

INAUGURATION OF THE XFEL FACILITY, SACLA, IN SPRING-8

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Abstract

The construction of the X-ray free electron laser facility (SACLA) in SPring-8 has started in 2006. After 5 years of construction, the facility has completed to accelerate electron beams in February 2011. The C-band linac accelerates beams up to 8GeV. The beam size is compressed to a length of 30fs, and the beams are introduced to the insertion devices to generate 0.06nm X-ray laser. The first SASE X-ray laser was observed at the beginning of June 2011. The first scientific experiment will start at the end of October this year. The control system for SACLA adopts the 3-tier standard model by using MADOCA framework developed in SPring-8. The upper control layer consists of Linux PCs for operator consoles, Sybase RDBMS for data logging and FC-based NAS for NFS. The lower consists of Solaris-operated VME systems and the PLC is used for slow control. The Device-net is adopted for the frontend devices to reduce signal cables. The beam-synchronized data-taking link is installed to meet 60Hz beam operation. The accelerator control has gateways to the facility utility system not only to monitor devices but also control the tuning points of the cooling water.

FACILITY STATUS

The X-ray Free Electron Laser (XFEL) is generated by a combination of a high-energy linear accelerator and a set of insertion devices (ID). The XFEL project in SPring-8, now called SACLA, has started in 2006 with the success of SCSS prototype accelerator [1]. The SACLA facility is designed to be compact to fit within 700m available spaces in the SPring-8 site with lower construction cost.



Figure 1: A bird eyes view of the SACLA facility. The electron beams are generated and accelerated from the right hand side to the left inside the linac yard. A picture of SPring-8 site is imposed.

The main component of the SACLA accelerator consists of 64 C-band RF units of 5.7GHz operation frequency to accelerate electron beams up to 8GeV. The initial beam length is compressed to produce the laser peak power generated by a length of 30fs electron beams. The 8GeV-electron beams are introduced to the 18 units of ID to generate less than 0.1nm X-ray laser. A total length of the accelerator is 400m, and that of ID is 230m. The SACLA has a unique experimental hall for cooperative experiments that uses both X-rays from SACLA and SPring-8 for example pump-up and probe experiments. The SACLA facility is shown in Figure 1.

The facility construction has completed in February 2011. The accelerator structure conditioning with RF high-power started from several months before the facility completion. The electron beam commissioning has started right after the completion. The electron beams were successfully accelerated up to 8GeV and the first light from an alignment ID was observed shortly after. After three months beam tuning, high brilliant SASE X-ray was observed at the beginning of June as can be seen in Figure 2. The SASE laser signal has homogeneous round shape, and the maximum laser power is ~4GW. The laser beam intensity is quite stable (~18%) to be ready for coherent X-ray experiments.

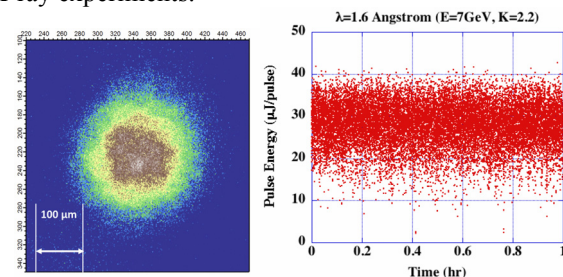


Figure 2: The observed profile of the SASE laser signal at 110m downstream of the last ID with 10keV (left). And the measured laser intensity stability (~18% fluctuation) during one-hour operation (right).

The laser wavelength has been improved from 0.16nm in June to 0.08nm at the end of July along with the progress of the beam tuning, as can be seen in Figure 3. Now, the laser beams are reproducible [2]. The electron beam tuning continues to achieve the laser coherency saturation and the first scientific experiment will start at the end of October this year.

The SACLA control system started smoothly at the early stage of the electron beam commissioning. The established MADOCA control framework helped smooth rise up of the SACLA control system and reduced time-consuming debugging work for the operation software.

Because of a large number of control points, however the control system had to be tuned suitably to meet high load, and system reliability was achieved along with the progress of the beam commissioning.

