ISBN: 978-3-95450-193-9 doi:10.18429/JACoW-ICALEPCS2017-FRAPL03

STATUS OF THE CONTROL SYSTEM FOR THE SACLA/SPring-8 ACCELERATOR COMPLEX

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Abstract

At the SPring-8 site, the X-ray free electron laser facility, SACLA, and the third-generation light source, SPring-8 storage ring, is operated. The SACLA generate brilliant coherent X-ray beams with wavelength of below 0.1nm and the SPring-8 provides brilliant X-ray to large number of experimental users. On the SPring-8 upgrade project we have a plan to use the linac of SACLA for a full-energy injector of the storage ring. For this purpose, two accelerators should be controlled seamlessly and the SACLA has to provide low emittance electron beam to generate X-ray laser and injector for the SPring-8 simultaneously. We start the design of control system to meet these requirements. We redesign all of a control framework such as Database, Messaging System and Equipment Control include with NoSQL database, MQTT and EtherCAT. In this paper, we report the design of control system for SACLA/SPring-8 together with status of the SPring-8 upgrade project.

INTRODUCTION

Last twenty years, the SPring-8 as the highest electron energy, large scale third generation synchrotron radiation facility in the world. Construction of the SPring-8 facility was started in 1991 and it has been open for user experiments since October 1997. At the SPring-8 site, the SACLA (SPring-8 Angstrom Compact Laser) project started in 2006 with 5-year construction schedule and and it has been in operation for user experiments since 2012. Figure 1 shows a bird-eye view of SPring-8 site. We designed the SACLA linear accelerator to be used for a full-energy injector for the SPring-8 storage ring. An ultra-low-emittance electron beam delivered from the SACLA should be compatible with the future upgraded SPring-8 facility.

The SACLA is delivering pulsed X-ray laser beams whose pulse duration is as short as a few femtoseconds. The peak brilliance of the SACLA is so high. The complementary use of storage-ring light sources and pulsed X-ray laser is essential for opening new frontiers in science and technology. However, there is a wide gap between the current SPring-8 emittance and SACLA's equivalent emittance. The SPring-8 upgrade should narrow the gap from the storage ring perspective. In 2013, we have decided to aim for an ultra-low emittance ring with an emittance value of ~100 pmrad. The conceptual design report on upgraded SPring-8, which called SPring-8-II, was published in September 2014 [1].

At the SPring-8-II the dynamic aperture is markedly narrower than the current SPring-8. We cannot use the existing injector system without a large-scaled modification. In addition, long injection interval during top-up operation it is necessary to keep the injector system in a stand-by condition. In the result, it is increasing the operation cost. On the other hand, the linac of SACLA is always running for its own user experiments independently from SPring-8-II. Therefore, if the injection beam is delivered from SACLA, the operation cost will be minimized. To achieve the SACLA's users operation and the beam injection to SPring-8-II in parallel, it is necessary to control of the beam energy and the peak current on a bunch by bunch basis.

Figure 1: The SPring-8 facility and the SACLA. The transport line.

OVERVIEW OF SACLA AND SPring-8

Figure 2 shows the machine layout of SACLA and SPring-8. The SACLA consists of an electron gun [2], 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 [3]. The electron beam repetition rate is 60 Hz. A peak current of several kA 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 use 128 units of the C-band accelerating structure. The beam energy will reach 8 GeV and the X-ray laser wavelength is below 0.1 nm. A number of in-vacuum undulators of 4.5 m length are aligned after the accelerator. There are 22 units of the undulator on BL3 and 18

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units of the undulator on BL2. A pulsed kicker magnet is used to switch the beam route to BL2, BL3 and a beam transport line to the SPring-8. The beam transport line from SACLA to the exit of the existing synchrotron booster tunnel and after the synchrotron to connects the exit of the synchrotron booster and the storage ring. If the injection beam is delivered from SACLA to SPring-8, a peak current of the electron beam should be reduced to a few hundred amperes to prevent the emittance degradation at the transport line.

