DEVELOPMENT OF AN IN-VACUUM UNDULATOR SYSTEM FOR U-SAXS BEAMLINE AT PLS

Joe Kulesza, Dave Waterman, Alex Deyhim, Eric Van Every, ADC, NY 14882, U.S.A

K. Ingvar Blomqvist, Sweden

Abstract

The design of a hybrid in-vacuum undulator with 20mm period, effective peak field of 1.05 Tesla, and 1800 mm magnetic length is being presented (Figure 1). The design requirements and mechanical difficulties for holding, positioning, and driving the magnetic arrays are explored. The structural and finite element analysis, magnetic design, and electrical considerations that influenced the design are then analyzed.

This in-vacuum undulator (IVU) is being installed at Pohang Accelerator Laboratory (PAL) for U-SAXS (Ultra Small Angle X-ray Scattering) beamline. The IVU will generate undulator radiation up to ~14 keV using up to 9th harmonic undulator radiation with 2.5 GeV PLS electron beam.
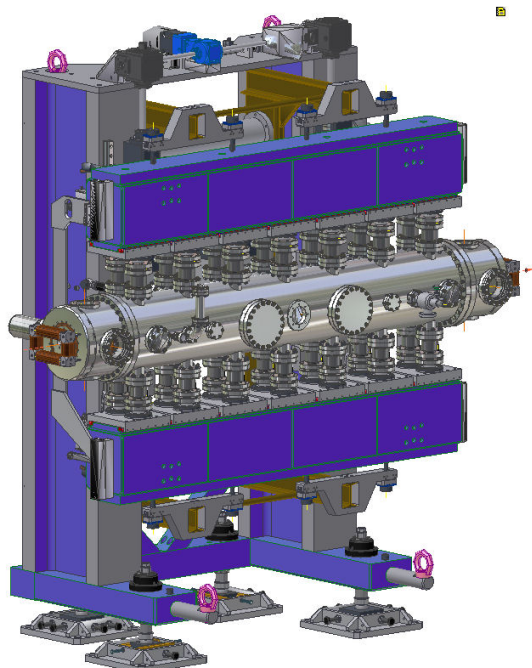
Figure 1: PLS In-Vacuum Undulator

The IVU has a long history of development. The first IVU was constructed in KEK [2] in 1990 and installed in the TEISTAN accumulation ring. Later an IVU for Spring-8 was constructed in 1996 [3]. Commissioning of this IVU was successfully completed by July 1997 [4].

CONTROL ARCHITECTURE

The in-vacuum undulator U-SAXS will be controlled with a Seimens S7-315 PLC (Figure 2). The purpose of this document is to describe and define what variables and format will be used for passing commands and status data to and from a system host using EPICS 3.14.9. The Seimens S7 PLC is a sophisticated controller with the capability of controlling 2 or more stepper or servo motors with encoder feedback. The software format is structured text. Software is developed in a text editor and downloaded to the unit for execution.

Communication is accomplished using an EPICS driver running on an IOC between the system host and the PLC. This driver was developed by SSRF. The driver allows a system host to read certain dedicated variables for commanded position, encoder position, commanded velocity, status, errors, and inputs using a TCPIP Ethernet interface.

The task for us is to define what variables are to be used for what purpose and how to effect software handshake for program execution. The primary function of the Seimens S7 PLC is to position the gap between the upper and lower magnet arrays. There are two gap movements that are planned, the gap distance itself and taper.

Gap distance is controlled by 1 motor while taper is controlled by another. All motors are stepping motors. There is one incremental rotary encoder mounted directly to each motor for step verification. In addition, two linear encoders will be mounted across the gap on either end (left and right) of the girders. There will be no requirement to "Home" the motors. The absolute encoders will keep track of the magnet array position even thru a power cycle.

The gap stepper motor uses size 42 frames but may also have a gear reducer. This will impose an element of backlash in the system. The goal is to close the position loop on the linear absolute encoders. The ratio of steps relative to rotary encoder count and linear encoder count will be determined at build time.

The linear absolute encoders use SSI to send information back to the S7. The S7 will receive the position from these encoders and determine gap and taper. The linear encoders will be programmed for .1 micron increment. These have self contained electronics and a special programmer is used to program these devices.

