THE BINP HLS TO MEASUREMENT VERTICAL CHANGES ON PAL-XFEL BUILDINGS AND GROUND*

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Introduction

General matters about the hydrostatic leveling system (HLS) to be installed in PAL-XFEL were explained in Reference [1]. This paper will introduce principles of measuring water pipes that are references of HLS and Ultrasonic-type HLS of the Budker Institute of Nuclear Physics (BINP).

WATER VOLUME CHANGING BY TIDAL EFFECTS

The strength of gravity of planets in the solar system follows Isaac Newton's law of gravity and the superposition principle. There are three elements changing the gravity of the earth: the earth's orbit, the moon's orbit and leaning of the earth's rotational axis. As shown by Figure 1, the orbit of the earth circling around the sun is oval. The sun's tide generating force changes according to positions of the earth's orbit.

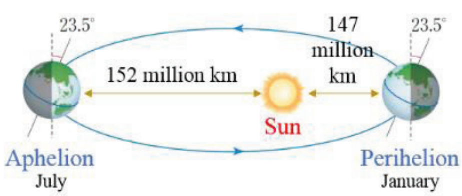

Figure 1: Earth's orbit.

As shown by Figure 2, the effects of tide generating force appear due to complex movements, such as the earth's rotation, the moon's orbit and the leaning of the moon's orbital plane. It is very difficult to gain theoretical access to them and they can be various depending on factors (such as composition of the continental ground, latitude, longitude and altitude) affecting regions whose tide generating force is to be measured, so it is difficult to analyze them. The effects of the tide generating force changing over time lead to changes in gravity and in consequence the earth's land and sea affected by gravity display tidal phenomena over time.

The tide generating force can be measured using an earth tide meter or a gravity meter. Figure 3 shows changes in the tide generating force measured in Korea using an earth tide meter. Changes in the tide generating force cause changes in the water volume and they appear as changes in the water height inside a water pipe in the process of measuring HLS. As explained in Reference [1], water produces volume changes because of various outside effects in addition to the tide generating force. In the case of water in a glass, the water height changes about 2μm/deg/cm because of temperature and the figure is about Max. 0.6μm/cm because of tides. There should be no temperature changes in order to observe the water height changing by tidal effects.

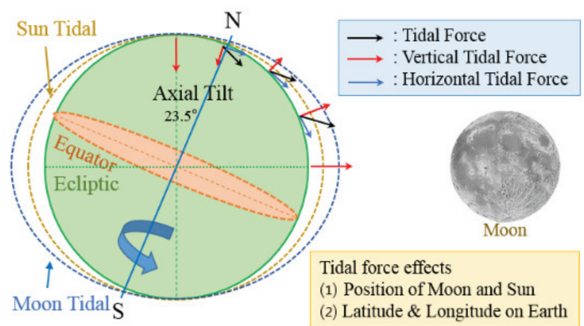

Figure 2: Distribution of the tidal force on the earth.

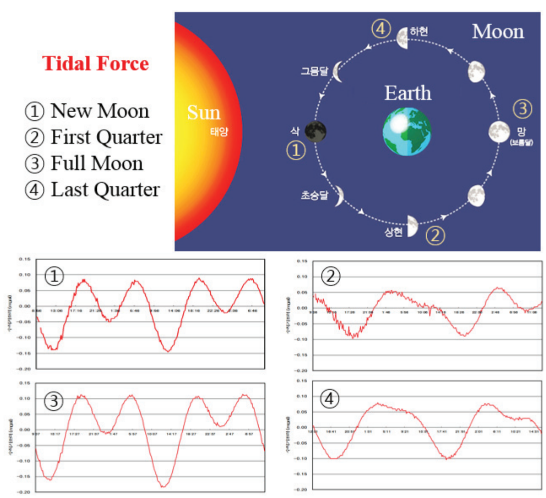

Figure 3: The tide generating force depending on positions of the sun and the moon.

Although the water volume inside a water pipe dynamically changes moment by moment due to temperature inside a tunnel and tides, the water height of the entire area of the water pipe will be maintained in the short term if the flow inside the water pipe is large enough. The space inside the water pipe is closed and hydrostatic levelling measurement is made under the condition where the amount of water is the same even if the water volume changes. As shown by Figure 4, water pipes are installed on the floor inside the tunnel. As long as an accelerator works, entries to the tunnel are prevented and there is no vibration caused by people.

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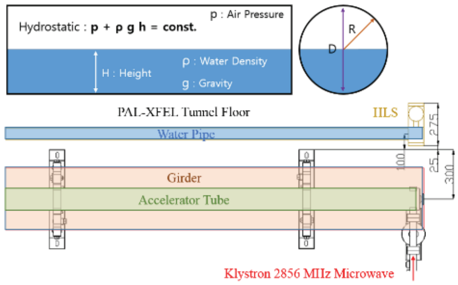

Figure 4: The position of water pipes inside the accelerator tunnel.

There should be sufficient water flow for all of the water inside the water pipes to maintain the same water surface. Figure 5 shows the diameter of a water pipe to secure proper flow in accordance with the length of the pipe. [2]

Distance (m)	Depth of water (m)	Period (sec)
1	0.0028	12
5	0.0053	44
10	0.0070	76
50	0.0133	277
100	0.0175	484
500	0.0334	1752
1000	0.0440	3050

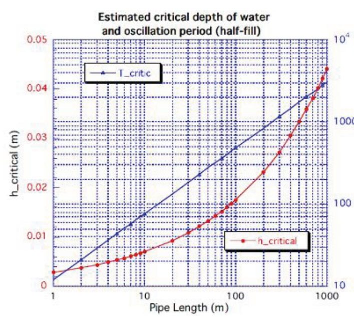

Figure 5: The critical (optimum) depth of water and the period of oscillation for different lengths of pipes in a half-filled system.