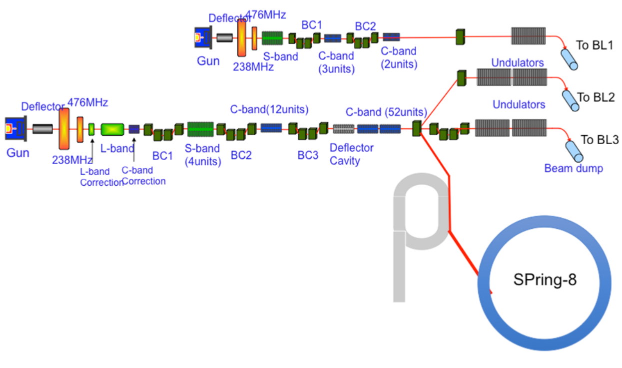

Figure 2: Schematic drawing of the SPring-8 accelerator complex.

DESIGN OF CONTROL SYSTEM

On the SPring-8 upgrade project we are going to use the linac of SACLA for a full-energy injector. For this purpose, two accelerators should be controlled seamlessly and the SACLA has to operate for user experiments and for injector of the SPring-8 simultaneously. In this case, we must control the beam energy and the peak current on a bunch by bunch. We started the design of a control system to meet those requirements. Figure 3 shows schematic of new control framework. A basic idea of the control system is keeping the MADOCA's DNA [4] but we redesign all of a control framework by using IT technology. The MADOCA framework is used at the SPring-8, the NewSUBARU, the SCSS test accelerator and the SACLA past twenty years. This concept is still useful to control a large accelerator and stable operation. We keep a following concept of the MADOCA,

1. Message oriented communication with human readable S/V/O/C style syntax
2. Relational database management system for a parameter database
3. Distributed control system communicating via the network.

When we designed and developed the MADOCA framework for the SPring-8 storage ring, a computing resource was very limited such as single core CPU, small size of disk and memory, only 10Mbps network bandwidth and no open source product. Therefore, the MADOCA framework could not use efficiently a rich computing resource of modern IT era. We redesign following components to resolve this problem to resolve the problem.

Database System

The database system is composed on three parts [5]. First one is an online database for machine status logging momentary. Second one is an archive database for machine status logging permanently. Last one is a parameter database to store the machine control parameter such as a calibration constant and a current setting of a magnet power supply. We use the Cassandra [6] for online database. We designed for maximum speed written data in 60Hz. This kind of architecture has good performance at writing speed, but it does not fit on a search and retrieve task. On the other hand, archive data is required search, select or retrieval function. Therefore, we selected the relational database management system for it. Parameter database need a flexible data manipulation and relational database is better to use this purpose. We selected MariaDB [7] for the archive and the parameter database. Because of a different architecture between the Cassandra and the MariaDB, we compromise a table structure for only one signal into one table. This may cause a logging data size to be large for relational database. We resolve this problem by storing sequential data to store into one column. We can take a benefit by this method which reduce a data size and minimize search speed by a smaller index.

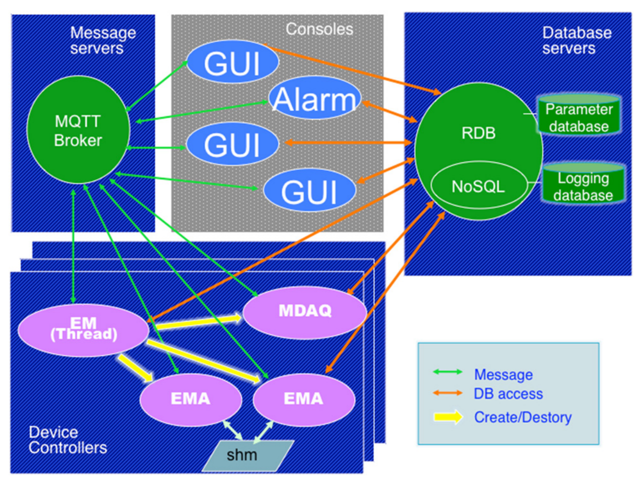

Figure 3: Schematic of the control framework for the SPring-8 accelerator complex.

