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HLS SYSTEM TO MEASURE THE LOCATION CHANGES IN REAL TIME OF PAL-XFEL DEVICES*

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Abstract

Several parts that comprise the large scientific equipment should be installed and operated at precise three-dimensional location coordinates X, Y, and Z through survey and alignment to ensure their optimal performance. As time goes by, however, the ground goes through uplift and subsidence, which consequently changes the coordinates of installed components and leads to alignment errors ΔX, ΔY, and ΔZ. As a result, the system parameters change, and the performance of the large scientific equipment deteriorates accordingly. Measuring the change in locations of systems comprising the large scientific equipment in real time would make it possible to predict alignment errors, locate any region with greater changes, realign components in the region fast, and shorten the time of survey and alignment.

For this purpose, a HLS's (hydrostatic leveling sensor) with 0.2um of resolution are installed and operated in a water pipe of total length 1km in the Pohang Accelerator Laboratory's X-Ray Free-Electron Laser (PAL-XFEL) building. This paper is designed to introduce the operating principle of the HLS, the installation and operation of the HLS system, and how to utilize the HLS system in order to ensure beam stabilization.

INTRODUCTION

All components of PAL-XFEL were completely installed in December 2015, and Hard X-ray 0.1nm lasing achieved through its beam commissioning test and machine study on March 16, 2017. The beam line users are use the hard x-ray since March 22, 2017 [1].

The HLS and WPS (wire position sensor) system has been installed since September 2016 to measure and record changes of the ground and the floor of the building in real time (see Fig. 1) [2].

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HLS ULTASONIC (ULS) SENSOR AND SELF-CALIBRATION

Deutsches Elektronen Synchrotron (DESY) conducted In-situ experiments to develop the ultrasound sensor for HLS in 2001 and the basic design concept of ultrasound sensor for HLS was built based on the result of the experiments [3]. The structure of ultrasonic pulse hydrostatic level sensor developed by Budker Institute of Nuclear Physics (BINP) is described in Fig. 2. The sound reflector made of invar metal that has a low thermal deformation acts as an absolute ruler at an interval of 7.5mm and self-calibrates the differences of water density due to the changes in temperature (sound speed) and electrical properties of the transducer.

The self-calibration function allows accurate measurement for longer periods of time. It is highly desirable to have a function that allows the sensor itself to be calibrated [4-6]. A reliable measurement sensor should be selected and used in order to obtain a reliable measurement value. Therefore, ultrasonic type HLS was selected for PAL-XFEL.

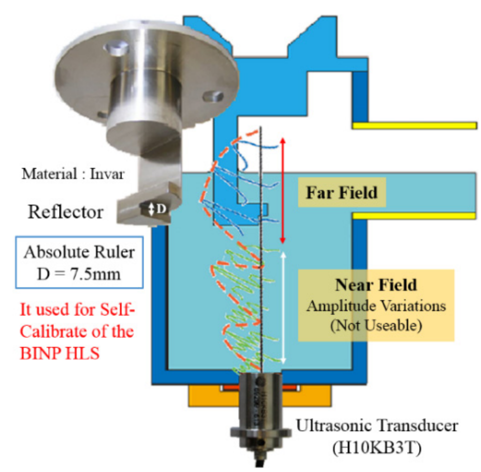

Figure 2: The HLS measurement concept using an ultrasonic transducer and self-calibration.

