TECHNICAL OVERVIEW OF INTER-UNDULATOR SUPPORT SYSTEM FOR PAL XFEL

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Abstract

Pohang Accelerator Laboratory (PAL) has been developing a SASE X-ray Free Electron Laser based on 10 GeV linear accelerator. The inter-Undulator (IU) support system was developed to be used in the intersections of the Undulator Systems. The IU supports consist of phase shifter, quadrupole magnet with mover, beam loss monitor, cavity BPM with mover, two corrector magnets and vacuum components. The adjusting mechanism of IU Support has manual alignment system to be easily adjusting the component. The mover of quadruple magnet and cavity BPM with submicron repeatability has auto-adjusting systems with stepping motor. The mover main specifications include compact dimensions and a ±1.5 mm stroke in the vertical and horizontal direction. Linear motion guide based on 5-phase stepping motors have been chosen. This paper describes the design of the stages used for precise movement and results of mechanical measurements including reproducibility will be reported.

INTRODUCTION

PAL-XFEL has been providing X-rays in ranges of 0.1 to 0.06 nm for hard X-ray line and 3.0 nm to 1.0 nm for soft X-ray line by using the self-amplified spontaneous emission (SASE) Schematic [1]. There are several undulators for Hard X-ray and Soft X-ray line. To generate X-ray FEL radiation, the PAL-XFEL undulator section requires high resolution beam position monitoring systems with < 1 μm resolution for single bunch. It will be used in the intersections of the Undulator Systems to achieve high resolution requirement.

The inter-undulator sections, shown in Figure 1, consist of phase shifter, quadrupole magnet with mover, beam loss monitor, two corrector magnets and cavity BPM with mover. The quadrupole mover developed based on the EU-XFEL concept with some modifications. It includes submicron repeatability for quadrupole magnet and a ±1.5 mm stroke in the vertical and horizontal direction. Compact linear actuators based on 5-phase stepping motors have been chosen. Vertical actuator works in a wedge configuration to take mechanical advantage. A closed-loop control system has been developed to achieve this repeatability. For the feedback, one LVDT sensor for each axis was used. Mechanical switches are used to limit movement. In addition, hard-stops are included for emergency.

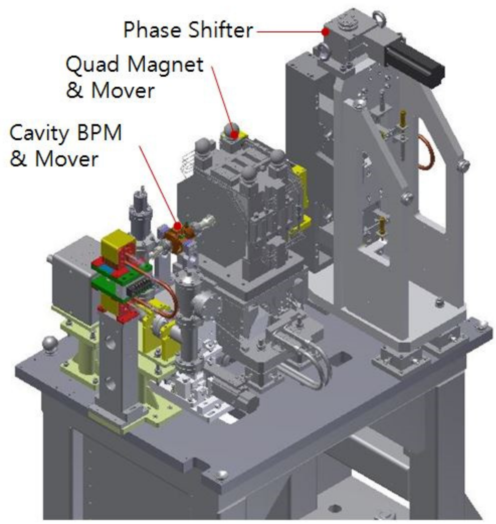

Figure 1: Lay-out of inter-undulator section.

OVERVIEW OF CAVITY BPM MOVER

The cavity BPM system had installed in between each undulator with other diagnostics tools. The cavity BPM Mover had been fabricated, tested and installed for the PAL XFEL [2]. The main specifications include submicron repeatability for a 10 kg cavity BPM within compact dimensions and a ±1.5 mm stroke in the vertical and horizontal direction. Linear motion guides based on 5-phase stepping motors have been chosen. For the measurement of the position, one digital probe sensor for each axis was used. Mechanical switches are used to limit movement. In addition, hard-stoppers are included for emergency.

Table 1: Main Specification for Movers

	Value	Details
Dimensions	332x140x255.5 mm^3	Long, wide, high
Axes	2(H & V)	±1.5 mm stroke
Load	10 kg	
Repeatability	< 3 μm	
Control Device	Digital probe closed-loop	EPICS
Ranges	±1.5 mm Limit Switch	±1.6 Hard Stopper
Driving System	5 Phase Stepping Motor	With brakes
Measure System	Digital Probe (DP/5/S)	< 0.15 μm
Limit Sensor	D4E-1C20N	

The main specifications for these movers are included in Table 1. The movers are composed of each stepping motor for horizontal and vertical, digital probe, limit switch and harder stopper. Figure 2 shows the 3D view of

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cavity BPM system. A robust and compact mover is required according to specifications therefore concept design includes some important features. The drive mechanism adopts a 5-phase stepping motor with ball screw for Oriental Motor's. The motor achieves high positioning accuracy in a space-saving design. The compact and lightweight body houses the rotating components as well as the linear motion mechanism of the stepping motor. The load position can be held with electromagnetic brake when the power is cut off. Since the work will not fall in case of power failure or disconnection, it can safely use equipment in which the work moves vertically. Linear motion (LM) guides and high-precision motors have been selected for both axes. LM guide in each row of balls is placed at a contact angle of 45° so that the rated loads applied to the LM block are uniform in the four directions (radial, reverse radial and lateral directions). Two digital probes are used to measure at horizontal and vertical direction movement.

