Instrumentation and Control System

Instrumentation and control system plays a crucial role in the commissioning and routine operation of a modern light source like NSRRC. The system at NSRRC was implemented a decade ago, while being constantly improved by upgrade and re-engineering. In the following, a historical overview of the system development and future prospect are presented.

Control System in the Early Stage

The control system of the accelerator complex is a distributed-type system and follows the concept of "Standard Model" control system for experimental physics. It's a two-level hierarchical system providing good real-time performance with a system update rate of 10 Hz. The overall architecture is simple, scalable, and easy in maintenance. Process computers and workstations at the upper -level control system provide the necessary computing power for machine modeling, data storage, and graphical user control interfaces. VME bus-based intelligent local controllers (ILC) are hearts of the lower-level control system that handles real -time device access and closed loop control. The two levels are connected by ethernet network using IEEE 802.3 standard and TCP/IP protocol. The software used on the upper-level computers includes database server, network server, simulation programs, various application codes, and X-window based graphical user interfaces. Device drivers, application programs for devices control, and communication programs are the major software components on the ILC level. The hardware configuration of the control system is shown in Fig. 1.

The console level computers, comprising a process computer and several workstations, handle the system-wide device control functions and provide a friendly operator interface. The process computer is a VAX 4500 that provides large storage space, computing power, and system resources maintainance. The workstation consoles serves as the platform to run graphical and control applications as well as the operator control console. The X-Window and OSF/Motif systems are used to develop the friendly, dedicated graphic user interface for facility operation. The ILC is a VME-based system that includes Motorola MVME-147 CPU board and a variety of interface cards. The ILCs are field level controllers, which perform data acquisition, local closed -loop control, and monitoring of the equipments of various subsystems. The ILCs are connected to the hardware devices via analog and digital input/output interfaces, IEEE-488 interface, and serial communication interface. There are 10 ILCs in the control system dedicated to the storage ring.

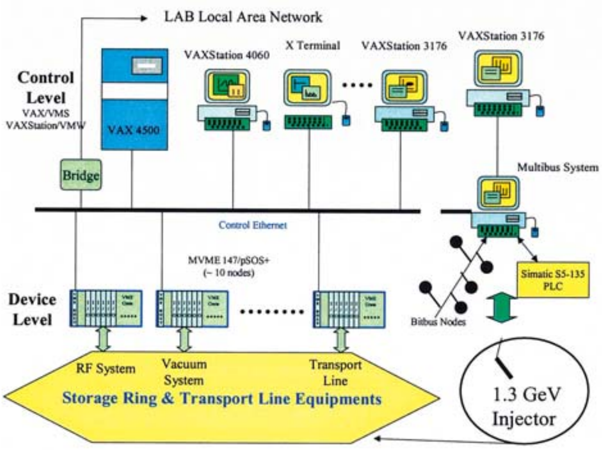

Fig. 1: Hardware configuration of the control system at the early stage.

The software structure is divided into several logical layers, as shown in Fig. 2. These include device access, network access, database management, graphical user interface, and applications. The purpose of software layering is to reduce the development time. Many applications run at console level computers; including the data logging and archiving, alarm checking and

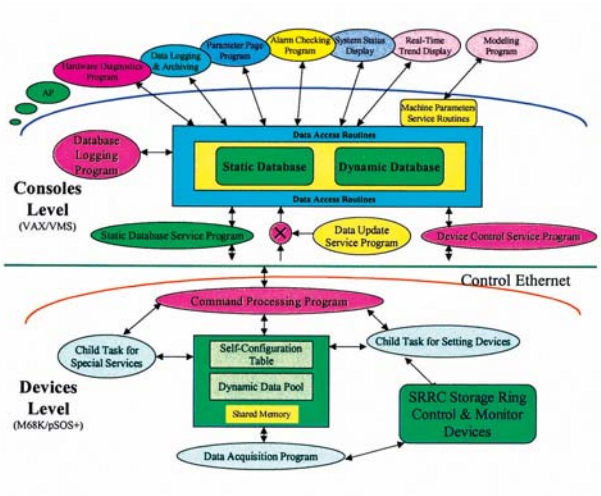

Fig. 2: Block diagram of the software system at the early stage.

machine modeling programs on the process computer.