Message Server

We use the MQTT [8] as a messaging protocol to communicate between an operator console and a equipment control device. The MQTT is an open industry standard and the de-facto standard for Internet of Things applications. Therefor there is lots of product on the market. The MQTT protocols are:

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1. A simple and lightweight Publish/Subscribe messaging protocol
2. Messages in MQTT are published on topics
3. Topics are treated as a hierarchy, using a slash (/) as a separator (Same as MADOCA message!!!)
4. Defines three levels of Quality of Service (QoS)
5. All messages may set to be retained
6. When a client connects to a broker, it may inform the broker that it has a will

and this makes

1. No need flow control of the queue
2. Easy to keep S/V/O/C style syntax
3. Reliable communication with QoS, retain and will
4. Central management of a broker.

We tested several products shown in the table 1 and we selected the eMQTT [9] because of

- Mosquitto [10] is small and simple but not for enterprise purpose
- HiveMQ [11], we cloud not find a distributor in Japan
- MessageSight [12] is high performance but too expensive
- VemeMQ[13], performance is almost same as eMQTT but eMQTT's user interface is better than VemeMQ.

We use Paho [14] as a client library to access MQTT protocol. We tried to fail-over test to simulate a machine trouble with use of eMQTT and Paho. At first, we disconnected a network connection of active broker and reconnected a network to standby broker and boot it with arp command for a resolution of network address. A client such as a GUI on an operator console was working correctly without restart. If we can allow several minute of downtime we do not need the expensive High Availability equipment.

Table 1: MQTT Broker

	procurement	**HA**	**UI**
Mosquitto	Open Source	No	No
eMQTT	Open Source	Yes	Yes
VemeMQ	Open Source	Yes	No
HiveMQ	Commercial	Yes(Cluster)	Yes
MessageSight	Commercial	Yes	Yes

Equipment Manager

The messaging scheme is moved to the MQTT and each topic is send or received without queuing. Therefore, the equipment manager (EM), which controls devices, has to be implemented with multi-thread. If the EM is running as a single thread application, we need a blocking mechanism to prevent an overwriting of topic. In the meanwhile, a single thread option is still needed to keep backward compatibility. In this case, we need to wait a response from the EM before to send next topic. Because of most of topic are related with the objects to control device, we set a granularity of a thread same as corresponding to a device descriptor.

We decided the EM as an only process at a boot-up. Other processes such as a data acquisition process or a feedback control process will be forked from the EM. We use a shared memory to communicate between processes. The EM controls creation and initialization of the process. This makes easy to manage processes and resources.

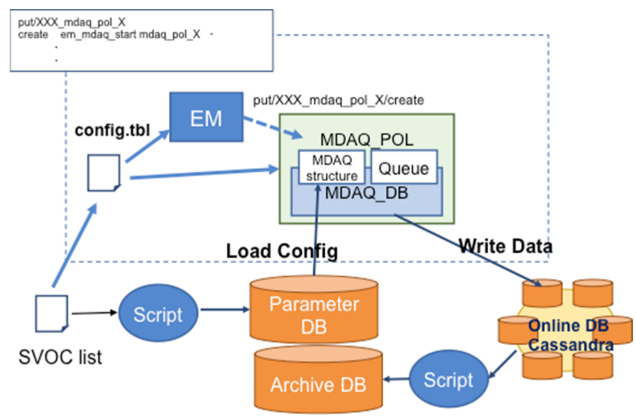

Figure 4: Schematic of the data acquisition framework. This shows a point data acquisition scheme to be polling.

Data Acquisition

The data acquisition scheme as shown in Fig. 4 is based on a daemon process, we called MDAQ, forked from the EM. We are preparing several types of process.

- A point data with fixed acquisition interval by polling. This may use for slowly varying data such as a slow control.
- A point data acquired by triggered event, such as a beam position monitor of the SACLA.
- A one-dimensional array such as a waveform
- A two-dimensional array such as a picture of a beam profile monitor

Configuration parameters of the MDAQ are loaded from the parameter database on MariaDB and a data is written to online database on Cassandra. A state of the MDAQ is controlled by using message with C as create, start, stop and destroy. If the EM receive a create command, the EM fork the MDAQ process. A start (or stop) command means to start (or stop) data taking. If the EM receive a destroy command the EM kill a MDAQ process. The MDAQ process has a keep alive function to report up to date status such as stand-by, pause, running and stop.