High repeatability (+/- 1 micron) switches will indicate negative limit while less repeatable switches will indicate positive limit. Each limit has a kill switch associated with it that will stop the motor.

SOFTWARE

The Siemens S7-315 PLC (Figure 3) is a sophisticated controller capable of sequential control, motion control, Ethernet communications, process monitoring, and complicated mathematics. The software can be written in

ladder logic, structured text, function block diagram, and sequential flow chart. ADC will use a combination of ladder and structured text.

PLC systems are built up from components. Typically, there will be a CPU module, power supplies, Input-Output modules, Analog IO modules, counters and motor controllers. The modules snap together and are mounted on a DIN rail. The communication buss is carried through each module. A sample system is shown below.

The PLC will be responsible for controlling the gap position and girder taper, reading of the linear encoders, calculation of the gap and taper, vacuum controls, temperature monitoring limit and kill switches, water flow monitoring, EPICS interface, and correction coil control.
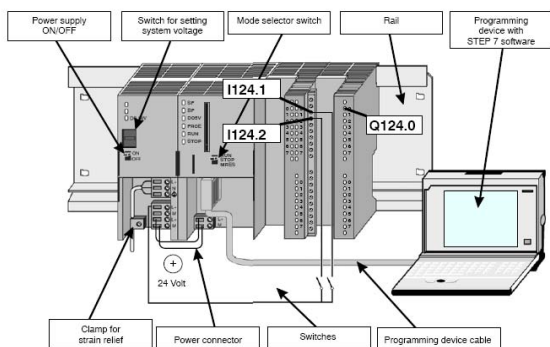

Figure 3 Siemens S7-315 PLC

VACUUM CONTROLS

There are 2 Ion pumps, 2 TSP pumps and 2 getter pumps planned for this system. The 2 ion pumps use a Varian 929-7013 dual controller. The 2 TSP pumps each use one Varian 929-7030 controllers. The 2 getter pumps each use a Saes 3B0351 controller. Also, there is one Varian Multigauge vacuum measurement controller which feeds back 2 analog vacuum pressures.

The communication to the vacuum pump controllers is serial RS232 to the Varian Dual Ion pump controller, analog IO to the Varian TSP controllers, analog input from the Varian Multigauge controller, and IO to the Saes getter pump controllers. In addition there is an interlock output to the Host system controller to indicate good vacuum threshold and the ID control system can accept an input from the system host to enable or disable vacuum pump control at the ID control system. Many threshold vacuum parameters can be defined at the individual controllers. The system host will be able to read an EPICS variable for the local vacuum pressure and enable or disable vacuum control at the ID via an EPICS bit variable.

MAGNETIC DESIGN

The design calculations have been done using RADIA [1], a three-dimensional magnetic field program from ESRF especially developed for the design of insertion devices. The relative permeability of the permanent magnet material, 1.05 parallel and 1.17 perpendicular to the easy axis are included in the calculations. Table 1 describes the undulator specifications.

Table 1. Magnetic Specifications for the In-Vacuum Undulator.

Undulator Type	Hybrid
Undulator Symmetry	Asymmetric
Undulator Period Length	20.0 mm
Number of Full Size Poles	176
Total Number of Poles	178
Length of Magnet Assemblies	1780.9 mm
Length Including Correction Magnet Hold.	≈1800 mm
Gap Range	4 – 40 mm
Effective Peak Field at 5 mm Gap	1.053 T
Effective k at 5 mm Gap	1.97
Magnetic Force at 4 mm Gap	22.8 kN
Pole Material	soft steel
Magnet Block Material	NdFeB

ADC's unique taper drive design features separate limit switches and hard stops for taper which do not interact with gap limit switches and hard stops. This can be considered more robust than tilt switches and encoder readings interpreted through software, for preventing over-tapering or getting magnets too close to the beam.

