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SwissFEL UNDULATOR CONTROL SYSTEM

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Abstract

SwissFEL has successfully commissioned the Aramis beamline, hard x-rays (2 – 12.4 keV), and the Athos line, soft x-rays (200 eV to 2 keV), will start commissioning in 2020. The Aramis undulator line is currently composed of 13 variable-gap in-vacuum undulators. The Athos line will be made of 16 APPLE II type undulators (Advanced Planar Polarized Light Emitter). Both beamlines have each undulator segment on a 5D mover system; they both also have phase shifters and movable quadrupole tables in between segments. PLCs and DeltaTau motor controllers are used to control motion, for I/O interface, and interlocks. EPICS IOCs communicate with the controllers and provide additional logic and some high level functionality. Further higher level functions are provided through python scripts and other high level languages.

INTRODUCTION

Free Electron Lasers, FELs, represent the forefront in high brilliance x-ray light source technology. They are able to produce light twelve orders of magnitude brighter than a synchrotron [1]. Also, as opposed to synchrotrons, FELs provide very short coherent pulses, a short pulse x-ray laser. FELs are used to probe the structures and properties of organic and inorganic materials, but with much better resolution and speed than synchrotrons. SwissFEL is such a machine, built at the Paul Scherrer Institute, PSI, near the town of Villigen, in the canton of Aargau in Switzerland. Construction started in 2013 and commissioning in 2016.

All current FELs are composed of three fundamental parts, a short pulse electron accelerator, a coherent x-ray generating section, and experimental hutches. The x-ray generating section consists of undulators and supporting devices. Undulators are repeating magnet structures built in such a way as to modulate the electron beam in order to generate coherent and amplified X-ray pulses. This process is known as self-amplified spontaneous emission, or SASE. SwissFEL will have two parallel X-ray generating sections, Aramis for hard x-rays (2 – 12.4 KeV), and Athos for soft x-rays (200 eV to 2 keV) [2]. The Aramis line is operational and commissioning for Athos will begin in 2020.

SwissFEL Aramis Undulator Components

The Aramis undulator line is built from two repeating structures, the undulator assembly, and an inter-undulator section. There are currently thirteen undulator assemblies, and 20 inter-undulator sections. The undulator assembly and part of the inter-undulator section are in movers, as alignment of the undulators and optical elements within a few microns is critical for x-ray laser generation [2].

At the heart of the undulator assembly is a variable gap, in vacuum, permanent magnet undulator. The movable gap is actuated using a wedge system mounted on slides with motors outside the vacuum assembly. A large cylindrical vacuum chamber surrounds this part, which is then mounted on a large frame for mobility and stability. Supporting devices on this assembly are temperature sensors, and emergency off switches. The undulator assembly is then mounted onto a 5D, (x, y, pitch, roll, and yaw) cam mover system.

The inter-undulator assembly also has a 2D, x and y, wedge mover system, on which a focusing quadrupole, corrector dipoles, and a beam position monitor are mounted to. Another section of the inter-undulator contains a phase shifter, which is a small variable gap, permanent magnet device used to correct the natural phase delay between the electrons and the x-rays. The last element in this section is a retractable, compressed air actuated, alignment quadrupole

SwissFEL Aramis Basic Undulator Controls

The undulator assembly has two independent Beckhoff PLC controllers mounted onto its frame. One is for the variable gap undulator, the phase shifter, and alignment quadrupole, and the second one is for the 5D mover system (Fig. 1). Each has a touch panel interface for local controls. The PLCs provide motor controls, kinematics, digital and analog I/O, and interlocks.

The mover system for the inter-undulator assembly is controlled by a custom DeltaTau motor controller installed outside of the accelerator tunnel. This controller supports eight motors and encoders, and runs Linux. DC power supplies for the quadrupoles and dipoles are also installed outside the accelerator tunnel, along with vacuum support equipment.