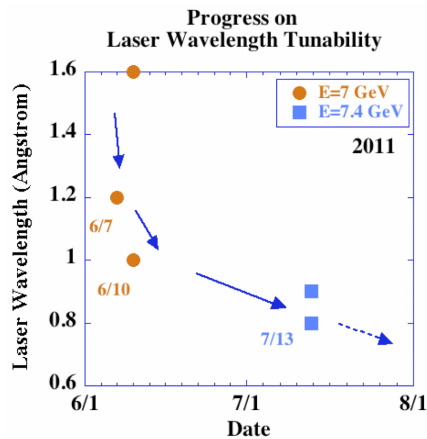


Figure 3: Improvement of laser wavelength of SACLA. The wavelength improved from 0.16nm to 0.06nm after two months beam tuning.

DESIGN CONCEPT

The design of the control system for SACLA is based on that of for SCSS test accelerator [3]. SCSS was constructed for the principle study of the free electron laser mechanism by using a linac and technology assurance towards the coming 8GeV XFEL machine, SACLA. We used common control devices for each subsystem of SACLA as much as possible [3]. This comes from the short construction period for the fast start up and less human resources coming from the joint project management sharing with SPring-8 operation.

Methodology Toward X-ray Laser

The basic elements for the SACLA control system shares commonly with those of SCSS, except for the difference coming from energy difference. The electron beam energy of SCSS is 250MeV on the other hand SACLA is 8GeV. This difference results the difference of the number of elements of the control system to build and equipment precision coming from the short wavelength. The wavelength of SCSS laser is around 50nm, on the other hand SACLA generates very short X-ray less than 0.1nm. The short wavelength also requires fine alignment of accelerator components and a series of ID, precise LLRF phase control, stable temperature both for high frequency timing signals and cooling water for accelerating structure [4]. Hence, we realized the facility utility control from the accelerator control [5].

Standard Control Structure with 3-tire Model

The SCALA control system follows the standard control structure with the established 3-tire model. The upper control layer consists of PCs running with SuSE Linux for operator consoles, Sybase RDBMS for data logging and FC-based NAS for NFS file server. The RDB

data schema and the file server configurations are copied from existing SPring-8 control system with minimum modification. The lower layer consists of Solaris-operated VME systems for the faster control. The programmable logic controller (PLC) is used for slow control for example vacuum systems. The Device-net connected to the PLC module, is adopted for the frontend device control to reduce the number of signal cables. The VMEbus systems have a beam-synchronized data-taking link of a shared memory network to meet 60Hz beam operation for the beam tuning diagnostics [5]. The upper and lower layers are interconnected via many Gigabit Ethernet switches on which the MADOCA middleware runs. The 10GbE is introduced as a backbone data transfer line for user experiment. The outgoing 10GbE line is connected to the 10PFlops K-supercomputer in Kobe for the on-line analysis of experimental data that will be generated from two-dimensional X-ray detector. The schematic view of the control system is shown in Figure 4.

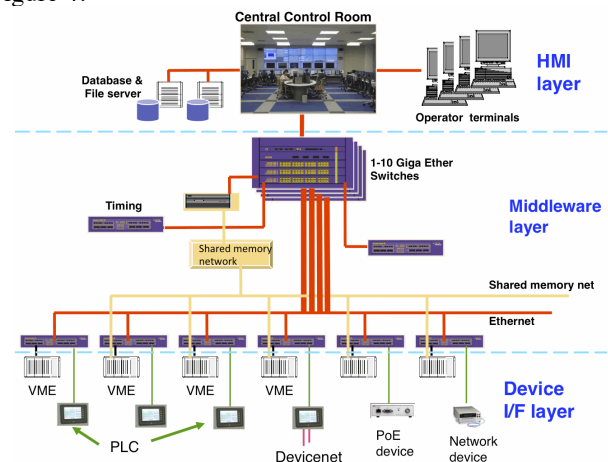


Figure 4: A 3-tier schematic structure of the SACLA control system. Beam commissioning is performed at the local control room nearby SACLA facility.

SACLA has an electron beam transport line to inject the electron beams to the SPring-8 storage ring as shown in Figure 1. At present, the injection is not scheduled yet, but SACLA works independently by using its own beamlines for X-ray FEL experiments. In order to avoid unexpected interference to the SPring-8 duty operation and guarantees independent operation between two facilities, the control network zone between SACLA and SPring-8 is loosely coupled. Also, the server computers such as a database machine and a NAS-based NFS file server are installed separately. On the other hand, the program development environment for SACLA shares with SPring-8 for the common software development. This configuration is good for the cooperative software development and timely program installation to the SACLA server without interference to the SPring-8 user-mode operation.