The framework is supported on 3 points using feet that are adjustable in X,Y and Z directions. The range is +/-25 mm in X and Z and +/- 30 mm in Y. For this reason it was determined that an automatic lifting mechanism is unnecessary. The undulator will be set to the critical beam height by hand. The feet employ a 50 mm diameter steel ball at each of the 3 points of support. This provides reduced friction but also provides a repeatable means to relocate the machine if it is ever removed from the ring.
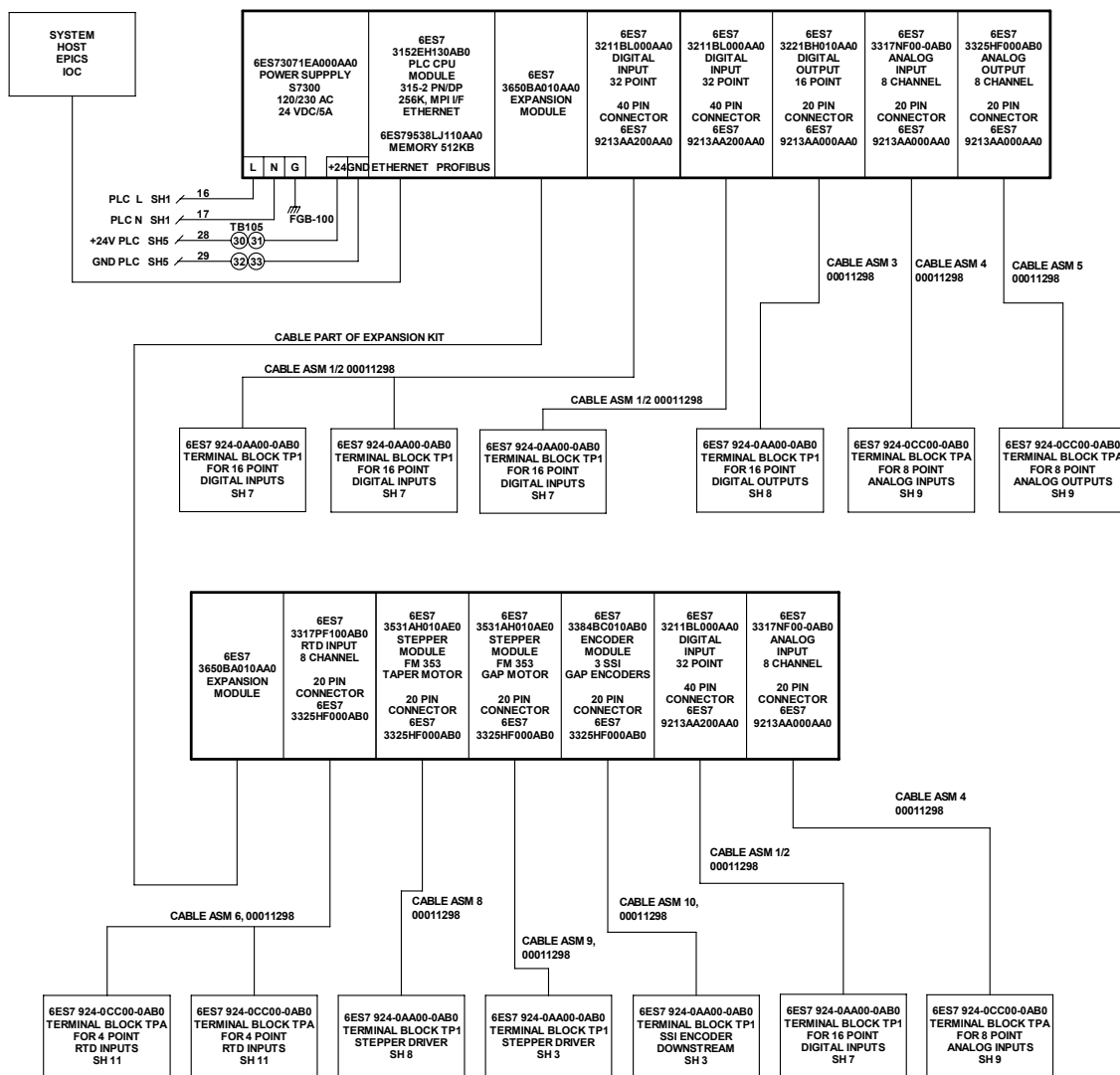
SIEMENS SIMATIC S7-300 PLC
PLS IN-VAC U-SAXS

Figure 2 layout of the Seimens S7-315 PLC

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