The dynamic data are updated into the database of the console computers at 10 Hz. The devices access processes run on ILC, as well as the control tasks and various input and output tasks. The $pSOS^+$ real-time kernel provides the ILC with support for task scheduling, memory allocation, event handling, and message queuing. The pNA^+ network support package provides socket network programming interface. The hardware dependent device drivers are also implemented. Downloading the database from the process computer into the ILC to form a local distributed database is under development. The network access software takes control of the data exchange between console level computers and ILCs, while the communication protocols UDP/IP and TCP/IP provide an open environment for easy expansion.

The console level computers use the VAX/VMS system, and the software package is developed using high-level language. Functions of the process computer and workstations are slightly different. The process computer holds the system-wide static database and maintains it. At system start-up, each workstation requests and receives a copy of the static database from the process computer. Each console computer then has all the database information necessary to process dynamic database frames received from the ILCs. The workstations are mainly used for the user interface. The process computer initiates the upload event after receiving the event ILCs broadcast the dynamic data sequentially. All of the console level computers receive dynamic data and update database at the same time. Hence, the console level computers can be expanded easily without increasing the network traffic. The central database on console level computer is used as a buffer between the low-level tasks at ILCs and the console level applications. The application programs access equipments parameters directly from database rather than from ILC, and therefore are devices transparent. The development of the application programs can parallel with the development of other programs at ILCs. Among the many applications run on the console level computers, the data logging and archiving, alarm checking and machine modeling programs are run on the process computer, and the graphic-oriented applications such as real-time trend display, machine parameters display, are run at the workstations. Since the workstation has a powerful processor, it can also run some computation-intensive tasks.

The booster control system is a turnkey system provided by Scanditronix AB in 1990. The conceptual layout of the injector control system before 1997 is shown in Fig. 3. The system is a Vaxstation that stores the database and functions as the control console. A Multibus Crate is used as

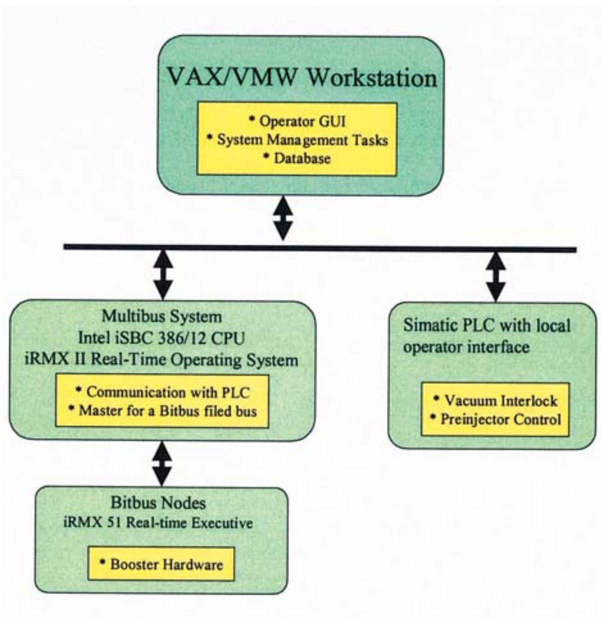

Fig. 3: Conceptual layout of the 1.3 GeV injector control system.

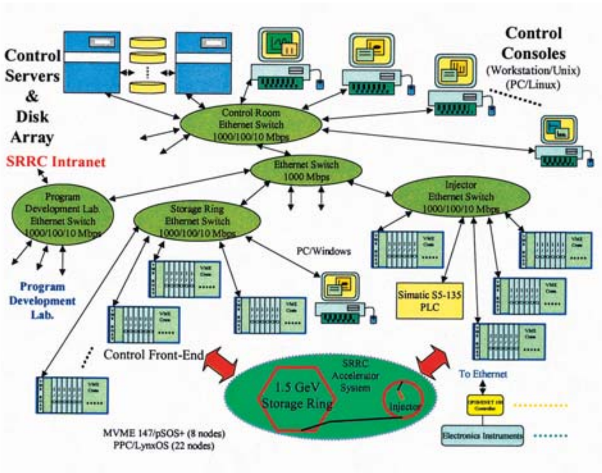

Fig. 4: Infrastructure of the control system in 2003.

the data collector. The pre-injector control system is a PLC-based system using Simens' Simatic S5-135 PLC and is connected to Multibus crate by Ethernet. A BitBus network that connects about 20 nodes together to Multibus crate controls all booster devices. The control system are operated in stand-alone mode before the control system integration in late 1997.

