

FIELD MEASUREMENT FACILITY FOR PAL-XFEL UNDULATORS*

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Abstract

Pohang Accelerator Laboratory (PAL) is developing the SASE based FEL for X-ray coherent photon sources. The PAL developed the prototype undulator that was 5.0 m magnetic length, 7.2 mm minimum gap with ~ 0.908 T of magnetic field. The PAL has constructed the undulator field measurement facility to confirm the field qualities of the XFEL undulators in the assembly building. Two field measurement benches that included Hall probe scan, flip coil and stretched wire system were installed and evaluated their performances. This paper described the field measurement facility with the performance test results of the benches.

INTRODUCTION

The Pohang Accelerator Laboratory (PAL) has been carrying out the PAL-XFEL construction project since 2011. It generates 0.1 nm hard X-ray FEL using the 10 GeV S-band linear accelerator. The layout of the linear accelerator was figured hard X-ray beam lines and soft X-ray FEL beam lines as well as undulator lines. The length of the PAL_XFEL building will be 1100 m including about 120 m undulator section. The out vacuum undulators which are a similar EU-XFEL style have been developing at the PAL. The specifications of the PAL-XFEL undulator were described in Ref. [1].

All undulators have to be measured the magnetic properties precisely and be carried turning process to minimize the field errors that come from the mechanical imperfection assembly and the magnetic blocks which have not the uniform field performances[2-3].

There is needed to build the new magnetic field measurement facility for XFEL undualtor in the PAL. Two undulator field measurement benches had been installed in two separated rooms inside a large assembly building. The measurement rooms that temperature stability was within ± 0.1 °C are constructed. In this paper, the various test results of the installed measurement systems are described. And the facility performances for keeping the high measurement stability were also presented.

MEASUREMENT ROOM FACILITY

The facility for undulator field measurement was constructed inside a large assembly building in the PAL. It separated into three compartment rooms, two measurement rooms and one shared room for buffering the air flow when people coming and going. The size of the measurement room(MR) is 11000 mm \times 5700m \times 3500

mm (L \times W \times H). Some portion of the ceiling of the MR was able to open when an undulator moved into the room or vice versa. The wall of the MR was composed of non-magnetic materials to reduce the field deformation. The temperature of the MR is controlled in 25 ± 0.1 °C to minimize the field variation of a magnetic block which is a temperature coefficient of -0.12 % [4]. And the mechanical structure of the undulator such as linear encoder also was so sensitive to the temperature variation that the permitted repeatability is less than ± 1 μ m. The figure 1 shows the temperature variation in measurement room for 6 hours. It confirmed the temperature was controlled within a given specification.

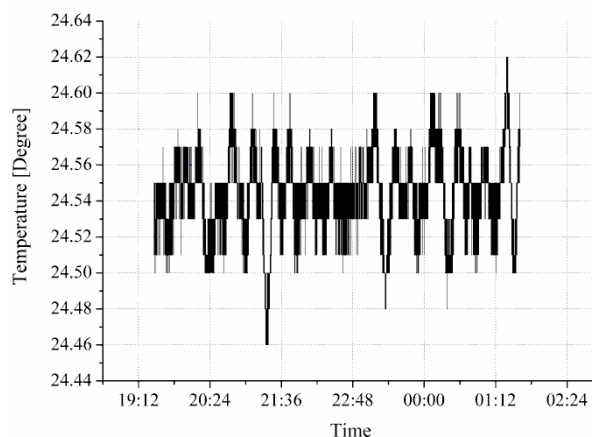


Figure 1: Temperature variation of the MR which is within ± 0.1 °C.

The exterior space of the measurement room was reserved for assembling the control system, testing and temporary storing undulators before and after measurement procedures. This space was also limited temperature variation in ± 3 °C as a temperature buffer to the high stable measurement rooms,

MEASUREMENT SYSTEM

Two field measurement benches from Bruker ASC were installed in the PAL. The bench comprised of three different field measurement systems such as Hall probe system (HPS), flip coil system(FCS) and stretched wire system(SWS). Some specifications of the HPS and FCS were summarized in the table 1.

A granite block of the HPS is a basic component with the size of 350 mm \times 600 mm \times 7050 mm (D \times H \times W). The magnetic assembly of the linear motor is mounted in between two high precision guiding rails along the top of the granite block.

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Table 1: Specifications of the HPS and FCS

Parameters	Value
Hall probe system	
Operating range	Up to 1.8 T
Accuracy	± 1.0 G
Positioning accuracy x,z,s	± 2.5 μ m
Scan range in s axis	6.5 m
Scan range in x axis	± 20 mm
Scan range in z axis	± 100 mm
Flip coil system	
Repeatability	± 2.0 Gcm
Measuring range s axis	Up to 6 m
Measuring range x, z axis	150 mm

The linear motor operates as a servo motor with a Renishaw TONIC linear encoder of resolution of 0.1 μ m, whose scale parallels to the guide rail of the motor. The Hall probe carrier assembled on the linear motor is equipped with two stages to move the Hall sensors to z and x axis. The figure 2 shows the block diagram of the measurement system for the undulator consisting of the HPS, the FCS and the SWS.

