DEVELOPMENT OF UNDULATOR CONTROL SYSTEM FOR XFEL/SPRING-8

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Abstract

We developed a prototype system for controlling the undulators of the X-ray free electron laser (XFEL) at SPring-8. The XFEL consists of an 8-GeV linear accelerator and the undulators. The undulators are a critical component for lasing of an intense X-ray beam and require positioning accuracy of the undulator gap of less than 1 μm, that is, the undulator gap must be controlled at sub-micrometer resolution. To realize this degree of control, we implemented a proportional and an integral (PI) controller algorithm with linear encoders. In this paper, we report in detail the design of the undulator control system for XFEL/SPring-8.

INTRODUCTION

The X-ray free electron laser (XFEL) project at SPring-8 aims to build an 8-GeV XFEL facility on the SPring-8 site.

The facility consists of a C-band linear accelerator and 18 in-vacuum undulators per beam line. Two beam lines will be constructed initially, and three additional beam lines are planned to be subsequently built.

Since the magnetic attraction force causes positioning error of the undulator gap, this error must be compensated by precisely controlling the gap tuning to satisfy the lasing conditions. To provide accurate position control, a feedback system is necessary to control the motors.

Deviations in the temperature of the magnet arrays affect their magnetic field, and thus it is necessary to stabilize the cooling water temperature of the magnet arrays and to monitor their temperature.

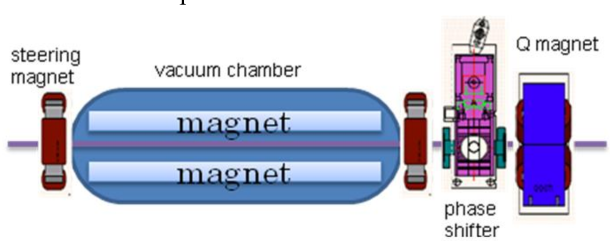

Figure 1: Configuration of undulator system.

The configuration of the undulator system is shown in Figure 1. A pair of magnet arrays is located in a vacuum chamber. Stepping motors are used to adjust the height of the chamber and the width between the magnet arrays. A phase shifter adjusts the optical phase between undulators and a stepping motor is used to control the phase. There are steering magnets attached to each end of the vacuum chamber. These are used to correct the error field of the magnet arrays. A quadrupole (Q) magnet focuses the electron beam, and a magnet power supply has been developed for these magnets. These magnets require precise and accurate control.

For the XFEL, we divided the device control system into two control layers. One is a programmable logic controller (PLC) that is the master node of DeviceNet. The other is a VMEbus system.

The front-end system consists of the VMEbus system and the PLC. PLCs are used for local control of systems including the undulator control system, the precise water temperature control system, and the vacuum system.

The VMEbus and PLC are connected via FL-net, which is an Ethernet-based factory floor network. A useful feature of this network is the ability to use network hubs and a network protocol analyzer as debugging tools. The PLC communicates with equipment such as the motor driver and encoders via DeviceNet [1], which is one of the open networks used in the automation industry.

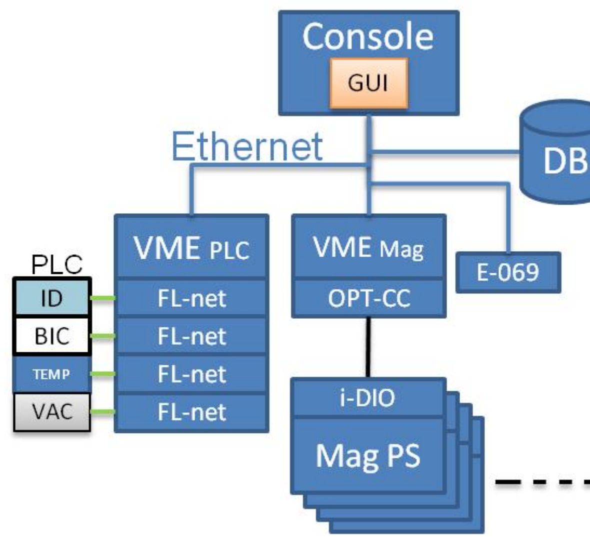

Figure 2: Schematic of ID system.

