integration test and accelerator commissioning [2]. User service of the TPS was started since 2016.

Adequate and reliable functionality of control system is one of the key to the success of TPS commissioning. Control system for the TPS is based on the EPICS framework [3]. The EPICS is based on the definition of a standard IOC structure with an extensive library of driver and support a wide variety of I/O cards. The EPICS toolkits have various functionalities which are employed to monitor and to control accelerator system such as control page creation, data archiving, alarm handling and etc.

The TPS control system consists about three hundred of EPICS IOCs. The CompactPCI (cPCI) is equipped with input/output modules to control subsystems as standard IOC. The other kinds of IOCs are also supported by the TPS control system, such as BPM IOCs, PLC IOCs, various soft-IOC and etc.

To achieve high availability of the control system, emphasis has been put on software engineering and relational database for system configurations. Data channels in the order of 10^5 will be serviced by the control system. Accessibility of all machine parameters through control system in a consistent and easy manner will contribute to the fast and successful commissioning of the machine. High reliability and availability of TPS control system with reasonable cost and performance are expected.

SYSTEM COMPONENTS

The TPS control system provide an environment for operation of the accelerator system. It integrated various subsystems together [4]. Details of some parts of control system are summarized in the following paragraph.

Control Server Environment

Various servers include file server, archiver server, database server, alarm server, boot servers, ...etc. are supported by the control system. There server support operation of the whole system.

General EIPCS IOC Interface

There are many different kinds of IOCs at equipment layer to interface various subsystems and instruments. They need meet various requirements of functionality requirements, convenience and cost consideration. Type of IOCs are summary in Table 1. Most of the devices and equipments are directly connected to cPCI IOCs with EPICS. The cPCI EPICS IOC is equipped with the cPCI-6510 CPU board. The cPCI-7452 128 bits DI/DO module is used for BI, BO solution. ADC and DAC modules in IP (Industry pack) module form-factor are used for smaller channel count application, such as insertion devices control. Event system modules are in 6U cPCI form-factor. Private Ethernet will be heavily used as field-bus to connect many devices. Power supplies of all magnets except for correctors are equipped with Ethernet to the EPICS IOC. Multi-axis motion controller with Ethernet interface is the standard for the control system.

Ethernet attached devices are connected to the EPICS IOC via private Ethernet. Devices support VXI-11, LXI, Raw ASCII and Modbus/TCP protocol are connected to EPICS IOC directly by TCP/IP interface. Devices of this category include intermediate power supply, temperature acquisition (RTD or thermocouple), digital multi-meters, oscilloscopes, signal generator, and other instruments.

All corrector power supplies are controlled by the corrector power supply controller (CPSC) module [5]. The CPSC embedded EPICS IOC, it can access via channel access protocol. The CPSC equips with 20 bits DAC and 24 bits ADC. Two SFP ports supported by the on board FPGA, these SFP ports are receive correction setting from fast orbit feedback FPGAs located at BPM platforms via AURORA protocol.

All BPM platform are embedded EPICS IOCs. Some PLC based embedded IOC were adopted for machine protection and interface of pulse power supply of pulse magnet.

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Table 1: Type of EPICS IOCs

Type	Quantity	Applications
6U CompactPCI	~ 40	CIA IOCs, Timing, RF, ID, etc.
PLC embedded EPICS IOC	13	Pulse Power Supply, MPS
Fanless platform with PCIe	~20	Beamline gateways and Timing
Embedded w POE	~5	Image IOCs
Embedded IOP	~122	Corrector PSs
COM Express Embedded (µTCA platform)	72	Storage ring and booster synchrotron BPMs
1U platform	13 (xScale)	Transfer line BPMs
Micro ATX	3	Bunch-by-Bunch Feedbacks
Miscellaneous	~20	Software IOCs, LabVIEW IOCs, etc.

Power Supply Control

TPS power supplies control interface is divided into three categories based upon products from three different vendors. The small power supply for corrector magnets and skew quadrupoles is an ±10 Amp class power supply. This category power supply will be in module form-factor. Each power supply sub-rack can accommodate up to 8 power supply modules. A custom designed CPSC module was installed at control slot of the sub-rack. The CPSC will be embedded with EPICS IOC and provide fast setting SFP ports to support orbit feedback functionality. Power supply modules installed at the same sub-rack will interface to this CPSC module.