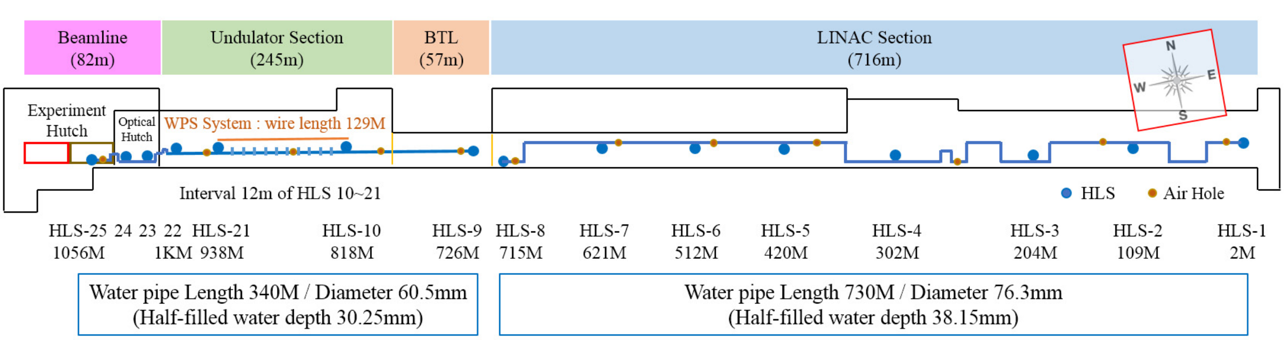

Figure 1: The position of HLS and WPS and specification of HLS water pipe in PAL-XFEL (top view).

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HLS REFERENCE: WATER PIPE

The most important thing about HLS system is the water pipe which provides the measurement reference. Water within the water pipe should have good fluidity even with changes in the surrounding environment such as changes in temperature and pressure in order to maintain the constant level of water in the water pipe (see Fig. 3). It's the only way to calculate the floor deformation accurately using the measurement of all HLS vessel floors. In terms of the fluid behaviour, after investigating studies about the way of calculating the water pipe diameter which is most appropriate for the length of full-filled and half-filled water pipes and the consequential stabilization time of water oscillation, the half-filled water pipe was found to be measured accurately [7-8]. Some studies even show a comparison between the thermal deformation of the material of the water pipe according to changes in temperature and changes in water volume [9].

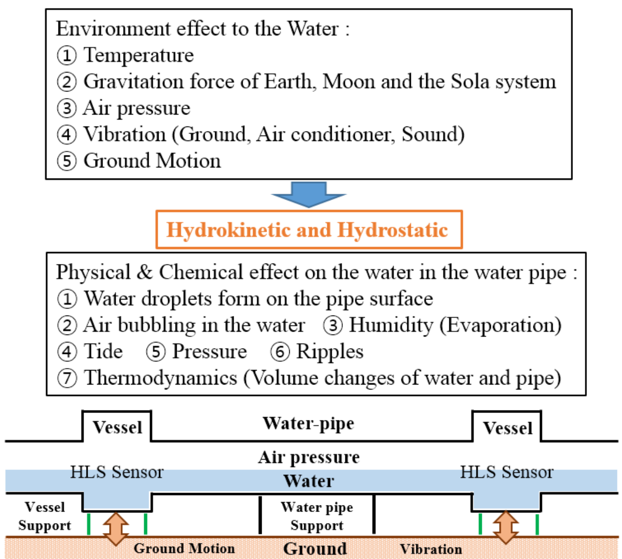

Figure 3: The surrounding environment influencing HLS.

PAL-XFEL installed large-diameter water pipe to provide smooth flow of water and constant water level (see Fig. 1). As water maintains balance owing to the force of gravity, so its flow gets slower when a pressure difference within the water pipe arise. After additionally installing air ports at intervals of 100 meters in the water pipe for smooth flow of air and water, we injected or drained water within the measuring range of a HLS (17.5±2.5mm) to observe the flow of water and measuring status of the HLS (see Fig. 4). It was observed that the flow rate of water got faster after installing air holes (see Table 1).

Table 1: Time Required to Attain Equilibrium of Water after Adding Air Holes

Section	Before adding	After adding
LINAC	14 hours (air hole 2ea)	4 hours (air hole 7ea)
Undulator	2.5 hours (air hole 2ea)	1.5 hours (air hole 4ea)

After installing the HLS system, change the water level inside the water pipe and make sure that the HLS measurement range is well measured and the flow rate is sufficient. It is a method to check whether the HLS system is operating normally.

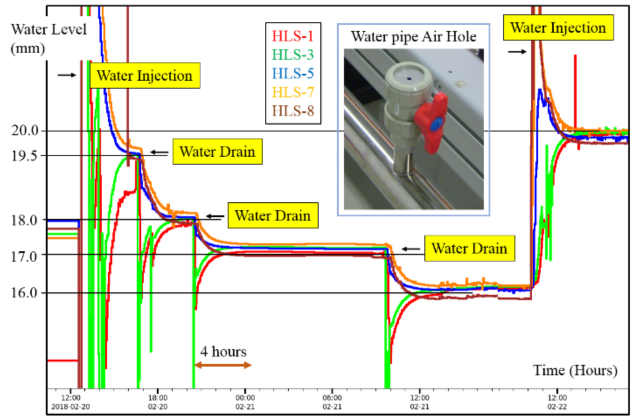

Figure 4: Test for flow of water in the water pipe.