SwissFEL Aramis Undulator High Level Controls

The SwissFEL project decided on using EPICS, Experimental Physics and Industrial Control System, due to experience at the Swiss Light Source, SLS, also at PSI, and for being in used in other FELs like the Linac Coherent Light Source, LCLS, at the SLAC National Accelerator Laboratory in Menlo Park, in the state of California, USA [3]. This implies that all controllers ultimately talk to an IOC, Input Output Controller, running EPICS, in order to interface to the SwissFEL control system.

The undulator-assembly connects to two master IOCs, one for all PLCs which support the variable gap undulator, the phase shifter, and alignment quadrupole, and the other one for all PLCs for the 5D mover system. These

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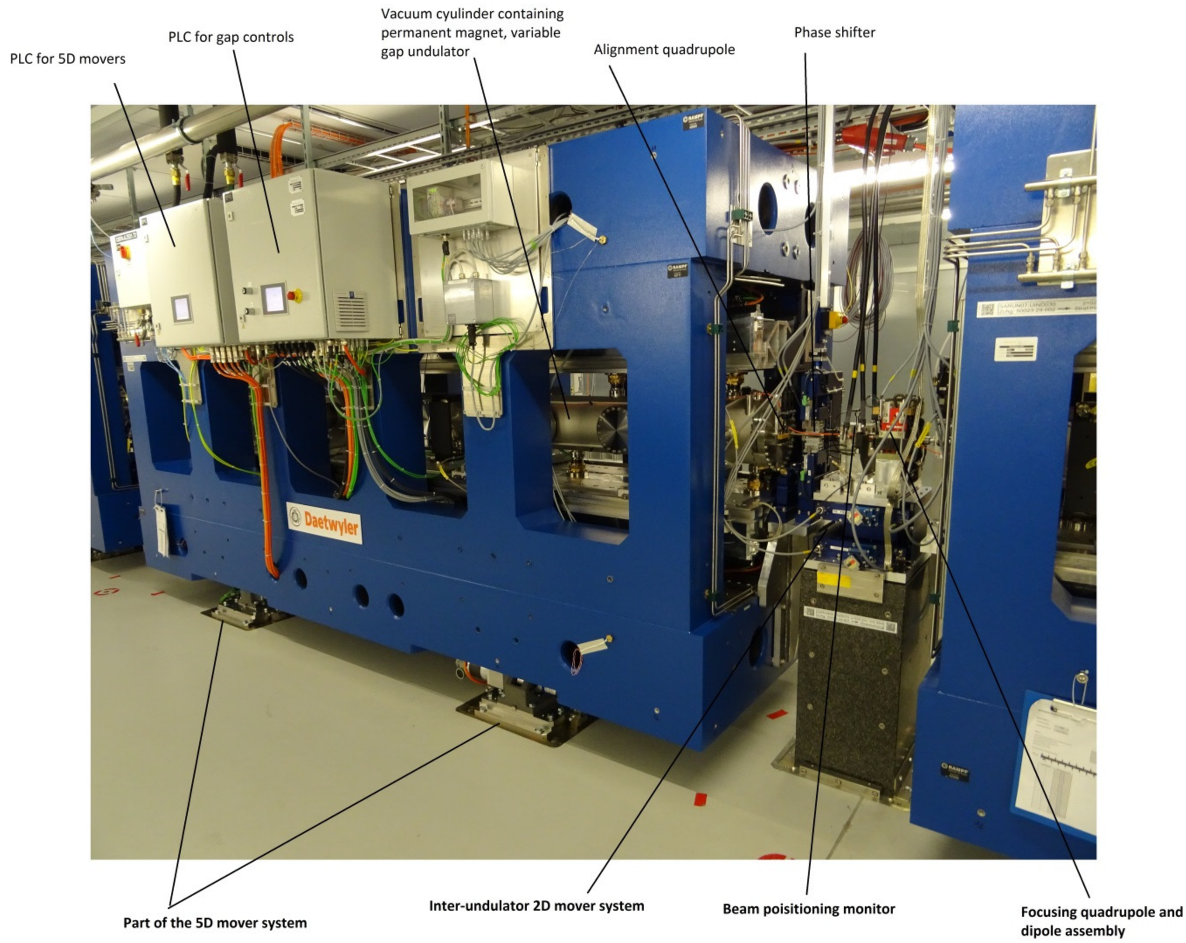