The number of equipment used for SACLA control is listed in the Table 1.

Table 1: The Number of Equipment for Controls

Equipment	SACLA	SACLA+SPring-8
Consoles	27	332
VME systems	175	450
Interlock stations	122	812
Network switches	181	758

EQUIPMENT CONTROL

The VMEbus systems and PLC stations are main base components of the SACLA accelerator control [4]. The C-band linear accelerator consists of mainly accelerating structures with 5.7GHz RF systems. We made one RF control unit and repeated the same configuration as much as needed. Additionally, fine timing system and beam monitoring system is necessary for the beam tune. Interlock systems are installed for the machine protection system (MPS) and personnel protection system (PPS), as shown in Figure 5.

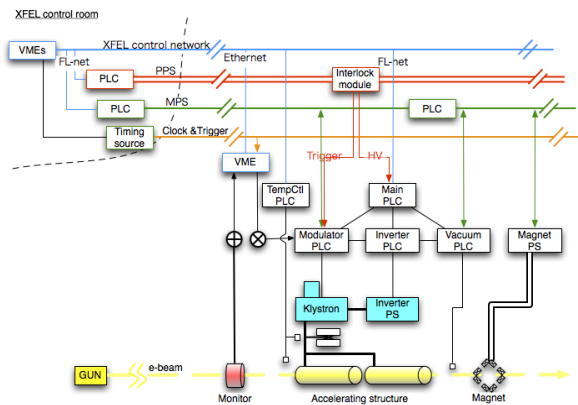


Figure 5: A schematic view of the SACLA control system. A typical control unit using PLC module for one C-band accelerating unit is shown in the figure.

The PLC system is used for RF high power (A, V) device control and the interlock systems. The PLC system is simple and suitable for the slow control with high robustness and reliability. On the other hand, the VMEbus system is suitable for the fast device control such as beam steering magnets and so on. To satisfy the stability requirements of the phase and amplitude of the cavity voltage, newly developed boards, such as DAC and ADC are equipped for LLRF VMEbus systems. A feedback control process (EMA on MADOCA) that runs on the VME CPU plays essential role to stabilize the phase and amplitude, which contributes the laser stability.

Implementation

The single-core CPU board, SVA041 already used in SPring-8, was selected for the SACLA control even though single core processor. The well-established CPU is good for smooth start-up of the control system. At the beam commissioning stage, the accelerator repetition rate is 1~ 10Hz, but it will go up to 60Hz and finally 120Hz

(maybe 300Hz later). So far, signal process power of the Intel VMEbus CPU is enough but it is approaching to the marginal level, especially for the large data processing such as waveform data monitoring in on-line. A faster multi-core CPU with low power consumption is now available. The multi-core CPU (Core i7) will replace the current CPU if computing power is tight. The DMA and block transfer scheme was introduced to meet the waveform data handling from the 16bits ADC boards..

The FL-net is a FA-link that interconnects VMEbus systems and PLC stations. The FL-net link is divided into several links to keep independency of the device groups. The multiple links on the single VMEbus system is handled by using the virtual machine technology, Solaris10 Container. The I/O board configuration of the VMEbus had to adjust such that the I/O boards do not share one bus together with the large-data handling boards and also the slow control FL-net links. We prepare the monitoring and notify mechanism for FL-net unexpected link-down.

Database and Servers

The SPring-8 database system can process many data as we expected, however SACLA database system used almost full CPU power. The heavy load sometimes caused unexpected delayed responses to the accelerator operation GUI. Actually, the number of data was about factor two more than we estimated at the beginning of the database design phase. We adjusted the Sybase RDBMS configuration such as the procedure cache size, data cache size, the size of data log area and table lock mechanism. And we, also, optimized the periodic machine data-taking cycle to ease the database load. The alarm surveillance and monitoring programs handle many watching points as well. Especially at the alarm process start-up time, the heavy accesses from the alarm programs to the database deteriorated operation response.

We will add a 3GHz 12core FT-server with 48GB memory together with the current database machine of a 2GHz 8core CPU with 16GB (now 48GB) memory. We don't change NAS-based disk system because it has no problem. We, also, will tune the alarm software algorithm for much efficient surveillance and lighter database access.

