CONTROL SYSTEM IN SWISSFEL INJECTOR TEST FACILITY

M. Dach, D. Anicic, D. Armstrong, K. Bitterli, H. Brands, P. Chevtsov, F. Haemmerli, M. Heiniger, C. E. Higgs, W. Hugentobler, G. Janser, G. Jud, B. Kalantari, R. Kapeller, T. Korhonen, R. A. Krempaska, M. Laznovsky, T. Pal, W. Portmann, D. Vermeulen, E. Zimoch,
Paul Scherrer Institut, 5232 Villigen PSI, Switzerland

Abstract

The Free Electron Laser (SwissFEL) Injector Test Facility is an important milestone for realization of a new SwissFEL facility at Paul Scherrer Institute (PSI) in Villigen, Switzerland. The first beam in the Test Facility was produced on the 24th of August 2010 which inaugurated the Injector operation. Since then, the beam quality in various aspects has been greatly improved.

The primary goal of the Injector Test Facility is to demonstrate a high-brightness electron beam which will be required to drive the SwissFEL main linac. The Injector further serves as a platform for the development and validation of accelerator components needed for the SwissFEL project.

This paper presents the current status of the Test Facility and is focused on the control system related issues which led to the successful commissioning. In addition, the technical challenges and opportunities in view of the future SwissFEL facility are discussed.

INTRODUCTION

The SwissFEL project at the Paul Scherrer Institute (PSI) foresees the realization of a SASE X-ray Free Electron Laser (FEL) operating at 0.1–7 nm photon wavelength by 2016 [1]. To minimize the facility length, and thus cost, the concept aims at relatively low electron beam energy. For the extensive study of the generation, transport and compression of high brightness electron beams and for developing the necessary components, PSI is commissioning the SwissFEL Injector Test Facility, a highly flexible 250 MeV linear electron accelerator [2].

The Injector Test Facility consists of a laser driven RF gun followed by an S-band booster section, a bunch compression section and a diagnostics section featuring an RF deflector and a series of FODO cells for emittance measurements [1].

The commissioning of the test facility proceeds in three phases: in a first step (phase 1), the gun section with some dedicated diagnostics was put into operation [3].

The second phase, lasting from August 2010 to May 2011 referred to the assembly of the full accelerator, with the exception of the bunch compression chicane, which was installed in July 2011.

The bunch compressor chicane will be put into operation during the third commissioning phase, starting later in 2011.

CONTROL SYSTEM OVERVIEW

The control and data acquisition system in the Injector Test Facility is based on a concept derived from the Swiss Light Source (SLS), in order to reduce the implementation effort due to limited man-power resources. Nevertheless, far more effort than originally foreseen was required to develop new applications and to elaborate on an infrastructure that fits well to the different characteristics of the FEL (i.e. linear pulsed machine) as opposed to the SLS (i.e. storage ring). Ultimately, an integrated system based on the EPICS toolkit was provided for both injector control and experimental data-acquisition.

EQUIPMENT INTERFACE

Equipment to be controlled and monitored connects to the control system mainly via VME crates (which fulfil VME64x standard). This concept was directly derived from the SLS [4]. An approximate total of 40 VME crates have been installed in the Injector Test Facility. In addition, non-VME solutions were elaborated upon to meet FEL requirements and to make use of new technologies.

An image capturing and acquisition system based on the Firewrire camera has been provided. Around 40 cameras were installed mainly for diagnostic screen monitor systems. Such cameras are interfaced to EPICS via the PC/Linux servers. The serial devices are controlled by means of the custom made embedded controllers based on the Virtex-4 FPGA. Such systems run EPICS on top of Linux.

Another embedded solution based on Virtex-4 FPGA is the "data concentrator" controller which is used to control magnet power supplies via fibre-optical links.

Temperature and humidity are measured by means of dedicated sensors interfaced to EPICS via the MSCB bus with embedded controllers.

NETWORK

The network of the Injector Test Facility was designed in view of the requirements for SwissFEL. We assumed that the number of network ports needed will be too high to fit into one class C subnet. Figure 1 schematically shows the layout of the network. Every circle in the diagram represents a class C network with 254 addresses. The connections of the different subnets of the EPICS network are controlled by the so called Channel Access Gateways, computers running software to minimize network traffic. The control room is the central location from where programs, mostly for commissioning, are run.