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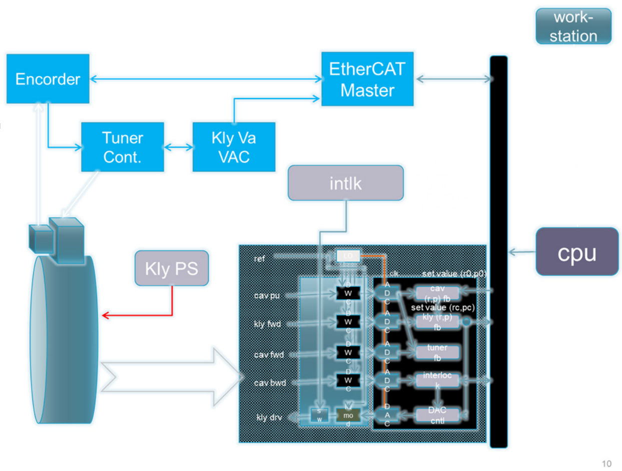

Figure 5: Schematic of RF test stand with MTCA.4 and EtherCAT.

Equipment Control Hardware

Because of a trend of the shrinking VME's market, we will replace a VME with MTCA.4 for high speed digital signal processing and PC and PLC for slow control.

We will adopt a MTCA.4 system to detect phase/amplitude signals generated by the klystron, and to generate rf signals with appropriate phase and amplitude for the klystron input. For this purpose, High-speed A/D and D/A boards working with several hundred MHz clock are used. The A/D and D/A combination allows a digital feedback of a low-level RF system for driving the klystrons. We were started the performance test of a digitizer AMC module with MTCA.4 standard at an RF test stand [15] as shown in Fig. 5. The AMC has 10 channels 16-bit ADCs, two 16-bit DACs, and a FPGA. This test shows successful results and we will replace the existing analogue based RF feedback system of the A-station of the SPring-8 to the full digital feedback system at the end of FY2017. Then we will replace the B, C, D-station at summer shutdown 2018.

To reduce the amount of wiring, we employ EtherCAT [16] as a remote I/O system. EtherCAT is a real-time Industrial Ethernet technology originally developed by Beckhoff Automation. The EtherCAT protocol is disclosed in the IEC standard IEC61158. The EtherCAT is also one of the key component for Industry 4.0 which originates from a project in the high-tech strategy of the German government. We already started to use the EthetCAT for the kicker magnet control and the position readout for insertion device [17]. And we will extend to use for a low-level RF system at SPring-8 A-station and a stepping motor control of insertion device at end of FY2017. A full digital controlled magnet power supply using EtherCAT is under development. We will use this power supply for the SPring-8 upgrade

An interlock system of vacuum, machine protection system and personnel protection system are configured with a PLC at SPring-8. It must be a highly reliable system especially a personnel protection system. This configuration will be kept at the SPring-8-II.

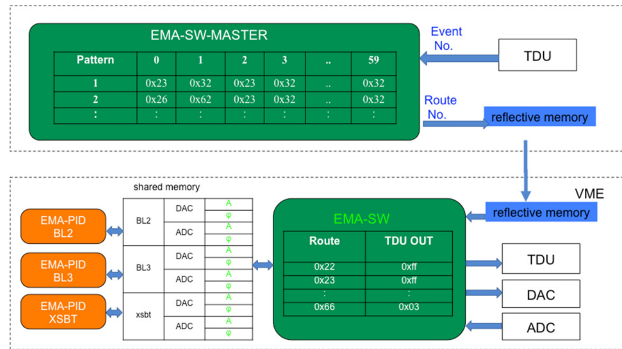

Figure 6: Schematic of bunch by bunch parameter control.

Bunch by Bunch Beam Control in SACLA

Because the SACLA has to control of the beam energy and the peak current on a bunch by bunch, we design and develop a system with reflective memory. A master controller store all pattern of parameters required for the low-level RF controllers. Each pattern consist of 60 rows which correspond to the parameter for 1 second with beam reputation rate of 60Hz. We can select the pattern every second by on demand. These processes will be introduce to the bunching section such as gun, beam deflector, prebuncher, booster, L-band correction, L-band, C-band correction, S-band and 12 units of C-band. Also, it will be working for the kicker magnet power supply.