Figure 2 shows a schematic diagram of the system. The undulator control system (PLC-ID), beam instrumentation controller (PLC-BIC), precise water temperature control system (PLC-TEMP), and vacuum control system (PLC-VAC) are connected to the VME PLC via FL-net. The VME-Mag controls the magnet power supply. A remote procedure call (RPC)-based communication layer connects the GUIs and VME systems over the Ethernet.

PLC-BIC controls the attenuators of the beam position monitor (BPM) and current transformer (CT), the actuators of the screen monitor (SCM), the stepper motors of the SCM system, and the beam collimator. Most of the equipment controlled by the PLC-BIC is the same as the equipment in the accelerator section. We have standardized PLC-BIC with the accelerator and insertion device sections to facilitate maintenance.

PLC-ID must perform high precision position control of the magnet array. We adopt a linear gauge and a rotary encoder to measure position, and drive the high-resolution pulse motor with a pulse motor controller (PMC).

PLC-TEMP controls the temperature of the cooling water and PLC-VAC controls vacuum components such as the ion pump, vacuum gauge, and gate valve.

Fluctuation in the temperature of the magnet array affects its magnetic field, and thus the temperature of the magnet arrays must be monitored. The temperatures are measured by an E-069 module with a Pt100 resistance temperature detector (RTD) that has a resolution of 0.01 °C.

DESIGN OF UNDULATOR CONTROL SYSTEM

We designed the XFEL control system such that a single PLC-ID controls the two undulators. PLC-ID is the master node of DeviceNet. Encoders, a linear gauge box, and PMCs are connected as slave nodes for motor control.

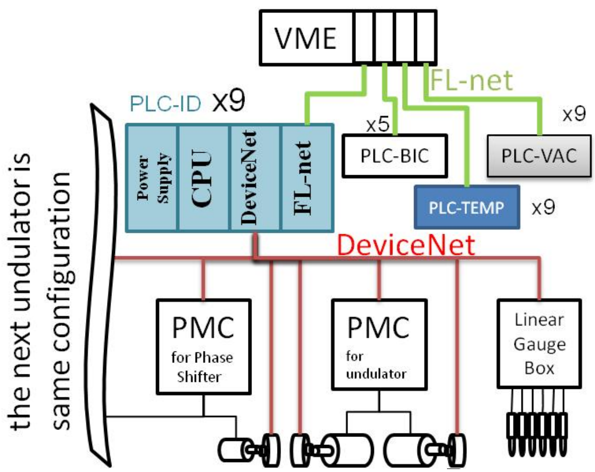

Figure 3: Schematic of PLC and control devices.

PLC

In the undulator section, there are 18 undulators. PLC-ID (Yokogawa Elec. FA-M3) connects two PMCs to move the magnet arrays, one PMC to control the optical phase, three rotary encoders, and two linear gauge boxes with DeviceNet.

PLC-ID and other PLCs share a graphical touch panel for local operation of the undulators.

Motors and Encoders

The PMC (Melec H743-00/GD5510E) and stepping motor with gears (H739-13 / TS3678N3401-HPG20-11 and H739-12/TS3678N3401-HPG20-15) drive the undulator.

The motor that controls undulator height is a 1/15 geared stepping motor that operates at 500 pulses per revolution. The undulator height controller is equipped with 6-mm pitch screws and a 96:1 reduction gear to drive the shaft. The resolution is 8.3 nanometers per step.

The motor that controls the undulator gap width is a 1/11 geared stepping motor that operates at 500 pulses per revolution. The undulator gap width controller is equipped with 10-mm pitch screws and a 200:1 reduction gear to drive the shaft. The resolution is 18 nanometers per step.

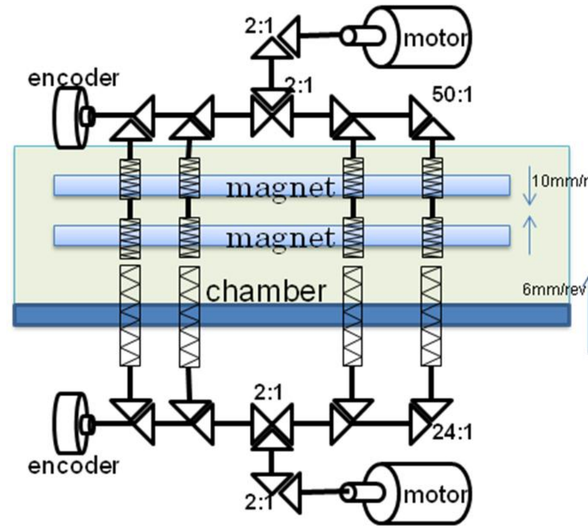

Figure 4: Undulator gears.

