CONTROL SYSTEM FOR A DEDICATED ACCELERATOR FOR SACLA WIDE-BAND BEAM LINE

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Abstract

The X-ray free electron laser facility SACLA has provided opportunities for the exploration of new science. However, these opportunities are severely limited, because only one beam line (beam line 3) is currently available for user experiments. Therefore, there is an urgent need to increase the number of beam lines available. One approach is to install an additional accelerator. We decided to move the SCSS prototype accelerator to an upstream space of beam line 1 in the SACLA undulator hall and reused it as a dedicated accelerator for the beam line. We started an RF conditioning of the dedicated accelerator in October 2014 using MyCC, a MySQL-based temporary data acquisition system compatible with MADOCA. After the RF conditioning, we smoothly transitioned the system from MyCC to MADOCA. The beam commissioning of the dedicated accelerator started in September 2015, and we successfully observed the first extreme ultraviolet free electron laser in October 2015. The control system ensures the coordinated seamless operation of the SACLA accelerator and the dedicated accelerator.

INTRODUCTION

The X-ray free-electron laser (XFEL) facility SACLA (SPring-8 Angstrom Compact X-ray free electron LAser) aims to generate coherent X-ray beams with a wavelength of less than 0.1 nm [1]. It consists of a 400-m-long 8 GeV linear accelerator and a 120-m-long insertion device. In 2011, a commissioning of SACLA was started with beam line 3 (BL3). After the success of generating XFELs, the user experiments at BL3 started in 2012. The SACLA is providing opportunities for the exploration of new science.

Because an XFEL facility employs a linear accelerator, it provides an electron beam for only one beam line at a time. This means that its availability for user experiments is severely limited compared to that of a storage ring-type photon facility such as SPring-8, which has 57 beam lines. Therefore, there is an urgent need to allow a multi-beamline operation of SACLA.

One approach is to deliver an electron beam to multiple beamlines pulse-to-pulse using fast switching magnets [2]. Originally, a DC bending magnet at the end of the accelerator was used to switch an electron beam path between beam lines. We replaced it with a fast kicker magnet and DC twin septum magnets in January 2015. As a result, we successively injected electron beams to beam line 2 (BL2) and BL3 and achieved simultaneous lasing in both beam lines.

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Another approach is to install an additional accelerator. Prior to the construction of SACLA, we built a SCSS (SPring-8 Compact SASE Source) prototype accelerator in 2005 to verify the feasibility of lasing using a thermionic gun [3]. We achieved the generation of SASE FEL with a wavelength of 50–60 nm in an extreme ultraviolet (EUV) region in 2007. After the initial purpose was accomplished, it was used for user experiments until 2013. We decided to move the SCSS prototype accelerator to an upstream space of beam line 1 (BL1) in the SACLA undulator hall, and reused it as a dedicated accelerator for BL1 [4].

The SACLA accelerator and the dedicated accelerator share one beam line, BL1. We had to coordinate both accelerator operations, while the independence was maintained as much as possible.

When we designed a control system for the dedicated accelerator, it was natural to use the MADOCA (Message And Database Oriented Control Architecture) control framework, which was already used at the SCSS prototype accelerator and the SACLA [5–7].

The requirements for the control system were as follows. The first priority was not to disturb SACLA user experiments. The RF conditioning was tightly scheduled to start in October 2014 and the beam commissioning was scheduled in September 2015. The human resources available to develop the system were limited. The period in which we could enter the undulator hall to test equipment was also limited. Moreover, the dedicated accelerator was operated at the SACLA control room.

Our strategies were as follows. We reused all control software developed for SACLA. At the start of the RF conditioning, we used a temporary data acquisition (DAQ) system compatible with MADOCA, because some RF components were not installed. After the RF conditioning and a completion of the construction, we switched the DAQ system from MyCC to MADOCA.

In this paper, the status of the dedicated accelerator is reported in terms of its control system.

THE DEDICATED ACCELERATOR FOR BL1

Figure 1 shows a schematic view of the dedicated accelerator for BL1 at the SACLA facility. Although we planned for five beam lines in the undulator hall, only three beam lines had been constructed until now. The bending angle of the transport lines from SACLA to BL1 is 3 degrees and BL1 is located 6 m apart from the SACLA accelerator in parallel. Therefore, a 110-m-long vacant space exists upstream of BL1. The dedicated accelerator was placed in that space.