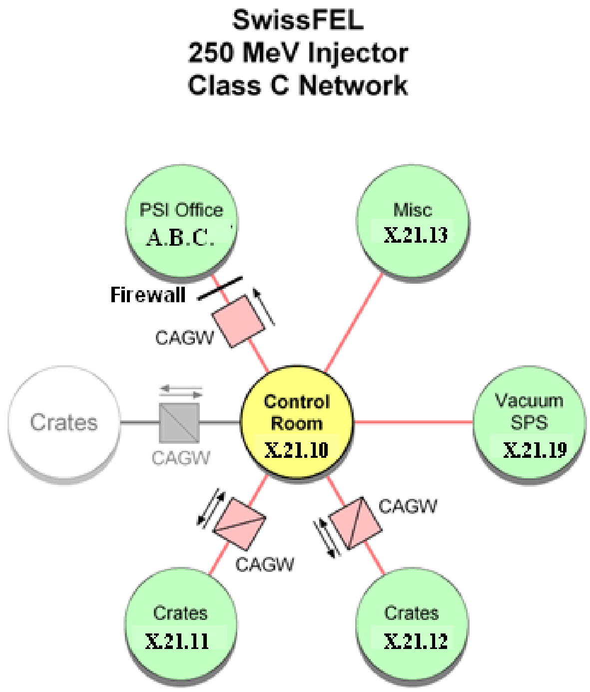

Figure 1: A schematic layout of the Injector Test Facility network consisting of several class C subnets.

SOFTWARE INSTALLATION

The control system software and configuration data is installed in a separate directory residing in a dedicated NFS file server. All files required to run VME and Linux IOCs and all client application configurations are located here. The 'swit' standard tool is used to install all control system applications at PSI.

PHYSICS APPLICATION

The Injector Test Facility is the first pulsed electron linac at PSI, and as such, the controls group had no previous experience in writing the necessary high level physics applications. These were mainly supplied by the physicists and engineers responsible for the commissioning. The controls group provides support by maintaining the MATLAB Channel Access (mca) interface to EPICS. Certain applications requiring primitive data types not supported by mca have made the transition to the more robust mocha (MATLAB Objects for Channel Access) package, which uses an in-house, C++ channel access library (CAFE) [5].

A number of physics process variables (PVs) have been implemented as soft EPICS channels (i.e. channels not connected to any hardware device) that hold information relevant for physics studies. One example is the emittance measured at a certain position along the beam axis. The measurement is time-consuming and invasive, but its value remains of interest for some time afterwards. It is therefore made available to other applications and status displays through a dedicated EPICS PV..

OPERATOR APPLICATIONS

As a backbone for operator applications we use programs from the EPICS toolbox like medm, alarm handler, and archiver. They are mainly chosen for compatibility to SLS as all accelerators are operated from the same control room and by the same operators.

Using a style guide for the application developers supports a consistent behaviour of all applications and a common integration of control room applications into EPICS. It provides rules for the application developer and simplifies the usage of the applications for the accelerator operators.

TIMING

Timing has a crucial role in the injector facility. It not only provides the triggering mechanism but also supports synchronous and reliable transmission of machine critical data. The timing system is based on the global event distribution by Micro Research Finland. We use the latest generation of the event system which supports real-time data transfer parallel to the event distribution. Non-VME systems e.g. Linux-based PCs which require timing, e.g. Firewire camera servers, receive timing information by PCI Event Receiver cards. The timing system is well integrated into the control system through which all its function are accessible. Sequencer of the event generator requires programming at high rate because some subsystems of the machine require trigger rates different than the machine nominal rate (i.e. 10 Hz). The sequencer is therefore programmed at the highest required rate which is 100 Hz in our case. Timing system capabilities has enabled us to realize a beam-synchronous data acquisition system for on-demand pulse-to-pulse correlated studies of the machine behaviour

DIAGNOSTICS

In order to support the extremely challenging SwissFEL Injector beam parameters, electron beam diagnostics components need to provide high performance with excellent reliability. At the same time, they have to be flexible enough to incorporate any improvements, which may be necessary to validate the final accelerator performance. Most of the beam diagnostics elements are based on the designs successfully implemented at the SLS as well as at other FEL facilities.

The major SwissFEL injector beam diagnostics tools include: integrated current transformer, wall current monitor, Transverse Deflecting Structures (TDS), beam profile monitors [6], beam position monitors (BPM), Electro Optical bunch length Monitors (EOM), and Bunch Arrival time Monitors (BAM).

Electronics of BPM systems (button, stripline, and cavity) is implemented in VME64x, which is the PSI standard for real time applications [7]. The digitized signals from BPM pickups are processed by dedicated FPGA modules. Calculated beam positions, at different averaging rates, are pushed into the EPICS database and immediately become available for the PSI control system.

The BPMs provide a high resolution (up to 10 μm) for a large range of electron bunch charges (10-200 pC).

Optical screen monitors together with direct (synchrotron and diffraction) radiation monitors are used to visualize the transverse electron beam profiles. The main controls components of these monitors are video cameras and VME based stepper-motor driving hardware.

Non-invasive monitoring of the longitudinal charge distribution in electron bunches is provided by EOM systems. Such systems for the SwissFEL are designed and built at the PSI [8]. Their resolution (~100 fs) is adequate for the expected bunch lengths. Core EOM elements are an advanced fiber laser system with pulse generating, phase locking, and synchronization electronics talking to the external world via serial (RS232) and GPIB communication lines. All EOM components are fully integrated into the PSI controls, which significantly simplifies their operations.