Expansion and Integration of the Control System

The demands on the control system have been increasing steadily for accommodating newly installed devices and for enhancing the performance of the accelerator control system. The control system benefits from the advances in electronic technology during the last decade on various application fields. The control network evolved from 10 Mb/sec coaxial CSMA/CD based

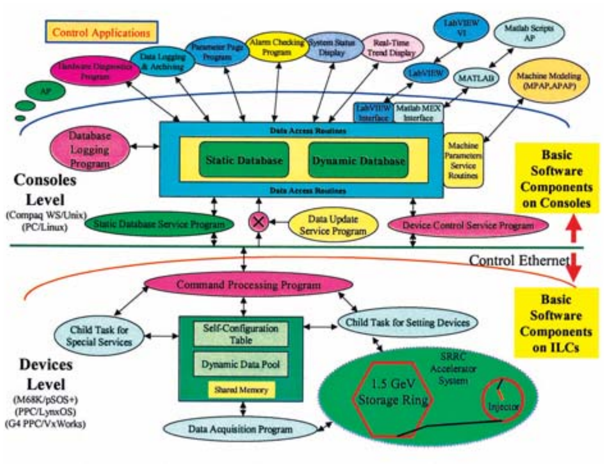

Fig. 5: Software structure of the control system in 2003.

Ethernet to hub based Ethernet during 1996~1998 and then to switched based network around 1998. The fast Ethernet was brought into the control system in 1999. The control network was re-engineered using 100 Mb/sec Ethernet with Gigabit Ethernet backbones in 2002. The computer hardware evolved from the slow VAX/VMS system to Unix-based workstation system. The control database was transfered to Unix system in 1997 successfully, and the Unix control console was also incorporated at the same time. Since the MVME-147 CPU board of ILC was discontinued by the vendor and fast clock rate CPU board was introduced in the market, we had to migrate the ILC environment onto the new PowerPC based CPU board. This was done in late 1997. Starting from 1997, all new VME systems have been implemented on PowerPC CPU modules. The architecture of the software environment on the new system is the same as that on the old system. All CPU modules are compatible with the previous version with only some minor changes, which allows an easy path for future upgrade. To simplify the operation of the injector system, integration of the old turnkey injector control system with the main control system was done in early 1998.

The present control system is a hybrid of old and new system with mostly new ILCs . Events of the evolving control system are summarized in the following list in chronological order:

1992: Control system prototype
1993: Control system commissioning
1994: W20 control system integration
1995: U10 control system implementation
1996: DSP -based orbit feedback system
1997: Storage ring quadruple power supply upgrade
U5 control system integration
Migrate database to Unix environment
1998: First Unix control console
Unix process computer
U10 control upgrade
Booster control system integration
PowerPC Lynx based ILC
1999: U9 control system integration
EPU5.6 control system implementation
Unix console
2000: Control system upgrade to support

1.5 GeV operation of the booster
2001: Matlab/LabVIEW interface
PC/Linux control console
2002: SWLS control system integration
G4 PowerPC/Lynx ILC
2003: G4 PowerPC orbit feedback system upgrade
Digital BPM integration
SMPW6 Control Integration
SRF control system integration

Operation Experience and Future Prospect

Control technology changes very rapidly compared with the lifecycle of the accelerator facilities. This situation provides many opportunities for the upgrade or more sophisticated re-engineering of the control system of the facility. The overall performance is improved although with an accompanying increase in the complexity of maintenance. A good control system will enhance the productivity of all end users, including operators, maintainance and development staff. It provides a mechanism for supporting communication and coordination among people. The improvement of the control system plays an important role in supporting major upgrades of the accelerator system of NSRRC, including super-conducting RF, superconducting insertion devices, and top-up operation. Based on the operation experience accumulated in the last decade, directions of the development of control system are summarized as follows:

Increasing performance and productivity:

- Control resolution (> 20 Bits ADC/DAC) upgrade for magnet system.
- Adopting commercial software tools.
- Sophisticated feedback system development.
- Application program development
- Signal processing techniques development
- VME64/PCI crate system for demanding applications
- Electronic log book development
- Object-oriented technology development
- Web technology development

Enhancing reliability and maintainability:

- Simplification of the system hardware and software
- Preventive maintenance of the system
- Upgrading pre-injector control system
- Replacing obsolete BITBUS node system
- Upgrading old VME CPU module
- Enhancing the reliability of the console computers
- Developing diagnostic tools for Subsystems
- Enhancing personnel training

All of above tasks are carried out continuously. The short-term goal is to provide a friendly and productive control system for facility operators after major upgrades of the accelerator system in the coming year.

Beam Instrumentation

Beam diagnostics is an essential element of any accelerator facility. It is the "sensory organ" of the accelerator showing the properties and the behaviors of the beam. Without adequate diagnostics, one would grope around in the dark and the fine tune function of accelerator or beam stability improvement can hardly be achieved.

The diagnostics for the pre-injector consists of gap and toroidal monitors to observe the transmission of the linac system and beam line. The booster synchrotron has 8 fluorescence screens to aid the tuning of the beam. There are 23 sets of BPMs for orbit measurement. One DCCT is used to measure the beam intensity of booster synchrotron. Two strip line electrodes are also installed to observe the bunch signal. A fast current transformer is installed for filling pattern observation. One synchrotron radiation port is included to measure the beam size as function of beam energy.

The diagnostic system for the storage ring is based on the well-established techniques adopted for many modern light sources. The main function of a storage ring's diagnostic system is to measure the main parameters of the beam in the time and space domain, and to provide the necessary data for the feedback system and machine control. During the early stage of commissioning, the storage ring were equipped with various types of diagnostic instruments, including beam position monitors, fluorescence screen monitors, intensity monitors, strip line electrodes, and synchrotron radiation monitor system. There were 47 BPMs equipped with multiplexing BPM electronics developed in-house during the commissioning phase. The signals picked up by the button electrodes was multiplexed by the RF multiplexer and processed by the heterodyne receiver. The demodulated signal is de-multiplexed by the timing circuitry that is synchronized with the RF multiplexing. Those BPM signals are acquired by a VME crate control system. Additional BPMs are installed both upstream and downstream of the insertion devices. There are 58 button-type BPMs installed in the storage ring in 2003. The beam intensity is measured by commercial DCCT and digitized by the 16 Bits ADC channel of a 7-1/2 digits DVM. Lifetime is calculated from the measured beam current. The screen monitors are used for visual observation of the initial trajectory of the injected beam and to aid operator in adjusting the injection conditions, being especially useful at the early commissioning stage. BTS diagnostics element includes stripline type BPM, current transformer, and fluorescence screen. The VME - based data acquisition and processing unit, as well as the timing control electronic module, are implemented to support the diagnostic operation.

There are increasing demands on the functionality and performance of the diagnostics system since the machine was commissioned and continuous efforts are necessary for improving the system. The multiplexing closed orbit measurement system for the booster synchrotron has been implemented in 1996 to investigate the orbit behavior during ramping. In order to study the field tracking performance of the three magnet families during ramping, three BPMs are equipped with log-ratio electronics and transient digitizers to record turn-by-turn beam position accompanied by beam excitation system. A diagnostics kicker was installed to shake the stored beam. In order to make the measurement of the low current single bunch beam more easily, a new current transformer is installed. Log-ratio BPM electronics are applied in the BPM system of the transport line. This system is a complementary tool to the screen monitor for optimizing and tuning the performance of the transport line. BPM electronics developed in-house for the storage ring closed orbit measurement has been replaced by commercial BPM electronics in 1998, with improvement in reliability and performance. To serve various beam physics studies and beam parameter measurements, log ratio BPM electronics are brought into the storage ring to acquire turn-by-turn beam position. Newly developed digital BPMs prototypes which use digital receiver techniques are integrated into the existing system for evaluating their performance The system supports multi-operation modes, including closed orbit and turn-by-turn measurements.

High performance diagnostics is essential to fulfill the stringent requirement of operating a highly stable beam in longitudinal and transverse planes. To enhance the functionality of the beam diagnostics and to support routine operation and beam physics studies are the main directions of our efforts.

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