INSTALLATION AND OPERATION OF HLS

Data-acquisition PCs for HLS should be stably operated for a long time. For this, PXIe-8135 produced by national instrument was selected. The program for measuring HLS was prepared with LabVIEW. The experimental physics and industrial control system (EPICS) communication for storing HLS measurement values in the database used CA Lab, which was developed by the helmholtz-zentrum berlin (BESSY) research center in Germany, after downloading it [10].

There should be no error to measure HLS in real time. However, two kinds of errors were observed in HLS measurements on the LINAC section. The first one was a measurement error by vibration from klystron modulator on the LINAC section (see Fig. 5). The vibration problem will be solved if a vibration-resistant HLS support is installed.

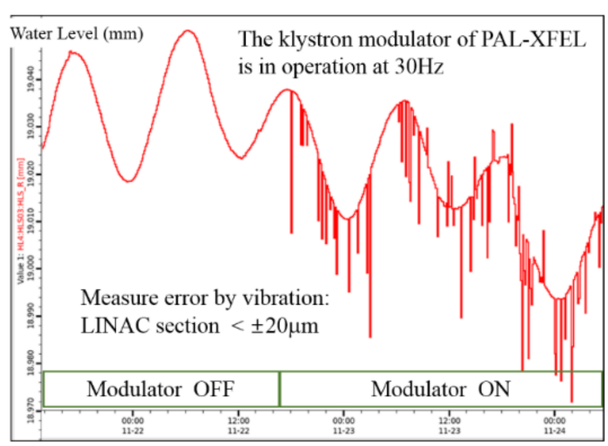

Figure 5: HLS's measurement error by vibration.

The second error is caused by tides. The water level inside the water pipe changes owing to tidal force twice a day. Then the water level doesn't change evenly just as in Fig. 6 (a). According to analysis of tide-wave measured in

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the HLS, the direction of tide-wave (sin θ) is 180° opposite from east to west starting from the center of water pipe and the amplitude of tide-wave is the largest in both ends and the smallest in the middle (see Fig. 6 (b)). It can be conformed that the tide observation data in pohang area are in agreement with the HLS measured value waveform of PAL-XFEL (see Fig. 7).

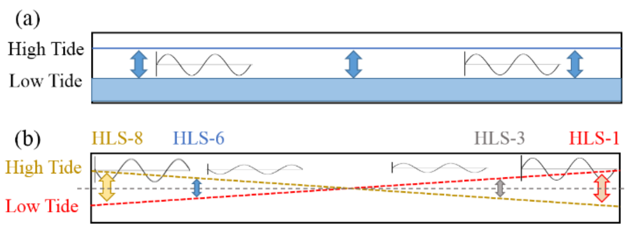

Figure 6: Variation of water level by tides in the water pipe.

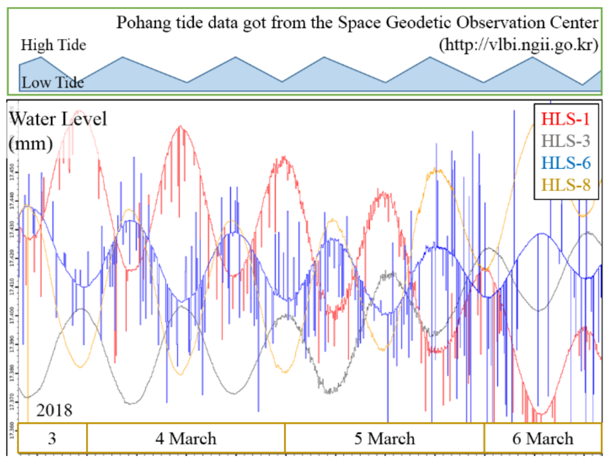

Figure 7: HLS measurement value waveform and tide observation data.