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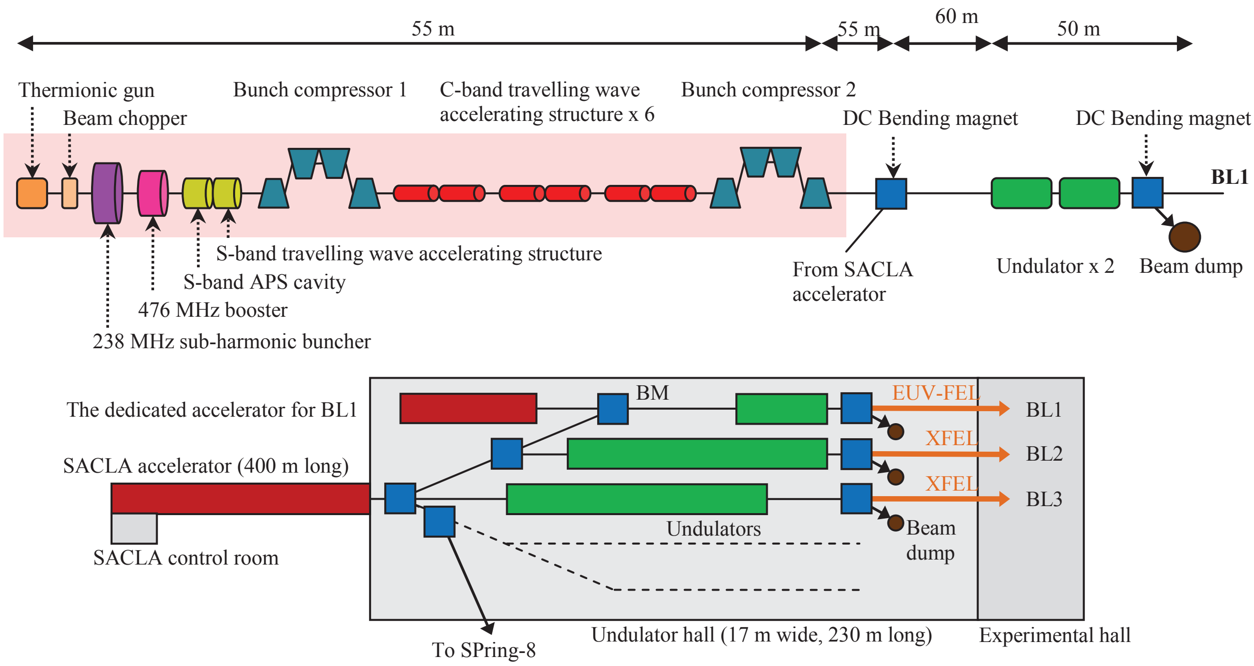

Figure 1: Schematic view of the dedicated accelerator for BL1 at the SACLA facility.

All RF components except C-band were reused from the SCSS prototype accelerator. The C-band accelerating structure was newly designed to increase the beam energy per unit length. We installed 3 C-band units at this stage. All low level RF (LLRF) modules, timing modules, and monitor modules, such as the beam position monitor and beam current monitor, were replaced by modules developed for SACLA to achieve higher stability and to standardize their control system. The design parameters of the dedicated accelerator are listed in Table 1. At the downstream of bunch compressor 2, a space of 9 C-band units is reserved for a future upgrade. If 9 C-band units are added, electron beam energy will reach 1.4 GeV and we can provide soft X-ray FEL to users.

Table 1: Design Parameters of the Dedicated Accelerator

Accelerator	Beam energy	420 MeV
	Bunch charge	0.3 nC
	Peak current	300 A
	Repetition rate	60 Hz
Undulator	Periodic length	18 mm
	K parameter	2.1 (max)
	Number of periods	460
FEL	Wavelength	42 nm (K = 2.1)
	Pulse energy	100 uJ

We had to concentrate the construction work in the undulator hall to summer shutdown periods, because we could not enter it during the user experiment periods of SACLA. In summer 2013, the injector part from an electron gun to bunch compressor 1 was installed. The remaining part was installed in summer 2014. However, works outside of the undulator hall (for example, the installation of 19-inch racks containing the VME systems, programmable logic controllers (PLCs), and power supplies) were performed during user experiments on the condition that the works did not disturb user experiments.

