STATUS OF THE X-RAY FEL CONTROL SYSTEM AT SPRING-8

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Abstract

The X-ray free electron laser (XFEL) project at SPring-8 aims to build an X-ray lasing facility that generates brilliant coherent X-ray beams with wavelength below 0.1nm. The facility consists of short-period in-vacuum undulators and an 8GeV high-gradient C-band linear accelerator that makes the machine compact. The total length of the facility is 700m. The machine tunnel construction started in April 2007, and electron beam commissioning will start in February 2011. We designed the control system for the XFEL based on the present SCSS test accelerator. The control system is implemented in MADOCA framework that follows a 3-tier control model. The three layers consist of an I/F layer based on DeviceNet, PLC and VME; RPC-based communication middleware; and Linux consoles for the human-machine I/F. The control system also has a synchronized data-taking scheme to achieve fast beam-based optics tuning. Most of the XFEL RF control equipment will be installed in water-cooled 19inch racks to maintain constant temperature in order to guarantee stable RF phase control. In this paper, we give an overview of the project and describe the design of the control system.

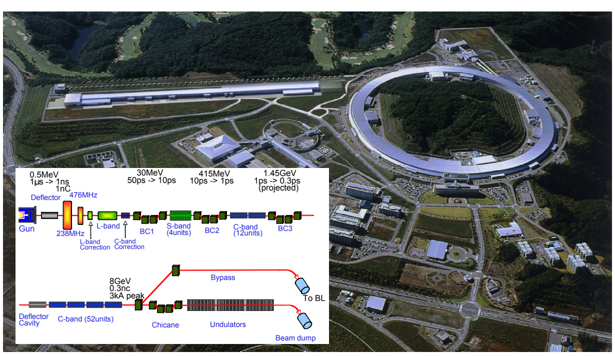

Figure 1: SPring-8 SR facility, XFEL (under construction) shown by computer graphics (upper left) and layout of XFEL (lower left).

INTRODUCTION

The X-ray FEL (XFEL) project at SPring-8 aims to build an 8GeV XFEL facility in the SPring-8 site. An XFEL based on the self-amplification of spontaneous emission usually requires a large-scale accelerator and a long undulator, which would make the construction cost quite high. A combination of a short-period in-vacuum undulator and a high-gradient C-band accelerator makes the machine compact and lowers the cost. The length of the accelerator (undulators) is about 400m (230m). Figure 1 shows a bird's-eye view of the SPring-8 synchrotron radiation facility and the XFEL completed facility that is imposed by computer graphics. Five X-ray beamlines will be built to provide various opportunities for experimental use of the XFEL, and synergetic operation with the present synchrotron radiation facility will open the door to a new era. The XFEL construction started in April this year, and electron beam commissioning will start in February 2011.

The first phase of the XFEL project is the construction of a test facility, that is, the SCSS test accelerator [1][2]. The test accelerator consists of essential components for the XFEL. In the SCSS, all components were checked to ensure feasibility and reliability.

OVERVIEW OF XFEL

Figure 1 shows the machine layout of XFEL. The XFEL consists of an electron gun [3], beam deflector, prebuncher cavity (238MHz), booster cavity (476MHz), L-band correction cavity (1428MHz), L-band buncher, C-band (5712MHz) correction linac, S-band (2856MHz) linacs, and main C-band linacs [4]. In addition, a number of in-vacuum undulators of 4.5m length will be aligned after the accelerator. A peak current of more than 3kA is generated by compressing the bunch length in the injector (prebuncher, buncher and booster) and in three stages of the magnetic-chicane bunch compressors. We will use 128 units of the C-band accelerating structure and 18 units of the undulator. The electron beam repetition rate will be 60Hz. The beam energy will reach 8GeV and the X-ray laser wavelength will be below 0.1 nm.

DESIGN OF CONTROL SYSTEM

We designed the XFEL control system based on the SCSS test accelerator [2], which uses the MADOCA (Message And Database Oriented Control Architecture) framework [5]. The control system employs the three-tier structure called "the standard model". We will install Linux PCs as operator consoles and database servers in the presentation layer. The device control layer consists of parts such as the VMEbus system, and Programmable Logic Controller (PLC). The RPC-based communication layer connects the operator consoles and VME systems over a Gigabit Ethernet, as shown in figure 2.

The facility requires extremely high RF phase stability to achieve the desired X-ray lasing [6]. This stability will be achieved by stabilizing the machine components locally. We do not strongly depend on the control system for stability. For the local control of those components, we adopt a slow control system deploying PLCs as one of the field buses from a VME system. PLCs are linked with VME systems through the FL-net, that is the Ethernet-based factory floor network [7].

