OPERATION EXPERIENCES OF THE TPS CONTROL SYSTEM

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Abstract

TPS Control system was operated near three years from summer of 2014 to support commissioning and operation of the TPS. TPS control system adopts EPICS toolkits as its framework. The subsystems control interfaces Include event based timing system, Ethernet based power supply control, corrector power supply control, PLC based pulse magnet power supply control and machine protection system, insertion devices motion control system, various diagnostics related control environment, and etc. Experiences accumulated in last three years in hardware, software have been confirmed it can fulfil its mission. Functionality and reliability were improved during last three years. Long term strategic for performance improvement and maintenance are revised. Efforts will be summarized in this reports.

INTRODUCTION

The TPS is a low emittance 3 GeV synchrotron light source which is constructed at the National Synchrotron Radiation Research Center (NSRRC) in Taiwan. The control system environment was ready at the summer of 2014 to support subsystem integration test and commissioning. The TPS has delivered its first synchrotron light [1, 2] on the last day of 2014. Since then the control system support follow-up machine commissioning and user service of the TPS.

Adequate and reliable functionality of control system play a key role to the success of TPS commissioning and operation. Control system for the TPS is based on the EPICS framework [3]. The EPICS toolkits provide standard tools for display creation, archiving data, alarm handling and etc. 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.

The TPS control system [4, 5] consists of more than two hundreds of EPICS IOCs. The CompactPCI (cPCI) is equipped with input/output modules to control subsystems as standard IOC due to its maturity and low cost. The other kinds of IOCs are also supported by the TPS control system, such as BPM IOC, PLC IOC, various soft-IOC and etc.

To achieve high availability of the control system, hardware and software configuration are very careful considered. Software engineering techniques and relational database for system configurations. Data channels in the order of 10^5 will be serviced by the control system.

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Accessibility of all machine parameters through control system in a consistent and easy manner will achieved. High reliability and availability of TPS control system with reasonable cost and performance are confirmed during last three years operation.

SYSTEM CONFIGURATION

The system installation and integration with subsystems for the control system was done. Details of the control system are summarized in the following paragraph.

Networking

Mixed of 1/10 Gbps switched Ethernet are deployed for the TPS control system [6]. 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. 1G/10 G service are available at beamline also. 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. Availability, reliability, cyber security, and network management are strengthened continually.

General EIPCS IOC Interface

There are many different kinds of IOCs at equipment layer to satisfy various functionality requirements, convenience and cost consideration, shown in Table 1. Most of the devices and equipment are directly connected to cPCI IOCs with EPICS. The cPCI EPICS IOC is equipped with the ADLINK cPCI-6510 CPU board. The ADLINK 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 power supply, temperature acquisition, digital multi-meters, oscilloscopes, signal generator, and other instruments.

All corrector power supplies are driven by the corrector

power supply controller (CPSC) module [7]. The CPSC equips with 20 bits DAC and 24 bits ADC. Two SFP ports supported by the on board Spatan-6 FPGA, these SFP ports are receive correction setting (Aurora and Gigabit Ethernet by using UDP/IP protocol) from fast orbit feedback FPGAs to slow orbit feedback computation server, feed-forward correction computer and IOC.

Table 1: Type of EPICS IOCs

Type	Quantity	Applications
6U CompactPCI	~40	CIA IOCs, Timing, RF, ID, etc.
COM Express Embedded	72 (Atom) + 13 (xScale)	BPMs
EPICS IOC Embedded PLC	13	Pulse Power Supply, MPS
Embedded w PCI/PCIe	10~20	Gateways and Beam-line Timing
Embedded w POE	~5	Image IOCs
Embedded IOP	~122	Corrector PSs
BananaPi IOC	5	Alarm announcer, Simple I/O
Miscellaneous	~20	Software IOCs, Bunch-by-Bunch Feedbacks, LabVIEW IOCs, etc.

Power Supply Control

TPS power supplies control interface are divided into three categories due to it provides by three different vendors. The small power supplies for corrector magnets, skew quadrupoles are in the range of ±10 Amp categories. 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 power supply sub-rack and interface with power supply via back panel of the sub-rack. The CPSC embedded with EPICS IOC and provide fast setting SFP ports to support orbit feedback functionality.

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 resolution and quadrupole power supply with 18 bits resolution DAC.

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 will 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 [8]. Control resolution of these power supplies has 18 effective bits.

Timing System

The event system consists of event generator (EVG), event receivers (EVRs) and a timing distribution fiber network [9, 10]. The 6U cPCI module form factor EVG and EVRs install various universal I/O mezzanine modules to meet different input/output requirements. 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 accelerator system across the TPS control system.

Insertion Devices and Front-end

Insertion devices (ID) control for all IDs for the TPS share the identical structure to simply maintenance [11]. Motion control was done by the Galil DMC-40x0 motion controller. In-house EPICS device support for this motion controller was developed. A cPCI EPICS IOC equips with AI/AO/BI/BO I/O modules were used. 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 compensation process. The user interface of insertion device with front-end layout is developed to support operation of IDs.

Diagnostic System

Various diagnostics were deployed for the TPS [12]. New generation digital BPM electronics is equipped with Ethernet interface for configuration and served as EPICS CA server with 10 Hz data rate. Another multi-gigabit interface will deliver beam position for fast orbit feedback purpose at rate up to 10 kHz. The BPM electronics will also provide post-mortem buffer for orbit analysis during specific event happened like beam loss. 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, synchrotron radiation monitor, X-ray pinhole camera 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 the accelerator control system related interlock system [13]. Yokogawa 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.