EQUIPMENT CONTROL HARDWARE

VME System

We used the CPU board XVB601 (Intel Core i7), manufactured by GE, for the LLRF component, and SVA041 (Intel Pentium M), manufactured by Sanritz, for the other components.

The high speed A/D board MVD-ADC01 (238-MHz sampling, 16-bit resolution, and 4-channel input), manufactured by MELOS, is used for RF phase/amplitude detection of the RF components and readout of the beam position monitor/beam current monitor. The high speed D/A board MVD-DAC02 (238-MHz sampling, 16-bit resolution, and 4-channel output), manufactured by MELOS, is used to control the phase/amplitude of the driving RF signal of a klystron using an IQ modulator. The high resolution A/D board MVD-ADC04 (1-MHz sampling, 24-bit resolution, and 4-channel input), manufactured by MELOS, is used for a CSR bunch length monitor.

An 8-channel trigger delay unit (TDU), manufactured by MELOS, generates very low jitter trigger signals from a 60 Hz master trigger signal distributed via the SACLA master trigger/reference RF clock distribution system. This means the dedicated accelerator and SACLA work synchronously. The TDU has a function to count the number of master trigger inputs, and the function is used

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to add a tag number to each A/D data in an event-synchronized DAQ process [8]. In the VME system without a TDU, an interrupt register board (INTREG) Axvme4900, manufactured by ARKUS, counts the number of master trigger signals.

To control the power supplies of the 97 magnets in total of the dedicated accelerator, an optical remote I/O system OPT-VME/OPT-DIO, manufactured by Hitz, is used. The OPT-VME is a master board and can control 4 OPT-DIO slave boards. Most of the OPT-VME/OPT-DIO boards used at the prototype accelerator were reused after cleaning and inspection to ensure that there was no degradation of quality.

To access PLC, we use a VME-based FL-net interface board. FL-net is one of the Ethernet-based open standard protocols for a factory floor network authorized by the consortium in Japan.

We prepared 24 VME systems for the dedicated accelerator. Table 2 lists the number of VME boards used. In basic terms, each VME system is located in the south klystron gallery near the equipment. However, the VME systems for FL-net are placed in the SACLA control room because that is the only network which requires it.

Table 2: Number of VME Boards for the Dedicated Accelerator

	CPU	MVD-ADC01	MVD-DAC02	TDU	MVD-ADC04	INTREG	OPT-VME	FL-net
LLRF	6	17	6	6	0	0	0	0
HPRF	2	0	0	0	0	0	0	4
monitor	4	11	0	0	1	3	0	1
timing	2	0	0	1	0	0	0	1
magnet	6	0	0	0	0	0	15	0
vacuum	2	0	0	0	0	0	0	3
utility	2	0	0	0	0	0	0	4
Total	24	28	6	7	1	3	15	13

PLC

PLCs are used where slow and rigid equipment control is required; for example, in the high voltage power supply of a klystron (HPRF), the cooling water system, the vacuum system, and the environmental parameter monitor of a 19-inch rack system. As mentioned above, PLCs are remotely controlled via the FL-net VME interface board. In addition, we prepared programmable graphic panels near the PLCs for local control.

Interlock System

The interlock system of SACLA consists of a personal protection system for human radiation safety, a machine protection system against the failure of the vacuum components or the magnet power supply, and a beam operation interlock system for the management of the beam route and the amount of electron charge/energy.

The beam operation interlock system for the dedicated accelerator was installed separately from the system for SACLA. However, both systems share the excitation current data of the DC bending magnet, located at a junction point of the two accelerators to manage which accelerator has the permission to inject an electron beam to BL1.

The machine protection system was modified to manage which gate valves should be closed if a vacuum leak occurred in one accelerator, because the user experiments of the other accelerator must not be disturbed.

SOFTWARE

Equipment Control

The operating system of the VME CPU is Solaris 11 (64 bit) for the LLRF component and Solaris 10 (32 bit) for the other components. In the VME system, three basic MADOCA processes are running. These are: a message server process which receives control messages from operator consoles, an equipment manager process which accesses equipment, and a poller process which collects data at a constant frequency, such as at 0.5 Hz. In LLRFs and the monitor VME, an event-synchronized DAQ process which collects data for all beams shot at 30 pps together with an event tag number is also running. Furthermore, in the LLRF VME, a PID feedback process to stabilize the RF phase/amplitude and an abnormal RF waveform acquisition process are running [9]. Although we are required to run such high-load processes in the LLRF VME, the VME system is still working well.