The intermediate power supply with current rating 250 Amp is equipped with Ethernet interface. Power supplies are expected to have internal data buffer with post-mortem capability. There are two versions of power supply in this category, sextupole power supply with 16 bits precision and quadrupole power supply with 18 bits precision.

Storage ring dipole DC power supply and power supplies for the dipoles and quadrupoles of the booster synchrotron are contracted to Eaton. Each power supply equips with RS-485 serial interface. MOXA serial to Ethernet adapters enable directly interface with the EPICS IOCs. The storage ring dipole will be control via this link. Booster dipole and quadruple power supplies are interface by precision analogue interface. The DACs and ADCs operated synchronize by the same clock and trigger to achieve better reproducibility. Waveform generate form the DAC on IOC will drive these booster power supplies. This functionality is essential for energy ramping of the booster synchrotron [6]. Control resolution of these power supplies has 18 effective bits.

Networking

Mixed of 1 and 10 Gbits/s switched Ethernet are deployed for the TPS control system [7]. The Gigabit Ethernet connection was delivered at edge switches installed at control and instruments area (CIA). The control network backbone is a 10 Gigabit link to the control system computer room. Private Ethernet is used for Ethernet based devices access which support fast Ethernet and GbE. Adequate isolation and routing topology will balance between network security and needed flexibility. The file and database servers are connected to the control and intranet network, allowing the exchange of data among them. Availability, reliability, cyber security, and network management are all considered.

Timing System

The event system consists of event generator (EVG), event receivers (EVRs) and a timing distribution fiber network [8, 9]. The EVG and EVRs can be installed with various universal I/O mezzanine modules to meet different input/output requirements. The mechanical form-factor of EVG and EVRs is in 6U cPCI module. The 125 MHz event rate will deliver 8 nsec coarse timing resolution. Fine delay is supported by the EVRTG which generates gun trigger signal. Its high resolution and low timing jitter provide accurate synchronization of hardware and software across the TPS control system.

Insertion Devices and Front-end

TPS will accommodate up to 21 sets of insertion devices (ID) in 2023 (Fig. 1). There are 10 sets in phase I (~ 2016), 7 sets in phase II (2017~2020) and 4 sets in phase III (2020~2023) for insertion devices projects. Phase I IDs include one set of EPU46, two sets of EPU48 [10] and seven sets of in-vacuum insertion devices (two sets of 2 meters long IU22-2m, three sets of 3 meters long IU22-3m, and one set of 3 meters long IUT22-3m with taper functionality). Construction for Phase II IDs are on-going consists of seven sets of 2 sets of in-vacuum undulator, 2 sets of cryogenic insertion undulator, and one wiggler, two EPUs. Motion control performed by using Galil DMC-40x0 motion controller. In-house developed EPICS device support for this motion controller was developed to support up to 200 Hz access. A cPCI EPICS IOC equips with AI/AO/BI/BO I/O modules were used for the Phase I IDs. All parameters of motion controller will be created as EPICS PVs. Update rate can be up to 200 Hz. This would be useful for feed-forward ID field error compensation which operate at 100 Hz rate at this moment. Control environment for Phase I and II insertion devices control as shown in Fig. 2 and Fig. 3 respectively. The user interface of insertion device with front-end layout is shown in Fig. 4.

To improve functionality and openness of control environment for future development and accompany with another application for upgrade of existed control system (such as the control system of Taiwan Light Source). Start from Phase-II, cPCI crate will replaced by PC platform in various form factor (include fanless embedded PC), the cPCI digital and analog I/O modules will replaced by EtherCAT modules. EtherCAT can support 200 Hz rate access which is compatible with current system.