Control Applications

Generic applications provided by the EPICS toolkit will be used for all kinds of applications. 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.

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

To restore a set of the machine parameters for subsystems during operation as well as to optimize and record working points for different machine configurations, 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.

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 [14]. An archive engine takes PV data from EPICS IOCs via 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" [15] 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.

The "BEAST" (Best Ever Alarm System Toolkit) of CS-Studio with the MySQL RDB is adopted as the alarm handler for the TPS. 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 to do adequate action.

MINOR UPDATE OF THE CONTROL SYSTEM

There are some minor problems was series studied and revision of the control system was done to satisfy various requirements during last two years. Some problems and revision are summary in this paragraph.

Integration Problem of Some Subsystem

The control system fulfills its goal to support the operation of TPS without major problem. No major problems related to the control system. However, there are several subsystems have its own control environments. These control environment link to the machine control system in weakly coupled manner. Only basic control functionality allows. No all data available for the control system. It will need time to further revise in future for a better integration in future.

Cold Start Connectivity Problem of Some Specific Devices

Some subsystem need re-initialized the EPICS IOC after cold start occasionally. Efforts to dig out the problem and fix is short goals. This caused extra maintenance load when power reset of that subsystem necessary.

SOC Module Based EPICS IOC

System on a chip (SoC) is widely used in embedded environment. Current generation SoC commercial products with small footprint and low-cost have powerful in CPU performance and rich interface solution to support many control applications. To deal with some embedded control applications, the "Banana Pi" which is a card-size single-board computer and runs Linux-based operation system has been adopted as the EPICS IOC to implement several applications [16, 17]. The efforts for implementing are summarized in this paper.

Injection Gating for Selective PVs

Orbit transient induced by injection will caused spike in the archived electron beam position data. It need to remove this spike for long-term data analysis, position data removed the injection spike are provided by another PVs. The injection transient gated out by the timing signal which synchronize with the injection process to discard the data during injection period. This is useful for long-term beam stability analysis. How to eliminate the injection transient fully need further study to improve injection elements or study new injection scheme which will be possible in future.

Beamline Interface

To interface with beamline control system and end-station control environment, an EPICS IOC with event receiver is installed at beamline rack. The EPICS gateway is installed at the same IOC to provide data exchange between accelerator control system and beamline/end-station control environments. The IOC provide necessary accelerator timing for end-station users.

Post-mortem Diagnostics

To identify various reasons which caused beam trip, a post-mortem system has been set up [18]. The system based on a distributed SOC based data recorder which embedded EPICS IOC. A post-mortem trigger is generated by the beam trip detector when the stored beam current

suddenly drops. This trigger is broadcast to facility-wide through an event timing system to trigger post-mortem data capture on the data recorder and BPM system. The data recorders will be updated on receiving a trigger. After a few seconds delay, all data from the recorders and subsystem parameters of interest will be saved through a PV access. The probable cause of the event will be analysis by the dedicated software to identify the reason and generate trip report automatically. The report will be generated and saved as a web page. Operators can access and analysis the event data from viewer GUI or web browser at any time.

The TPS BPM system [3] provides turn-by-turn orbit post-mortem data which can be used to analysis beam positions during the trip event. In addition, several EPICS embedded standalone data recorders support distributed data acquisition capability to collect data from different subsystems. Each data recorder has eight input channels with two types of configurations. These recorders provide waveform type signals which can be captured by many subsystems, including the storage ring beam orbit, machine protection system (MPS), RF and pulsed magnet system. In addition to these signals, some subsystem parameter set values need to be logged when an event occurs.

System Reliability

Reliability of the control system seem very good, only a few event which caused trouble due to bad interface design with the subsystem controller. Bad software in the subsystem controller might the major reason which caused problem. Further improvement is underway.

Another reliability related event is due to radiation induced soft error of the optical encoder of the elliptical polarized undulators (EPUs). The optical encoder is installed near the electron optical planes. The software error happened frequency which cause difficult to operate these EPUS. The problem solved after install 10 mm think lead shielding on each optical encoder.

OUTLOOKS

Due to fast evolution of the networking technology, the 1/10/25/40/100 G networking mature in near term. There are no difficult to adopt latest products to the control system and beamline when necessary.

Current EPICS version used is 32 bits release 3.14.12.x. The 64 bits EPICS environment is apply for some applications. Evolution to EPICS version 7 is in study. Develop sophisticated and integrated user interface are needed to eliminate tedious works from machine operation viewpoints.

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Python scripts are used for many sequential control includes injection, feed-forward compensation tables management of the insertion devices, …etc.

Work out precision timing supports for the beam-line and end-station which need for time-resolved experiments.

Phase II beam-line project launch form 2017. Control system to support of the project is planned. Phase II IDs include procure from vendors and in-house made, the control system will share identical control environment. Vendor deliver insertion devices without control system. This will simply maintenance works from spare parts and manpower viewpoints in future.

Beam trip events analysis is very important step to improve machine reliability and to increase machine mean time between failures (MTBF). Further improve the post-mortem data acquisition system and enhance intelligence of the analysis tool will be highly useful for the machine operation and maintenance. Accelerator recovery after beam trip might need less than 30 min. However, thermal recovery might need a couple of hours or more for the beamlines optics especially monolithic mirror used. Maximising MTBF will improve effectiveness of beamlines drastically.

SUMMARY

The TPS take advantages of the latest hardware and software developments to deliver a high performance, rich functionality, and economically control system. It was proved its good quality in operation of the last three years since the control system put into service. Minor revisions are ongoing to improve functionality and reliability continually. Rich control system related applications are developed on going to meet various requirements.

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