Database

As indicated by the unabbreviated name of MADOCA, the database is indispensable. The Sybase RDBMS is the main database in SACLA [10]. We use it for poller data logging, signal management, equipment setting parameter management, and equipment alarm management. We decided to treat the dedicated accelerator data in the SACLA database.

In October 2014 while SACLA user experiments were ongoing, we needed to start an RF conditioning of the dedicated accelerator. Before the start, new equipment data and tables related to the dedicated accelerator had to be added to the database. However, we did not want to do this because the smallest possibility of a disruption to user experiments caused by a mistake in database operation always existed.

We had developed a simple DAQ system, MyCC, which is compatible with MADOCA [11]. The target of MyCC is DAQ of a small number of signals in a limited acquisition period. This allows for frequent modification of the equipment system. The features of MyCC are as follows. A MySQL database dedicated for MyCC is used instead of Sybase. The three basic MADOCA processes on the VME CPU are used in MyCC without any change. The MyCC signal registration list is created from the MADOCA signal registration list. This means that if we

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finish the configurations of the MyCC signal registration list, we do not have to modify the MADOCA signal registration list. The MyCC database API has the exact same function calls as those of the MADOCA database API. Therefore, without any source code modification, an operation GUI application works for both MyCC and MADOCA, with the only relinking the API libraries. For these reasons, we adopted MyCC for the RF conditioning.

About 2,800 signals were registered in MyCC, and the RF conditioning was started on schedule. In January 2015 during a winter shutdown, the DAQ was smoothly transitioned from MyCC to MADOCA using a proof signal registration list. The RF conditioning lasted until July 2015 and achieved a sufficient acceleration gradient and an acceptable RF trip rate.

In addition to the Sybase server, a MySQL server for the event-synchronized DAQ and a Cassandra server for the abnormal RF waveform acquisition are also used in SACLA. In August 2015 during a summer shutdown, we registered equipment signals to these servers. Table 3 lists the number of equipment signals registered in the databases.

Table 3: Number of Equipment Signals Registered in the Databases

	SACLA		The dedicated accelerator	
	Sybase	MySQL	Sybase	MySQL
Analogue data	43,668	1,612	2,519	103
Digital data	16,130	902	1,103	62
Total	59,818	2,514	3,622	165

Graphical User Interface (GUI)

The SACLA is operated at the SACLA control room. We used nine PCs (IA architecture, SUSE Linux Enterprise, dual displays) for the operator consoles. Operation GUIs were developed using X-mate, a GUI development support tool based on X-Window.

Because the SACLA accelerator and the dedicated accelerator had to be operated seamlessly, we developed the integrated operation GUIs.

Figure 2 shows an operation GUI for the magnet power supplies. When a section of the overall view in the upper part is selected, a detailed view of the section is displayed in the lower part. To decrease the chance of mistakes in operation, the background color of the detail view is changed to clarify which accelerator is selected. The equipment parameters of BL1, such as the magnet power supply, timing delay, and beam monitors, differ between the SACLA accelerator and the dedicated accelerator. Therefore, the GUI was developed to select appropriate parameters using beam route information.

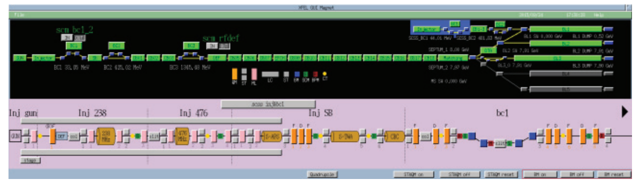

Figure 2: Operation GUI for magnet power supplies.

CONCLUSION

We constructed the control system of the dedicated accelerator for BL1 at SACLA. The MySQL-based temporary data acquisition system, MyCC, enabled the RF conditioning of the dedicated accelerator without affecting SACLA user experiments. After the transition from MyCC to MADOCA and the completion of the preparation for the all-control system, the commissioning of the dedicated accelerator started in September 2015. We successfully observed the first EUV-FEL at BL1 using the dedicated accelerator in October 2015. The control system ensures the coordinated seamless operation of the SACLA accelerator and the dedicated accelerator. We will start user experiments at BL1 before March 2016.

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