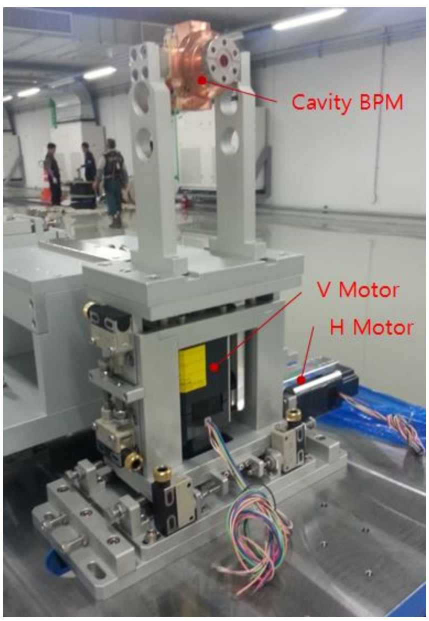

Figure 2: 3D view of cavity BPM Mover.

The repeatability is the most important specification of the movers, as submicron level must be reached. The cavity BPM mover is measured at both axes with external reference gauges. The positioning to a certain LVDT position reaches always exactly the same actual position from external references in a perfect repeatable system. The sets of measured movements are 0.2 mm steps along the vertical axis and the horizontal axis for the whole movement range. Results for direct movements from a given position have been found to have very high repeatability. Design has also a high ability to keep position under certain possible conditions. Repeatability is below ± 1 micron at every set of movements for both axes.

QUAD MAGNET AND MOVER

We have designed 11 families of quadrupole magnets. Two types of them are used in Undulator section [3]. Q6 is for HXU and Q9 is for SXU. Q6 and Q9 are indirect cooling system (heat sink) and they have horizontal and vertical steering functions. Figure 3 shows the conductor cross section and temperature distribution of quadrupole magnet Q6 and Q9. We prepare the field clamp to shield the leakage field from quadrupole magnet. The field clamp of 1mm thickness can reduce the leakage field to less than 5 Gauss beyond this clamp.

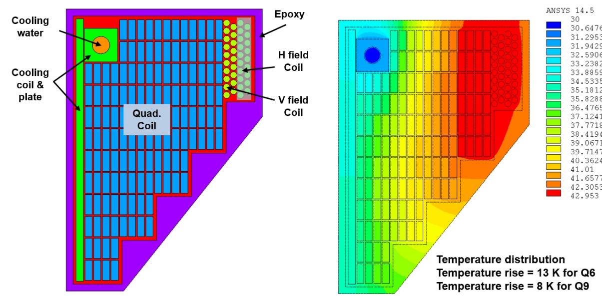

Figure 3: The conductor cross section and temperature distribution of quadrupole magnet Q6 and Q9.

Quad mover had been developed to be used for the Hard X-ray and Soft X-ray undulator line. On the basis design of EU-XFEL quad mover [4], we implemented some modification, fabricated and tested. The main specifications include submicron repeatability for a 70 kg quadrupole magnet within compact dimensions and a ±1.5 mm stroke in the vertical and horizontal direction. Compact linear actuators based on 5-phase stepping motors have been chosen. Vertical actuator works in a wedge configuration to take mechanical advantage. A closed-loop control system has been developed to achieve this repeatability. For the feedback, one LVDT sensor for each axis was used. Mechanical switches are used to limit movement. In addition, hard-stops are included for emergency. Figure 4 shows the quadrupole magnet Q6 and quad mover.

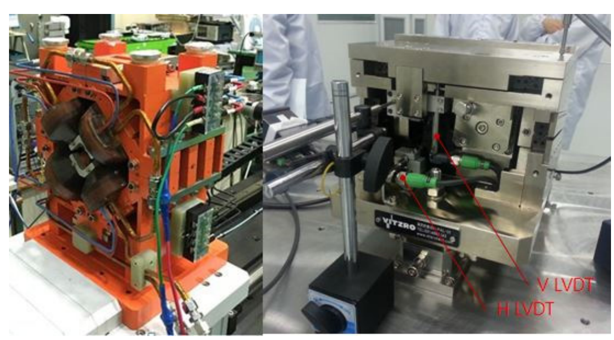

Figure 4: Q6 Magnet and quad mover.