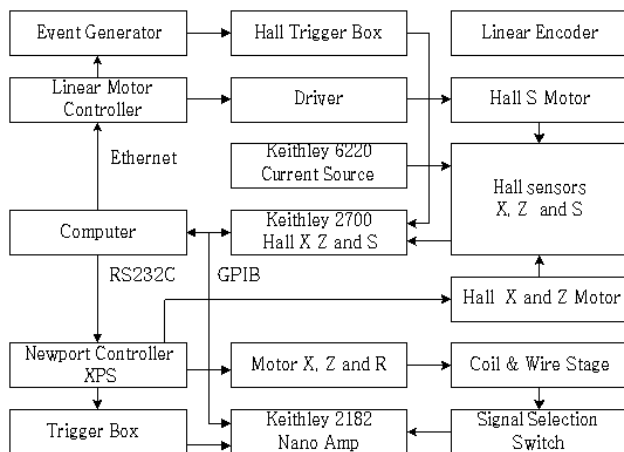


Figure 2: The block diagram of the undulator measurement System.

The Hall probe PCB was fabricated with three separate sensors which measured for the magnetic field of three orthogonal axes of x, z, and s, respectively. These sensors produce a Hall-voltage proportional to the magnetic field that is passed to its sensitive area. The Hall sensor is GH-700 from FW Bell, which sensitivity reaches to 50 mV/140 kG at 5 mA driving current. It was mounted on the end of an arm, a circular epoxy bar, which length is about 0.5 m. The sensors are not perfectly perpendicular with respect to each other. The errors coming from this configuration have to be corrected using the calibration table which was built with the dedicated reference magnet and a NMR tesla meter. This table was provided by the ESRF. The table which was also compensated the Planer effect of the Hall sensor was given to the field processing program.

A DC current source, Keithley 6220, was used to supply the high stable current of 5 mA to the Hall sensors that are daisy chained in series so that each one see the same current. The RMS noise of this instrument is about 0.4 μ A under the 1 Hz bandwidth at the 20 mA range

The measurements of the magnetic field profile along the bench are executed on the fly mode with the measurement speed of 24 mm/s. The Hall voltages which were in proportion to the field intensity of the sensor was digitized during the flying scan by the three Keithley 2700 voltmeters that dedicated to each axis of the Bx, Bz and Bs. They take one data per trigger clock, which translates the Hall probe position. The clock is generated by the programmable event generator of the ACS motion control system during the Hall scan. The digitized volts are stored in the memory of a Keithley voltmeter and transferred to the computer after scan finished through the GPIB. The voltmeter has the resolution of 10 μ V and the accuracy of 21 ppm within ± 1 $^{\circ}$ C temperature variation at the 10 V range.

The control software for the whole measurement system was composed using the Wavemetrics IGOR. It controls motors for HPS, FCS and SWS. A simple graphic user interface for motor movement was also written by IGOR. It also interfaces to the instruments to control and get the data by the GPIB, RS232C and Ethernet. The field analysis software B2E was written by ESRF.

EXPERIMENTAL RESULTS

A Renishaw XL80 laser interferometer was used to measure the straightness of the long S Axis of the scan bench. This laser interferometer was aligned with the travel direction of the long axis. On top of the Hall arm a reflector was installed. Thus it was possible to measure the pitch of the long axis. One measurement was taken every 1 mm over the full length of the bench.

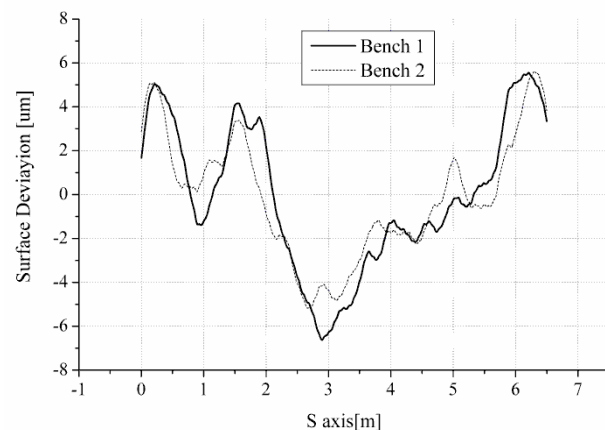


Figure 3: Deformation profile of the Bench 1 and 2.

This scanning was triggered by the control system of the measurement bench. By integrating the measured angle the change in height can be calculated very accurately. The results show a straightness of approximately ± 6 μ m for the Bench 1 and 2 as shown in the figure 3.