Figure 6 shows the schematic view of this system. Although RF control modules in SACLA's RF system are VME based one, the master controller is a MTCA.4 module because this module also works for an injection timing control of the SACLA and SPring-8. The master sends parameters to VME with past, present and future beam shots. As for the data acquisition timing of the pulsed machine linac, we need to wait a data conversion of the digitizer after trigger. It means a data obtained just after the trigger is related to past shot. For the timing of the parameter setting to the RF system, we need settling time for a DAC. We must set a data prior to the aimed bunch. From these conditions, the VME system has to receive past, present and future parameter to control with bunch by bunch control operation.

STATUS OF A PROJECT

On the SPring-8 upgrade project we were started to design a brand-new control system from 2016. Figure 7 shows a master plan of the project to replace the control system. At first we replaced few VME of the Test Stand to develop and debug the system. Next step is to replace the dedicated accelerator for BL1. [18] Before the replacement we made a feasibility study at a shutdown period in spring 2017. From this study, we found necessity of small modification of the control system but it was not serious

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problem. We replace the control system of the dedicated accelerator for BL1 at the summer shutdown period in 2017. We use the 18 server nodes for the online database. Each node has 4-core CPU, 32GB memory and 1TB SSD. For the archive and the parameter database, we use the server with dual CPU, 128GB memory and 9.6TB SSD. The control system is working well after the replacement.

We will replace the control system of SPring-8 at end of FY2017 and that of SACLA at a shutdown period in summer 2018. We also examined a feasibility study of the control system for SPring-8 at a shutdown period in summer 2017. We tried to change a RF system, magnet power supply system and vacuum system. We could control devices and collect a data successfully. At this study, we set minimum polling interval with 200msec. if the stored beam was dumped we must store transient data of vacuum and magnet power supply with 200msec time resolution for trouble shooting. Some of parameter database was working well. The data taking of beam position measurement system is under developing and we plan to test this at a shutdown period in winter 2017/2018.

After replacement of the control system we will start R&D of a graphical user interface for SPring-8-II. In this time, we still use X-Mate as a GUI builder, which is heritage from the construction phase of SPring-8. But this builder is not up to date for recent environment of Internet, such as web browsing. We plan to study a non-blocking scheme called co-routine or fibre. It provides a unit of execution even lighter in weight than the thread and ease to use.

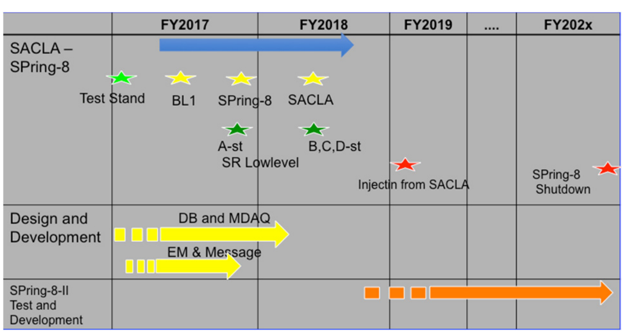

Figure 7: Schedule of the SPring-8-II project, the control system replaces to start at the Test Stand and SACLA to complete.

CONCLUSION

We design the control system to meet requirements where two accelerators, the SACLA and the SPring-8, should be controlled seamlessly. Also this system must cope with the operation of SACLA for user experiments and injector for the SPring-8 simultaneously with controlling the beam energy and the peak current on a bunch by bunch scheme. We redesign all of a control framework such as Database, Messaging System and Equipment Control include with NoSQL database, relational database and MQTT for messaging. We will use the MTCA.4 for high speed data and the EtherCAT to reduce a wiring.

We succeeded in replacement the control system of the dedicated accelerator for BL1 at summer shutdown 2017. We will replace the control system of the SPring-8 and SACLA at summer shutdown 2018 for seamless control of two accelerators. We will use this control system for SPring-8 upgrade and R&D of SPring-8-II will be based on this control system.

ACKNOWLEDGEMENT

The authors would like to thank all of contributors to the project, including members of RIKEN/SPring-8 and JASRI/SPring-8. Also, we thanks to SACLA/SPring-8 operators and RIKEN engineering team gratefully.

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