Figure 1: Aramis undulator module.

two IOCs run in servers next to the SwissFEL main control room. An EPICS driver is used to transfer blocks of data from the PLCs to the IOCs at a periodic rate setup by the PLC; this is the case for all read and write transactions. In this manner all PLC programmed functions are available in the SwissFEL control system.

For the inter-undulator assembly 2D mover system, the IOC runs within the DeltaTau, as this controller runs a Linux operating system. A series of EPICS drivers provide motor status and configuration access with the DeltaTau controller. For magnet controls, VME CPUs, outside of the accelerator housing, run EPICS in order to communicate with the power supplies. IOCs for vacuum controllers run on terminal server PCs, as some controllers require a serial connection.

The conversion from undulator gap to k, or the undulator strength parameter, electron path corrections due to gap dependent undulator fringe fields, automatic phase shifter adjustments, and photon energy calculations are currently all done in one soft IOC. Parameters for these conversions are uploaded by users to an online database, which is then used to configure the IOC.

SwissFEL Athos

From a controls perspective, the Athos undulator controls are quite similar to Aramis. The undulator itself is the most different, having four independent movable rows of magnets. This type of undulator is known as APPLE, Advanced Planar Polarization Light Emitter, and can provide linearly or circularly polarized X-rays. This makes it so Athos undulator controls require an additional layer for polarization controls, compared to undulators at Aramis.

The remaining of Athos controls will be the same, with the exception that Beckhoff PLCs will be used to control the inter-undulator 2D movers instead of DeltaTau controllers. Cold checkout will be starting in November of 2019, and full commissioning will start in 2020.

SwissFEL Aramis Commissioning Experience

Cold checkout started in the beginning of 2017. It consisted of exercising every movable part through its full range of motion, and checking all input and output signals. For the undulator assembly this went quite smoothly as the device had been checked and used in the magnetic measurement facility. Only minor cabling and network issues were encountered due to installation errors.

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Hot checkout is a bit more complicated for undulator lines, as the ultimate way to prove full functionality is to have a nominal intensity laser, and many accelerator systems can affect performance. Some issues were discovered after a few rounds of beam based alignment, which were corrected by reconciling beam based data with in tunnel alignment data. These alignment corrections were done by adding offsets to the 5D mover systems. So far, the maximum reached intensity has been about 600 uJ, which is within performance expectations.

Beyond commissioning, there have been some mechanical issues, the major one affecting the gap drive mechanism of undulator 13. The taper interlock, which protects the slides from damage, would regularly fault, around once per week for several weeks. Unfortunately, an access into the accelerator housing is required to recover this fault, and the whole process can take up to an hour. It would be good to reconsider the necessity to access the local controls to recover the taper fault, as even next to the device, additional diagnosis cannot be done, as the mechanical drive system is not easily viewable. The only advantage of local recovery is the possibility of hearing the drive system.

The undulator 13 issue has been mitigated by increasing the current of the motor driving the spindle. This only makes it so the motor is able to push through the mechanical constraints, so in the long run, the mechanism will wear out and fail faster than normal. Not much else can be done, since the work required to open and change the part is complicated.

CONCLUSION

The Aramis undulator controls commissioning has been a success. All elements have performed within expectations and issues have been limited. Interface improvements are being planned as users develop more efficient ways to run the machine. An additional consideration would be to rethink the need to have mechanical interlock resets only accessible within the tunnel, especially in cases where additional mechanical diagnosis cannot easily be accomplished.

Athos undulator controls commissioning will begin in November of 2019, and the experience from Aramis will help in making this project a success.

For any additional information or technical details, please contact the author.

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