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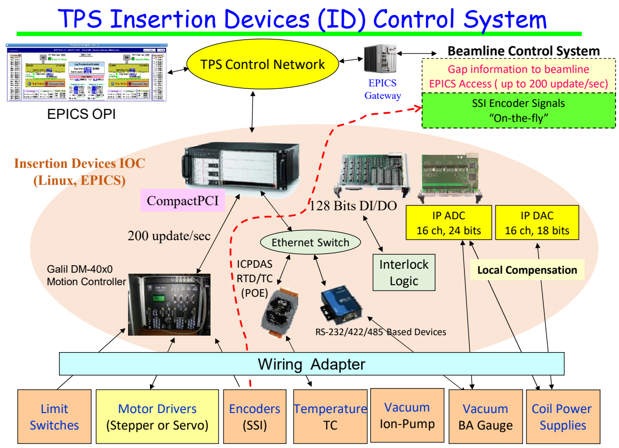

Figure 1: Standard hardware configuration for Phase I insertion devices control.

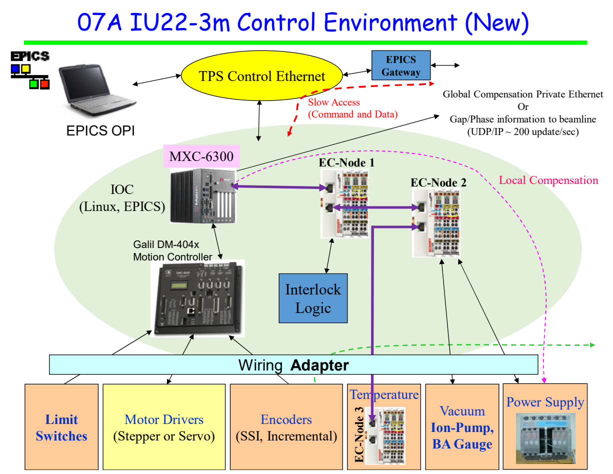

Figure 2: Standard hardware configuration for Phase II and future insertion devices control.

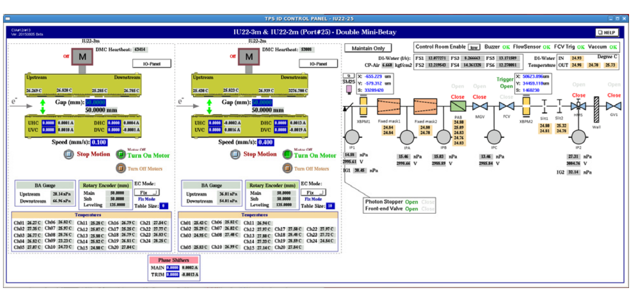

Figure 3: Graph user interface of two insertion devices (IU22-3m + IU22-2m) with front-end.

Diagnostic System

Digital beam position monitor (BPM) electronics is equipped with Ethernet interface for configuration and served as EPICS CA server with 10 Hz data rate. Another multi-gigabit interface delivery beam position for fast orbit feedback purpose at 10 kHz rate. Post-mortem buffer for orbit analysis during specific event happened like beam loss are also supported by the BPM platform.

Many BPM related applications were developed to help various applications [11, 12].

Fast orbit feedbacks [13], bunch-by-bunch feedback supports, post-mortem data acquisition for other signals other than BPM and data analyzer [14], …etc. are useful for the TPS delivery stable beam.

High precision beam current reading and lifetime calculation was done at a dedicated IOC. This IOC will install EVR to received booster cycle timing signals and high resolution IP ADC modules to digitize the DCCT signal and perform beam lifetime calculation.

The GigE Vision digital cameras support for screen monitor [15], synchrotron radiation monitor, X-ray pinhole camera [16] and other applications. Counting type and integrating type beam loss monitors was connected to the control system by counter or ADC modules installed at IOCs.

PLC and Interlock

The PLC was used for most of control system related interlock system [17]. FM3R with embedded EPICS IOC is also used for some applications, such as pulse magnet power supply control and machine protection system (MPS). The MPS collects various interlock signals from local interlock subsystem of orbit, vacuums, front-ends, and etc. The beam disable commands to trip beam or inhibit injection can be distributed to the specific devices or subsystem by the global machine interlock system or uplink functionality of the event system. The summarize control page is shown in Fig. 4.