The absolute rotary encoder (Danaher AC58/1214EK.72DVS) is used to read the vertical position the undulator. This encoder has a resolution of 14 bits per revolution and is equipped with 6-mm pitch screws and a 24:1 reduction gear for the encoder shaft. The resolution of the vertical position is 15 nm.

The same encoder is adopted for the undulator gap width. It is equipped with 10-mm pitch screws and a 50:1 reduction gear for the encoder shaft. The resolution of the gap width is 24 nm.

The accuracy of the rotary encoder for the gap width could not obtain sufficient precision due to backlash of the reduction gear and deformation of the undulator caused by the magnetic attraction force. In contrast, a linear gauge produces little error since it directly measures the distance between the gaps. Six absolute linear gauges are used in addition to the magnet array with resolution of 0.1 µm. To obtain the most accurate positioning, we will implement a PI controller algorithm that compensates for position deviation.

Preventing Breakage of Bellows

In this system, PLC-ID controls the vertical position of the vacuum chamber of the undulator, and PLC-BIC controls the vertical position of the Q magnet and BPM stage. The permissible deviation in the position of the bellows attached to the vacuum chamber is less than 2 mm. Moreover, the vacuum chamber and the stage must be moved simultaneously. To prevent breakage of the bellows, we adopt a limit switch box that receives signals from limit switches and sends a limit signal to each PMC. The limit switch state is read by PLC-BIC through DeviceNet.

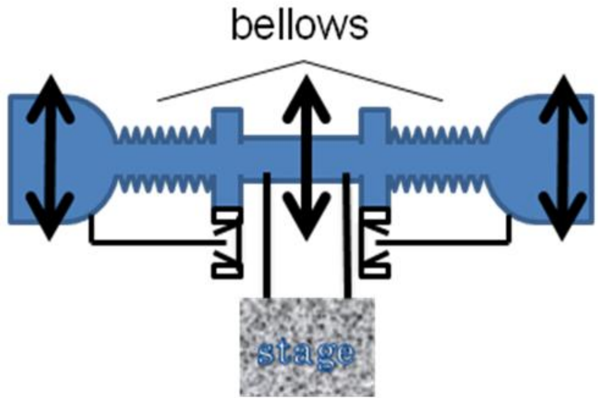

Figure 5: Bellows.

OTHER DEVICES

Temperature Monitoring

We measure the temperature of the magnet array with Pt100 RTDs. We adopt the E-069[2] module developed at SPring-8. The E-069 module connects 24 pairs of Pt100 RTDs, each with four terminal wires, and supports the Power over Ethernet protocol.

The temperature at 22 points on the magnet and 6 points on the Q magnet, as well as the BPM stage temperature, are measured by two E-069 modules [4].

Magnet Control

Each power supply is controlled by built-in remote I/O card, referred to as OPT-RMT i-DIO[3]. The i-DIO card communicates with the VME master card, referred to as OPT-CC, through a pair of optical fibers.

We adjust the width of the undulator gap in order to control the current steering magnets, and it makes to be transparent in the ID's whole magnetically.

Prototype System

We constructed a test system to examine the feasibility of motor control by DeviceNet. A Windows PC was used as the master node of DeviceNet instead of a PLC. As an application platform, LabVIEW was used to build test applications. The test system included a single PMC and two rotary encoders. We tested control sequences required for precise undulator control using the system. The results of the feasibility test indicated that the test system is sufficient for motor control. We installed the test system at the production facility where the undulators are being manufactured. The system is performing well in factory tests of the undulators prior to shipping.

SUMMARY

We have designed and developed a prototype system to control the undulators of XFEL/SPring-8. The required positioning accuracy of the undulator gap is less than 1 μm. To realize this level of accuracy, we adopted the PI controller algorithm to control the undulator gap width with linear encoders. A limit switch box that prevents breakage of the bellows is currently under development.

We have completed and tested a prototype front-end control system for the undulators by using LabVIEW. This system has been used in factory tests of the undulators prior to shipping.

AKNOWLEGEMENT

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