A robust and compact mover were required, therefore concept design includes the following important features.

High-precision linear motion guide had been selected for both axes X and Y. The wedge design has a slope so the force needed to lift the load is lower than the direct weight of the load. At the same time, diagonal movement instead of a vertical one results in a finer resolution for vertical axis. A closed-loop control system is implemented in order to achieve submicron repeatability. Two LVDTs are placed outside the mover to get a continuous measurement of each axis absolute position. Each LVDT has been arranged to measure just one axis at a constant contact point, which means that the LVDT and the measurement surface have no relative movement apart of the measured in-axis separation. Limit switches were added at the ends of movement of both axes to ensure that even under a failure of the LVDT sensors the mover will be reach a safe stop position. Moreover, mechanical stoppers have been implemented to exclude any possibility of over-travelling.

The repeatability is the most important specification of the quad movers, as submicron level must be reached. It was measured at both axes with external reference gauges. The positioning to a certain LVDT position reaches always exactly the same actual position from external references in a perfect repeatable system. The sets of measured movements are 0.2 mm steps along the vertical axis and the horizontal axis for the whole movement range. Results for direct movements from a given position have been found to have very high repeatability. Under such conditions, Repeatability is below ± 1 micron at every set of movements for both axes.

PHASE SHIFTER

On the basis design of EU-XFEL phase shifter, we implemented some modification, fabricated and tested. The main specifications of the design calculation are summarized in Table 2. Linear motion guide at each side of the magnet structure are installed to reduce a friction and guide magnet structure. One linear encoder is used at upper magnet beam to measure the gap movement. A left/right handed ball screw is used in order to change the magnetic gap. In this way only one single stepping motor drive system is sufficient to control the magnetic gap. The deformation of the magnet structure depends on the magnetic gap. A solid geometry is adopted for the backing beam and magnet structure. The gap position is determined by the ball screw using the values of the linear encoder. It measures the motion of the gap with a dial gauge.

Table 2: Main Specifications for Phase Shifter

	Unit	Value
Device Length	mm	171.6
Min. Gap	mm	12
Max. Gap	mm	160
Magnetic Period Length		45.8
Gap Repeatability	µm	± 5
Max. Gap Speed	mm/s	10
Magnet Material		Vacodym 863 TP
Pole Material		FeCo, annealed at 850°C
York Material		ARMCO soft iron

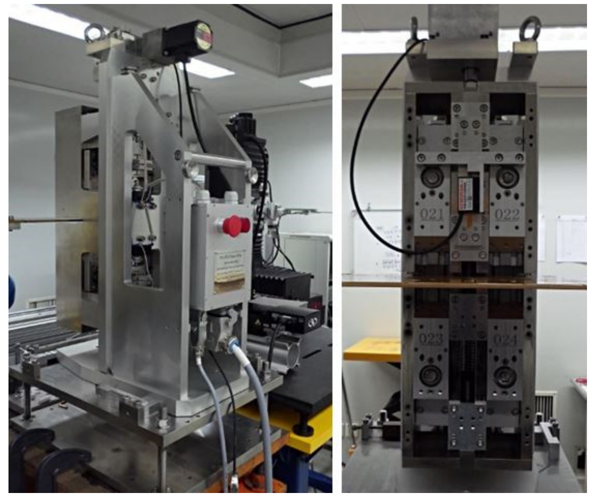

Figure 5: Rear and front view of phase shifter.

The moving tests were performed to the gap range of 11-30 mm, where magnetic forces are higher and the other gaps are negligible. The mechanical deformation of the magnet supports at minimum gap leads to a deviation of about several microns. This hysteresis is due to mechanical movement, back lash, elasticity and friction of the magnet systems in the iron yoke and in the guiding system. Limit switches were added at the rear of the phase shifter of upper and lower part to ensure that even under a failure of the linear encoder sensors, the mover will be reach a safe stop position. Moreover, mechanical stoppers have been implemented to exclude any possibility of over-travelling. Figure 5 shows the rear and front view of Phase Shifter.

SUMMARY

In this report, the status of the PAL-XFEL Inter-Undulator section is briefly described the mechanism of structure and component. It was already supplied and installed to Hard X-ray and Soft X-ray Undulator hall. Cavity BPM Mover and Quad Mover was supplied and tested from domestic company.

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