Signals of Equipment

The number of equipment signals of SACLA is much larger than that of the SPring-8 accelerator complex, on the contrary to the initial estimation. The comparison of the data size is listed in Table 2.

Table 2: The Number of Equipment Signals

Accelerator	Analogue points	Digital points
SACLA	19,500	225,000
SPring-8 (Li,Sy,SR)	22,000	90,500

The estimation is the base to select the database computer specification because the CPU load depends on the size of the database schema, hence the size of the data,

however the NAS storage provides enough data transaction performance. The difference originates in the number of the units of RF acceleration structures in SACLA.

FACILITY CONTROL

The facility utility control of SACLA has unique features [5]. The accelerator beam tuning to achieve the stable laser imposes severe stability to the RF cooling water and electric power for example. The facility control has a gateway to the accelerator control to receive “put” command from the accelerator side. If the observed temperature deviated from the monitoring point, the water set point would be actively adjusted from the accelerator side. The precision of the monitoring sensors for the cooling water temperature was 0.01C, however the precision has to be improved to 0.001C resolution because the RF phase of the C-band shifted according to the water temperature drift.

The room temperature of the accelerator house and the spaces for the control racks of the LLRF systems have been monitored and kept into the database right after the completion of the facility building. The long accumulated temperature data about one year is useful to understand the stability and drift of the room temperature before the beam commissioning.

BEAMLINE CONTROL

Finally, SACLA will have five beamlines for the experiments. Now, one beamline (BL3) is ready for the scientific experiment. The application layer of the SACLA beamline control uses MADOCA identical to that of SPring-8 in order to achieve smooth migration of the current software developers from SPring-8 to SACLA. The beamline control uses the VMEbus system as well. The beamline components consist of slits, screen monitors, beam position monitors, a monochromator and so on, those have equipment interfaces similar to the SPring-8 beamlines. Additionally, the synchronized data-taking scheme is introduced to the beamline control [6]. In SACLA, this scheme takes the set value of optical devices and pulse motor positions, and sends these data to the beam-synchronized data-taking system for the accelerator. The data will be used for the experimental analysis together with the accelerator status. The beamline control ramped up smoothly and has been working with good stability.

DETECTOR DATA ACQUISITION

A linac-based FEL facility with the small number of beamlines has a feature such that a linear accelerator, insertion devices, an X-ray detector and data acquisition system (DAQ) for experiments have to work with required performance as a whole in order to generate the scientific results. In SACLA, the accelerator control framework, MADOCA, was introduced to the DAQ for the experimental data taking [7]. MADOCA interfaces between the accelerator control and the detector DAQ

system to provide electron beam information to the laser experiment system, for example beam tag numbers as shown in Figure 6.

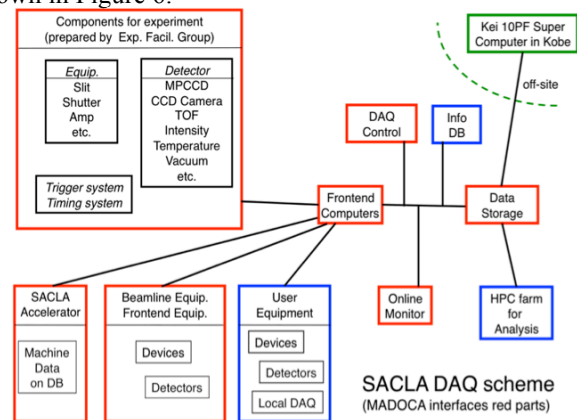


Figure 6: A schematic view of the SACLA DAQ for the X-ray detector. MADOCA plays as the middleware.

The multi-port CCD (MPCCD) sensor developed for SACLA experiments as workhorse detector has 0.5M pixels of 16bits data/pixel. Largest detector arrays consist of twelve MPCCD sensors. The DAQ system has to handle the data rate up to 720MB/s/system for 60Hz beam operation. The FPGA-based VME boards take the MPCCD image data via CameraLink interfaces. The data is compressed at the VME board then sent to the 240TB Infini-band storage system via data-handling PC servers. Whole the are pre-processed by a PC cluster, and transferred to the 10PFlops supercomputer “K computer” via 10Gbps Ethernet for on-line data mining and post analysis. The DAQ system is ready now and waiting for scientific experiments scheduled at the end of October this year.

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