We will apply shot-by-shot synchronous data acquisition from beam position monitors (BPMs) and fast control of power supplies of steering magnets to beam-based optics tuning. For this purpose, we build a fast control system using the VME system directly. We plan to introduce a shared memory network and an event-driven data acquisition framework for the shot-by-shot synchronous data acquisition [8]. An optical-linked remote I/O system, OPT-VME, is used to control the magnet power supplies [8]. The response time is a millisecond or less when there are assuming two or more magnet power supplies in operation at the same time.

Feedback from Test Accelerator Operation

During the operation of the test accelerator, we found that RF phase variation in the injector was very sensitive to lasing conditions. We needed to suppress the temperature change of the cavities to 0.01°C or less.

Because of the small tolerance of the RF phase stability, precise temperature measurement equipment must be used for cooling water controllers. In addition, we must take care with environmental conditions such as air temperature, water temperature and power line voltage drift. To satisfy these requirements, we plan to include the facility utility in the accelerator control system.

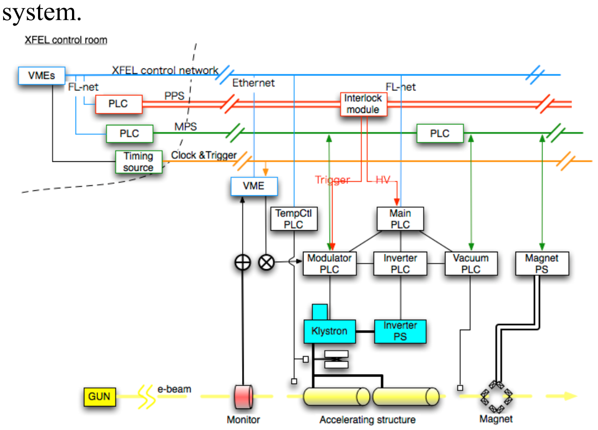

Figure 2: Schematic of control system.

CONTROL SYSTEM HARDWARE

Programmable Logic Controllers

As described in the previous section, PLCs are adopted for slow equipment control. They are preferable for rigid control such as PID control and local device interlock. In addition, they are useful for local operation using graphic panels. We apply PLCs to, for example, the modulators [10], vacuum system and cooling water system. Each PLC will be linked with an optical fiber to avoid electromagnetic interference.

To reduce the amount of wiring, we also employ DeviceNet as a remote I/O system of the PLCs.

VME Systems

We will adopt a VME CPU board based on the IA architecture and run Solaris 10 or later on it.

High-speed A/D and D/A VME boards [11] working with a 238MHz clock are adopted to detect phase/amplitude signals generated by the klystron, and to generate signals of Q and I components for the klystron input. The A/D and D/A combination allows a digital feedback of a low-level RF system for driving the C-band klystrons.

The trigger delay unit (TDU) [12] is a 5712MHz synchronous delay VME module. To synchronize the 5712 MHz RF signal, the TDU employs fast GaAs logic and FPGA with 15bit counters and prescalars. One of the counters will be used for beam shot number counting, which can be applied to shot-by-shot synchronous data acquisition.

To guarantee stable RF control, we will install RF low-level components including the TDU, A/D and D/A VME modules into water-cooled (26±0.2˚C) 19-inch racks to maintain constant temperature. In addition, the flow of cooling air must be designed to not shake the RF cables.

Network System

We adopt a simple network configuration to realize both high performance and simple network management. A Gigabit Ethernet with optical fibers will be installed as a backbone network of the facility, as shown in figure 3. The switched network without routers realizes a low-latency controllability of wire speed. To separate the function of the network, a virtual LAN (VLAN) will be used. VLAN allows the sharing of the backbone with a control network and FL-net network. For maintenance a wireless LAN will be installed in the klystron gallery and the accelerator tunnel. We are studying a 10Gigabit Ethernet for a real-time data acquisition of a 2- dimensional beam profile.

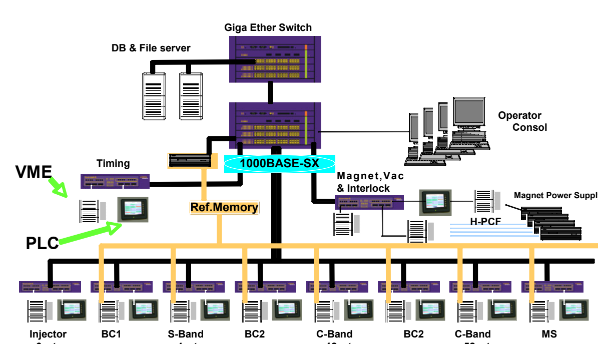

Figure 3: Schematic of network system.