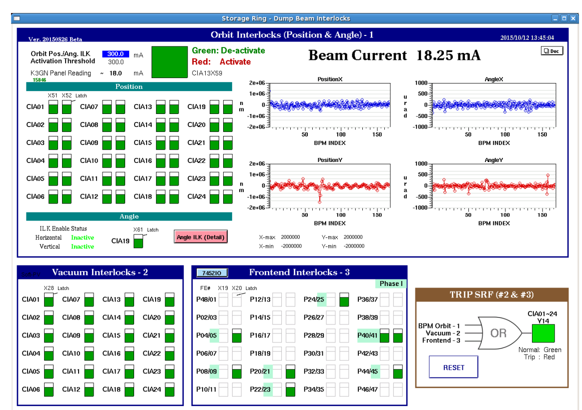

Figure 4: The machine protection system control page.

Beamline and Experimental Station Interface

To allow beamline and end-station users access to the accelerator control and timing systems, an EPICS gateway/EPICS IOC was set up. The gateway provides an interface to share data between accelerator and beamlines and to allow end-station users to control insertion devices. The EPICS IOC support provides beamlines with a flexible and configurable timing in support of experiments including injection gating, revolution clock, clock with specific frequency for streak camera triggers, beam current broadcasting via an event based timing system with a frequency signal which is proportional to the beam current, a trigger signal for data acquisition, etc.

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A low jitter RF clock (< 1 psec) is also distributed to the beamlines which need a high quality RF clock for laser system synchronization and a clock for streak camera synchro-scan operations via phase stabilized optical fibers (PSOF). This POSF fiber distribution is insensitive to ambient temperature variations which could otherwise cause timing drifts of tens of picoseconds with only a few degrees of temperature change. A frequency divider and phase locked loop (PLL) also support beamlines to generate a high quality clock at specific frequencies to support diverse applications. Figure 5 shows the configuration of this accelerator to beamline system interface. The fiber links include computer network for beamline and end-station, computer network for accelerator control systems, event timing system networks and a POSF fiber link.

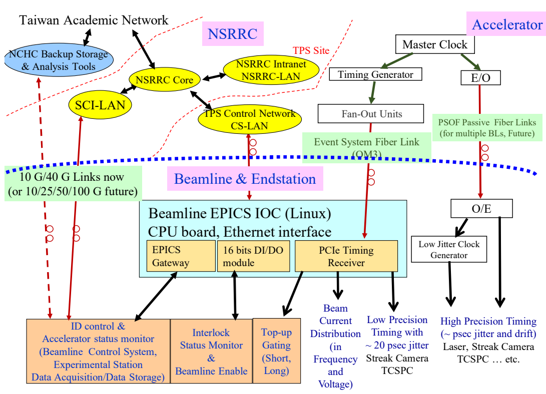

Figure 5: Accelerator control system interface with beamlines.

CONTROL APPLICATIONS

Generic applications provided by the EPICS toolkit will be used for all kinds of applications [18]. Standard tools such as the archive system, alarm handler and save/restore tools are supported. Channel Access (CA) is used as an interface for process variables (PVs) access. Simple tasks such as monitoring, alarm handling, display and setting of PVs are performed using EDM panels and strip tools. Cold start, warm up and shutdown process are done by MATLAB scripts.

Operator Interface

The operator interface level consists of Linux PCs for consoles and servers for various purposes. Operation user interface (OPI) is implemented by EDM, CSS (Control System Studio), MATLAB, and Python. The TPS launcher by the control page is built by the EDM toolkit shown as the Fig. 6. All control pages can be launched from this page. All control components are located at the foreground of the TPS accelerator illustration.

Save and Restore

To readily restore a set of the machine parameters for subsystems during operation as well as to optimize and record working points for different machine conditions, the mechanism of save and restore is developed. The save and restore function is established by using the MATLAB with the labCA. The various files of grouped PVs (Process Variables) list are created for saving the respective parameter values of each subsystem. The file with PVs and saved parameters is also selectable for resume the settings.