This phenomenon occurs in both LINAC and undulator section. The natural tidal force can't be prevented artificially. Tide-induced measurement errors are the least in point ② and ④ where they occur three to four times a day (see Fig. 8). Comparing LINAC and undulator section, it can be seen that the longer the water pipe length, the larger the HLS measurement error due to the tide effect.

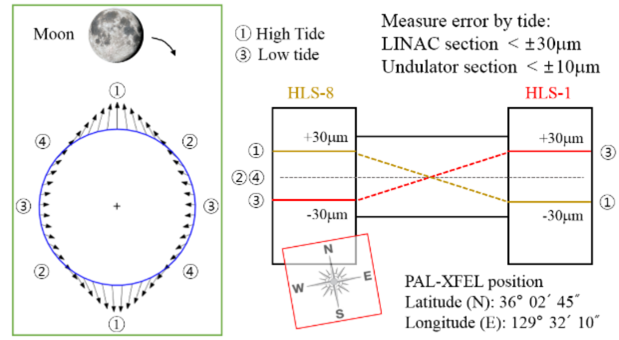

Figure 8: HLS's measurement error by tides.

CONCLUSION

As the ground and buildings change owing to many kinds of factors, various feedback control systems are applied to large scientific devices to overcome these changes [11]. While the floors of the PAL-XFEL building change by 1.5mm every six months, it provides high-quality photon beam for beamline users by the benefit of a feedback control system and beam base alignment (see Fig. 9) [2]. However, the feedback system has limitations. So the survey and alignment (SA) team periodically aligning the components where the position change occurred.

Large scientific equipment is large-scale and has many components, so it is impossible to be measured continuously by people's efforts. In addition, during operation of the accelerator, harmful radiation is generated to the human body, so people can't go into the tunnel for the surveying work. Based on the HLS measurements, the SA team can identify where and when the alignment needed.

In order to know exactly the change of the ground and the floor of the building, it is necessary to know the measurement error factor and the measurement error size of the HLS system included in the HLS measurement value.

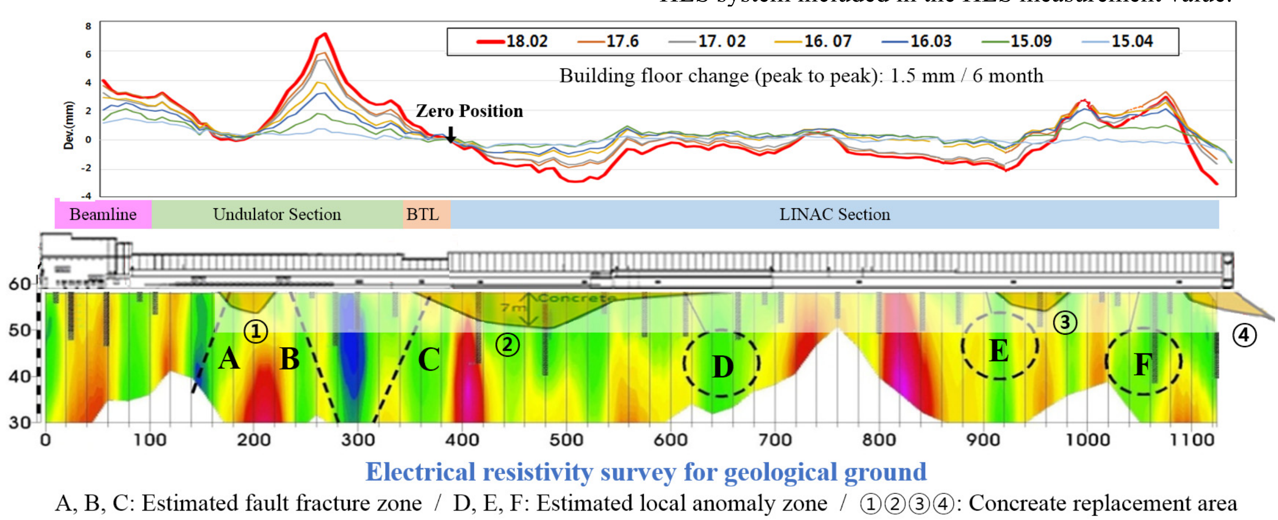

Figure 9: Ground structure and variations of PAL-XFEL (side view).

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