Operator Consoles and Database Servers

We select an IA architecture PC running on SUSE Linux Enterprise for operator consoles. These operator consoles are equipped with the dedicated graphic boards to support multi-displays.

For the main database of the XFEL control system, the existing Sybase-based DB server for SPring-8 will be extended. In addition we will install MySQL-based database servers for to enable fast data acquisition.

Interlock System

The XFEL interlock system is completely divided into a personal protection system (PPS) and machine protection system (MPS), because the XFEL is a large facility, which makes an interlock system simple. The PPS controls the entry of persons into the radiation-controlled area and prevents radiation damage. The MPS protects the machine from damage due to overheating, excessive voltage and vacuum leakage. When the PPS and the MPS are separated, the PPS can be made with small and simple logic, which improves the reliability of the system. Since the XFEL is a long facility, the PPS consists of PLCs with a high-speed optical FA link and custom modules for transmitting a fast signal that stops the gun and RF.

The MPS consists of PLCs in order to handle various machine operation modes. We use an optical link based on Gigabit Ethernet technology to guarantee the response time of less than 16msec.

CONTROL SYSTEM SOFTWARE

We use MADOCA for the XFEL control framework as well as for the test accelerator. The MADOCA software framework is adaptive and scalable from the test accelerator to the XFEL. Accelerator operation programs will be developed using X-Mate, a GUI builder on the bases of X-Window.

We will employ the MySQL database system for fast data storage in addition to the Sybase RDBMS for machine status logging [9]. We have tested MySQL for storing data of the test accelerator. We use the in-memory (heap) storage engine of MySQL for fast and sustained data writing. The in-memory database engine, which is not use a disk-I/O and a transaction function, is designed for maximum speed to store a data. It stores 44 BPM floating data in the form of one line text data for speed. Less than one of one million data written in 60Hz was lost in our measurement.

We will apply a virtualization technology, called Solaris Containers, to some of the VME systems that control multiple equipment groups. The technology enables us to separate such a VME system into some virtual hosts. Each virtual host manages an independent equipment group [13].

REFERENCES

[1] T. Shintake, “Status of SPring-8 compact SASE source FEL project”, NIMA21188, Nuclear Inst. and Methods in Physics Research, A, 507 (2003) 382-397.

[2] T. Fukui et al., “Status of the SCSS control system – first phase of an 8GeV XFEL project in SPring-8”, Icalepcs2005, Geneva, October 2005.

[3] K. Togawa et al., “Emittance Measurement on the CeB6 Electron Gun for the SPring-8 Compact SASE Source FEL Project”, APAC2004, Gyeongju, Korea, March 2004.

[4] T. Inagaki et al., “High Power Test of the Compact, Oil-filled Modulator for the C-band Klystron”, APAC2004, Gyeongju, Korea, March 2004.

[5] R. Tanaka et al., “The first operation of control system at the SPring-8 storage ring”, Proc. of ICALEPCS'97, Beijing, China, 1997, p. 1.

[6] Y. Otake et al., “Timing and LLRF system of Japanese XFEL to realize femto-seconds stability”, in these proceedings.

[7] http://www.jemanet.or.jp/Japanese/hyojun/opcn_e/top-opcn.htm

[8] T. Masuda et al., “Upgrade of the SPring-8 Linac Control by Re-engineering the VME Systems for Maximizing Availability”, Icalepcs2003, Gyeongju, October 2003.

[9] A. Yamashita et.al., “Data Archiving and Retrieval for SPring-8 Accelerator Complex”, Icalepcs’99, Trieste, Oct. 1999.

[10] K. Shirasawa et al., “KLYSTRON CONTROL SYSTEM FOR THE XFEL/SPring-8 LINAC”, Proceedings of Particle Accelerator Society of Japan, Wako, Japan, August 2007.

[11] T. Fukui et al., “A development of high-speed A/D and D/A VME board for a low level RF system of the SCSS”, Icalepcs2005, Geneva, October 2005.

[12] N. Hosoda et al., “Development of 5712MHz Synchronous Delay VME Module”, Proceedings of Particle Accelerator Society of Japan, Saga, Japan, July 2005.

[13] T. Masuda et al., “Application of a virtualization technology to VME controllers”, in these proceedings.