ISBN: 978-3-95450-193-9 doi:10.18429/JACoW-ICALEPCS2017-MOAPL04

SwissFEL CONTROL SYSTEM – OVERVIEW, STATUS, AND LESSONS LEARNED

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Abstract

SwissFEL is a new free electron laser facility at the Paul Scherrer Institute (PSI) in Switzerland. Commissioning started in 2016 and resulted in first lasing in December 2016 (albeit not on the design energy). In 2017, the commissioning continued and will result in the first pilot experiments at the end of the year. The close interaction of experiment and accelerator components as well as the pulsed electron beam required a well thought out integration of the control system including some new concepts and layouts. This paper presents the current status of the control system together with some lessons learned.

OVERVIEW

The SwissFEL free electron laser facility [1] is the newest accelerator at the Paul Scherrer Institute (PSI) [2]. PSI already operates three large user facilities: a third-generation synchrotron radiation source (SLS), the continuous-beam spallation neutron source (SINQ), and the continuous-beam muon source (SμS). SINQ and SμS are driven by the high-intensity proton accelerator (HIPA) which also serves the particle physics program with pions, muons and ultra-cold neutrons (UCN). In addition to its research activities, PSI operates Switzerland's sole facility for the treatment of specific malignant tumours using protons (Proscan).

Based on the experiences from both the proton and the electron accelerators, the SwissFEL construction was preceded by an intense R&D period that included the temporary construction of the SwissFEL Test Injector Facility. The goal was to build the shortest possible XFEL facility with the lowest possible electron energy to allow reduced costs for both construction and support of the facility.

SwissFEL

A schematic drawing of SwissFEL is shown in Fig. 1. The accelerator is divided into an S-band injector, a C-band main linac (divided into three parts) and an undulator line called Aramis. The Aramis line will provide hard X-ray radiation, in the wavelength range from 0.1 - 0.7 nm, to two experimental stations with the possible extension of one more in the future. The overall length of the machine (from gun to experiment) is around 720 m and the beam pulses will have a repetition rate of 100 Hz.

The construction of the SwissFEL building started in spring 2013 and in summer 2015 the installation of first accelerator components began. In August 2016 the first electrons were produced, and in December 2016 the first lasing (at 380 MeV, 24 nm) was achieved. Since then more C-Band accelerating structures were put into operation, resulting in the start of photon optics commissioning in August 2017 with an FEL beam of 1620 MeV (1.3 nm wavelength).

Table 1: Key Design Parameters of SwissFEL

Overall Length (Gun – Experiment)	720 m
Maximum Electron Beam Energy	5.8 GeV
Repetition Rate	100 Hz
Nominal Wavelength in Aramis Line	0.1 - 0.7 nm
Number of Endstations in Aramis	2 + (1)
Expected Photon Pulse Length	0.2 – 20 fs

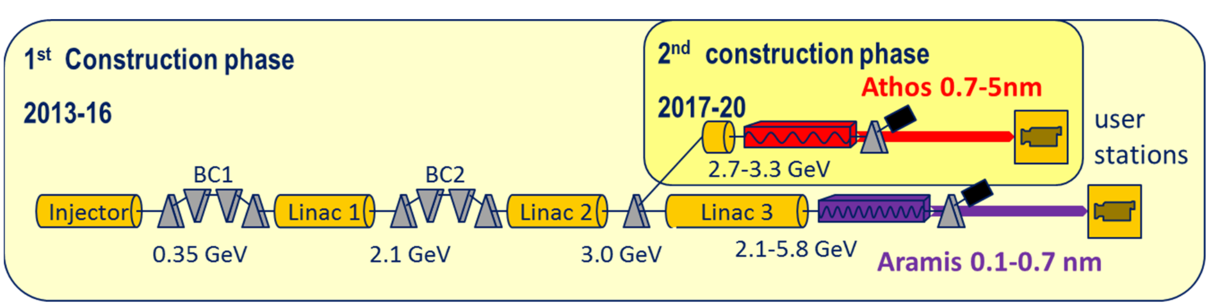

Figure 1: Schematic SwissFEL accelerator layout.

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The SwissFEL accelerator is designed to drive, in the future, a second beam line (called Athos), providing a soft X-ray beam with a wavelength between 0.65 and 5 nm. A two-bunch mode is planned, where the machine simultaneously accelerates two electron bunches at 100 Hz, with 28 ns spacing between the two bunches. The Athos beam is extracted with a resonant kicker magnet after Linac 2 (at around 3 GeV) to allow for the independent tuning of both lines (see Figure 1). The Athos line and its experimental stations will be built from 2018 to 2020.