BAM systems will allow one to determine the beam arrival time with the resolution of ~10 fs. BAM signals can be used, for example, in feedback loops preventing beam energy drifts and stabilizing RF amplitudes of the injector linac structures. Key BAM elements are remotely handled by VME stepper-motor drivers as well as standing alone high precision motor controllers and signal synchronization devices talking via serial (RS232) communication lines. The work on the BAM developments and their integration into EPICS is in progress.

LASER

Two laser systems are used during the commissioning of the injector test facility: a compact, turn-key Nd:YLF amplifier suitable for basic commissioning tasks and a more sophisticated Ti:Sapphire amplifier allowing longitudinal pulse shaping and wavelength tuning for detailed emittance studies [1]. Both of the lasers require many devises to be interfaced to the control system.

More than 50 stepper motors are used to control mirrors on the optical path from the laser to the RF gun. The end user is able to monitor the beam shape at various locations by means of several firewire cameras. The beam laser energy measurement is based on the photodiode readouts. The photodiode signals are first pre-amplified, integrated in the boxcar integrator and digitised by ADC. For the proper operation the laser based system requires stable conditions in terms of the temperature, humidity and air pressure. There are several sensors installed to monitor such parameters in the air-conditioned laser hutch. They are interfaced to the control system by means of the MSCB distributed monitors/controller nodes. One of the challenges from the controls point of view was to improve the beam pointing stability at run-time. This was achieved by a dedicated application which performs a beam spot analysis, and through the PID loop, controls the motor mirror along both the X and Y axis [9].

RF

There are in total 7 RF systems foreseen: an RF gun, four accelerating structures, one x-band cavity and a deflecting cavity. Each of these systems consists of three parts.

A modulator supplied with an integrated control system that has been interfaced to EPICS with a serial TCP/IP connection.

An interlock system and low level RF (LLRF) were developed at PSI, based on VME, and are fully integrated into EPICS.

ALIGNMENTS

Computer monitoring and movement control of several parts of the Injector Test Facility system are required.

A Gun Solenoid magnet mover system with five degrees of freedom (DOF), which is based on the SLS HEXGIR systems, has been installed.

A second system is currently under construction to allow controlled movement of the RF XBand diagnostic equipment at the end stage. The HEXGIR girder mover system is flexible and can be adapted to different mechanical girder layouts. It is highly configurable with all physical parameters defined in one file. The system was designed to allow six degrees of freedom movement if needed [10]. The bunch compressor dipole magnet system has a simpler alignment system for horizontal movement only. All of these systems use EPICS in a single VME crate.

CONCLUSIONS

The SwissFEL Injector Test Facility provided us with an opportunity to develop and evaluate new ideas in light of the future SwissFEL project. The successful commissioning (phase 1 and 2) revealed some points for future improvement. The stability and performance of the Channel Access Gateways is questionable. The choice of firewire camera standard seems to be far from optimal for highly distributed SwissFEL environment. The GigE standard was chosen to improve the stability and reliability of the existing video system in the future. The fast feedback system is under investigation.

REFERENCES

[1] T. Schietinger et al., "Commissioning Status of the SwissFEL Injector Test Facility", IPAC 2011, San Sebastian, Spain.

[2] M. Pedrozzi., "250 MeV Injector Facility for the SwissFEL Project", FEL 2009, Liverpool, UK; M. Pedrozzi (ed.), "250 MeV Injector Conceptual Design Report", PSI Report 10-05 (2010).

[3] T. Schietinger et al., "First Commissioning Experience at the SwissFEL Test Injector Facility" LINAC 2010, Tsukuba, Japan.

[4] S. Hunt et al., "Status of the SLS Control System", ICALEPCS 1999, Trieste, Italy.

[5] J. Chrin and M.C. Sloan, "CAFÉ, A Modern C++ Interface to the Channel Access Client Library", These Proceedings, ICALEPCS 2011, Grenoble, France.

[6] M. Pedrozzi et al. "250 MeV Injector Facility for the SwissFEL Project", FEL 2009, Liverpool, UK, 2009

[7] B. Keil et al. "The European XFEL Beam Position Monitor System", IPAC 2010, Tsukuba, Japan, 2010.

[8] F. Mueller et al. "Electro Optical Sampling of Coherent Synchrotron Radiation for Picosecond Electron Bunches with Few pC Charge", Beam Instrumentation Workshop 2010, Santa Fe, USA, 2010.

[9] T. Pal et al.,"Laser Pointing Feedback Control at the SwissFEL Test Injector", These Proceedings, ICALEPCS 2011, Grenoble, France.

[10] A. Streun "Six-dimensional Girder Positioning", http://controls.web.psi.ch/TWiki4.1.2/pub/Main/HEXGIR/hexgir.pdf