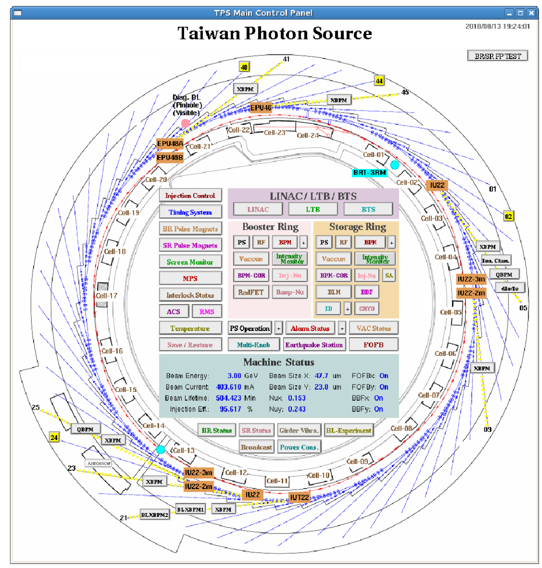

Figure 6: The TPS main control page made by EDM tool.

Injection Control

Injection control for TPS have been served since the machine commissioning [19]. Top-up injection functionality is available from day one of machine commissioning stage to assist vacuum conditioning. During last two years, several updates have been done to enhance flexibility for the injection control to help efficiency operate of the TPS. The injection control includes foreground and background processes to coordinate the operation of e-gun, linear accelerator, booster synchrotron, storage ring by the help of event based timing system. Lifetime calculation of the storage ring is also synchronized with the injection process.

Alarm Handler

The “BEAST” (Best Ever Alarm System Toolkit) of CS-Studio with the MySQL RDB is adopted as the alarm handler for the TPS, as shown in Fig. 7. A distributed alarm system monitors the alarms in a control system and helps operators to make right decisions and actions in the shortest time. In the CS-Studio alarm system, each alarm is supposed to be meaningful, requiring an operator action. An alarm is no status display that operators may ignore. Each alarm requires an operator to react because the control system cannot automatically resolve an issue.

Archive and Logbook

The archive system of CSS (Control System Studio) named BEAUTY (Best Ever Archive Toolset, yet) was built to be used as the TPS data archive system [20]. An archive engine takes PV data from EPICS IOCs via

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channel access, and stores them in the data storage. The PostgreSQL RDB (Relational Database) was adopted as the data storage for the BEAUTY. Both the historic PVs data and the archive engine configuration are saved into the same RDB. The archived data can be retrieved in a form of graphical representation using the CSS-based data browser. Taking the performance and redundancy into considerations, the storage servers and RDB table structures are tuned relative.

The "Olog" [21] solution is selected for the TPS electronic logbook. The TPS logbook is recorded the progress about commissioning information by the commissioning team and operators, and supports print function to copy data into the logbook for logging.

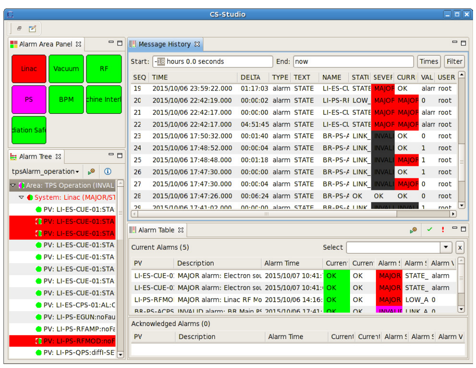

Figure 7: The CS-Studio alarm handler interface.

Miscellaneous

There are many special type applications supported by the control system such as earthquake data acquisition, Raspberry Pi/Banana Pi based EPICS IOC for special embedded applications. All of these application enrich the contents of the control system.

FUTURE PROSPECTIVES

To cope fast evolution of hardware and software technologies for future development of the TPS, small scale development with limited resources is under way. Theses development include MTCA.4 platforms for diagnostic and timing applications, aTCA platform for multiple EPICS gateway applications, open source event receiver for future beamline and end-station timing support, Python application development for next step application programs, etc.

SUMMARY

The TPS take advantages of the latest hardware and software developments to deliver high performance, rich functionality, and economically control system. TPS control system working well during last five years. During these period, several minor revised were performed to enrich of contents of the control system. Performance index includes scalability, reliability, and performance, maintainability, etc. were improved significantly since its deploy.

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