Table 2: SwissFEL Commissioning Progress

Year	Date	Achievement
2016	Aug. 24	First electrons from the gun with 7.9 MeV
	Nov. 11	First beam transport through undulators to main beam dump
	Dec. 2	First lasing at 380 MeV, 24 nm
2017	May 15	Lasing at 910 MeV, 4.1 nm
	Aug. 30	Lasing at 1620 MeV, 1.3 nm
	Aug. 31	First FEL photon beam in optics hutch

SwissFEL Control System

Like the other facilities at PSI the SwissFEL Control System is based on the EPICS [3] toolbox. SwissFEL is using EPICS version R3.14.12.4 (plus bug-fix patches). There are more than three hundred control computers (IOCs), running different flavours of the Linux operating system [4]. New standardized hardware solutions were introduced for SwissFEL [5]. On the console computers in the main control room and for the experimental station we use caQtDM [6] for simple GUIs and PShell [7] for scripting of measurements. In addition, the machine physicists and expert groups are free to develop their own programs using the Python programming language.

At PSI the same Controls group is responsible for controlling the accelerators as well as for the control of the experiments. This has great benefits as the same tools can be used and interfaces are simplified.

LESSONS LEARNED

Some knowledge gained during the design, installation, and commissioning phases of SwissFEL is invaluable to the involved people. Of course, a lot of the experiences are intimately connected to the organisation of PSI and the restrictions (technical and otherwise) the SwissFEL project faced. The following list of lessons learned presents just the tip of the iceberg that in our view might be useful for other facilities or projects.

Lesson 1 – Pulsed Machine

The first plan for the SwissFEL Control system was just to copy the system we use for the Swiss Light Source (SLS) synchrotron. However, the SwissFEL Injector Test Facility showed us the errors of this strategy [8]. The pulsed beam that is characteristic for an FEL requires that measurements are done in a triggered way. Furthermore, the results of those measurements need to be tagged in a uniform and unambiguous way that allows identification and correlation of all measurements of the same pulse. If the trigger comes too early or too late there is nothing to measure beside noise and maybe dark current.

Therefore, the SwissFEL Timing and Event system soon became a central part of the Control System. It is based on Micro Research Finland cards [9] connected in a star topology. In addition to trigger signals (called Events), some flags holding the beam status, and a unique id of the beam pulse are distributed. All IOCs equipped with a timing card can read these flags and the id and can tag their data with them.

Special care is needed when collecting measurements taken at different parts of the accelerator (and experiment). For example, the position of the beam at the 119 Beam Position Monitors (BPMs) might be disturbed due to the main power frequency (50 Hz). Therefore, it is crucial to check that all positions are tagged with the same bunch id for a consistent measurement of the complete beam orbit.

We had to learn how to integrate a Beam Synchronous Data Acquisition system [10] into most of our control computers. We found that it is vital to stay with a modular and failure tolerant design of components (software and hardware). It turned out to be very easy to block systems and the network completely with the amount of data that could be produced. Therefore, beside the technical work a careful education of the physicists and experts about the limits and boundaries of the BSDAQ system was vital to achieve usable results.

Lesson 2 – Network Devices

At the SLS we have around 200 control nodes for a linac, booster, and storage ring (around 570 m of accelerators in total). By just scaling this numbers to a total length of 720 m for SwissFEL we initially expected no more than 300 control nodes.

This estimate proved to be wrong by more than a factor of five. Currently around 1500 devices are directly connected to the SwissFEL network (photon beamlines are not yet completed). It seems that many devices are no longer connected to some control node computer by a field or backplane bus, rather they act as control nodes themselves.

Even though EPICS offers the possibility to control such network attached devices with SoftIOCs we think that our assumptions about the control system structure need to be revised. In the future, more controls logic might be implemented directly on devices using the capabilities of FPGAs or embedded computers. Such developments might lead to discussions as to where the boundaries of the control system lie.

Another consequence from the number of network connected devices is the size of the network. To ensure a safe and manageable operation the network was constructed in a star topology flattened out along the machine. Unfortunately, the boundaries between the branches of the star

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could not be aligned to the accelerator sections due to building constraints (i.e., doors in disadvantageous places). Therefore, the network subdivisions do not align with device naming which makes filtering difficult.

A technical solution to mitigate this obstacle could be the establishment of VLANs (virtual networks that can be freely configured over several switches). However, the introduction of such VLANs needs dedicated configurations on every involved network switch which makes maintenance and exchange of such switches more difficult. At the moment, the existing limitations do not hinder the control system enough to justify that additional complexity.

Lesson 3 – Management and Planning

The management and planning of the SwissFEL control system posed a challenge with the given constraints of manpower and budget. In addition, scheduling of the overall project was both optimistic and tight.

Test systems have been used by different expert groups to meet these requirements. Unfortunately, the effort required to provide a working control system at several different test sites was underestimated. For example, it showed that all subsystems and devices needed to be tested with the timing system available. We ended up with more than six timing master systems in use dispersed in the PSI area where we planned for only the one in the SwissFEL building.

Even though the benefit of system tests including the control system interface is undeniable, those test systems require serious effort in manpower and hardware availability. In addition, a controls environment was needed (archiver, user interfaces, source code repository, deployment tools, etc.) and has to be maintained. As a consequence of a less than optimal planning and thereby unstructured approach to test systems we have a lot of reorganization and tidy-up work waiting for us once SwissFEL is fully operational.

CONCLUSION

The SwissFEL Control System is working and enables physicists and experts to run the accelerator for beam operation and experiments. But it will need improvement over the next years including the lessons learned during the system commissioning.

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