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The pure electronic random noise level was specified to be better than ± 1.0 G for the Hall probes. This test was realized by scanning along the whole travel range of the bench of 6500 mm. To avoid any influence from environmental magnetic fields, the Hall probe resided inside a zero-gauss chamber for this test. The temperature stability was guaranteed within ± 0.1 °C by the temperature control of the measurement room. All specifications on the noise level of < 1.0 G could be achieved as shown in the figure 4. The standard deviation of the random noise level is on the order of 0.06 G. The required measurement accuracy for the magnetic field using the Hall probe was limited to less than as $\text{dB/B} = 10^{-4}$.

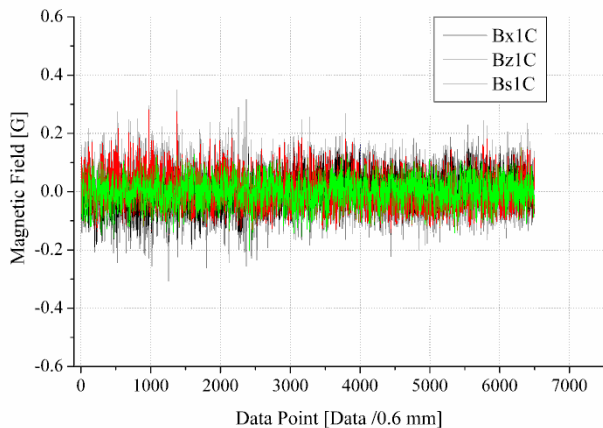


Figure 4 : Back ground noise of the HPS.

The figure 5 shows the field profile of the prototype undulator for PAL-XFEL at the gap of 7.2 mm. The undulator was installed in the measurement room and aligned to the measurement bench precisely. The data are digitized every 0.6 mm by the Keithley 2700 voltmeter. The total data point amounts to 6500, but only beginning part of the full data is drawn in the figure 5.

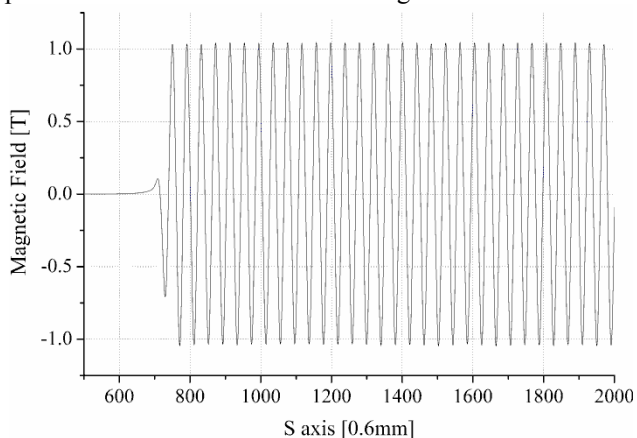


Figure 5: Field profile of the prototype undulator measure by the HPS.

The field intensity in the outside section of the undulator is equal to the measured noise level as the figure 4.

The Hall probe repeatability was confirmed by means of a series of 10 scans over the full undulator length of

5500 mm with a step size of 0.6 mm at the scanning speed of 24 mm/sec. The data of the 3436th around peak field position was randomly chosen. The data variations of the Bz were within ± 1 G as shown in the figure 6.

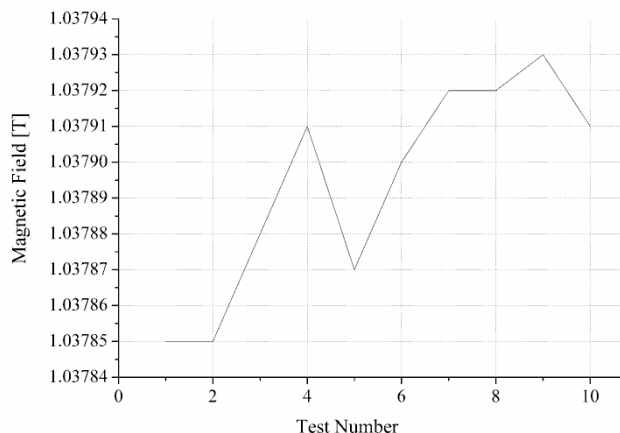


Figure 6: Test results of the system reproducibility. The variations are within ± 1 G.

CONCLUSIONS

The field measurement facility for XFEL undulator has been finished. The measurement benches were installed in the high stable field measurement room. The Helmholtz coils were installed in a MA to reject earth's magnetic field around the undulator position. The vibration of the benches were less than $100 \text{ nm}/\sqrt{\text{Hz}}$ at the frequency of 30 Hz. The temperature inside the measurement room was controlled within 25 ± 0.1 °C and the outside was 25 ± 3 °C. The deformations of the benches were less than ± 6 μm over the 6.5 m in s axis. The linear scale of the bench is corrected using the laser interferometer. The back ground noise of the Hall probe system was within ± 1 G. The system reproducibility of the Hall probe system with ten series of scan was also less than ± 1 G. The test results of the flip coil between maximum and minimum around peak field is ~ 1.8 Gcm. The shimming process to the prototype undulator has been carrying out at the PAL now.

ACKNOWLEDGMENT

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