Figure 6 shows the length and diameter of water pipes to be installed in PAL-XFEL. The material of pipes is anti-corrosive stainless steel SUS304 whose surface was treated sanitarily. The right diameter of a pipe for the length of the pipe was calculated according to Figure 5 and then pipes whose diameter is close to the calculation result were selected among pipes commercially available.

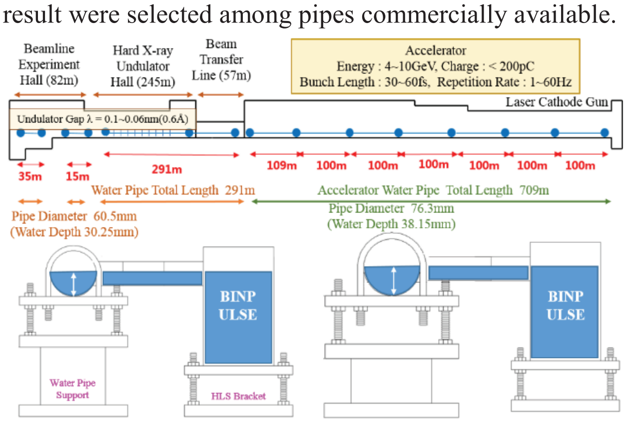

Figure 6: The length and diameter of a water pipe.

COMPOSITION OF BINP HLS AND PRINCIPLES OF MEASURING IT

A measurement concept of BINP HLS measuring the height of water using an ultrasonic transducer is shown in Figure 7. The transducer is H10KB3T (7MHz) used for ultrasonic flaw detectors made by GE Sensing & Inspection Technologies. The range that can be measured by the transducer is the far-field area. A reflector that adopts the role of an absolute ruler and the height of water surface can be measured correctly only when they are placed within the far-field area. [3] The height of the HLS bracket shown in Figure 6 should be adjusted properly so that the height of the water surface doesn't veer from the far field due to vertical changes in the building foundation. If there are serious vertical changes in the foundation, the water pipe support of Figure 6 should be adjusted too.

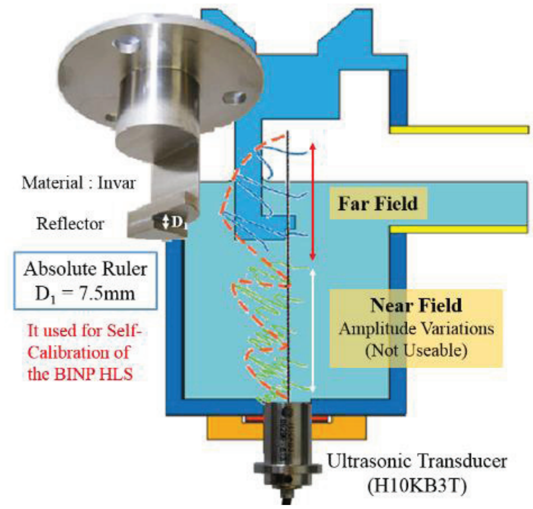

Figure 7: The HLS measurement concept using an ultrasonic transducer.

As shown by Figure 8, ultrasonic waves that take place in the transducer are reflected in the reflector and water surface and are conveyed to the transducer. Even when the performance of the transducer and water temperature change, the height of the water surface can be measured correctly because the time gap between Wave-t1 and Wave-t2 reflected by the absolute ruler (D1) is 7.5mm. Such a self-calibration function improves the accuracy and credibility in the measurement of BINP HLS.

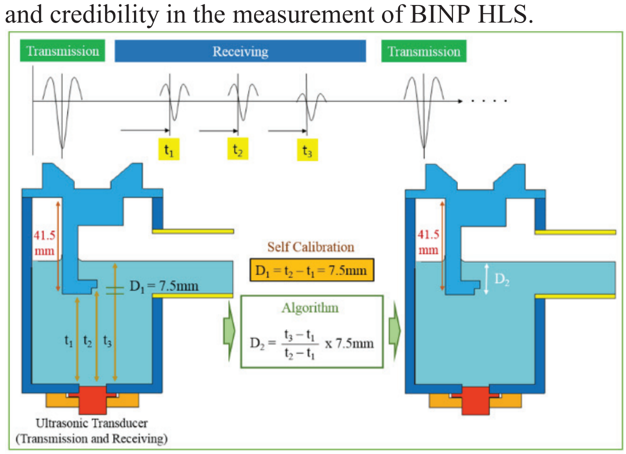

Figure 8: Measuring the height of water surface using ultrasonic waves.

Figure 9 shows a block diagram, an electronic circuit of BINP HLS. Reflected ultrasonic waves are recorded as time at the TDC (Time to digital converter) through a comparator. Timing jitters can occur at the system clock

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8MHz of an electronic circuit or time delays can occur at a microcontroller, but these effects are equally applied to all return waves. As shown by Figure 8, timing jitter and time delay elements of the electronic circuit are removed with a formula [(t3-t1)/(t2-t1)] for calculating the length of D2. [4]

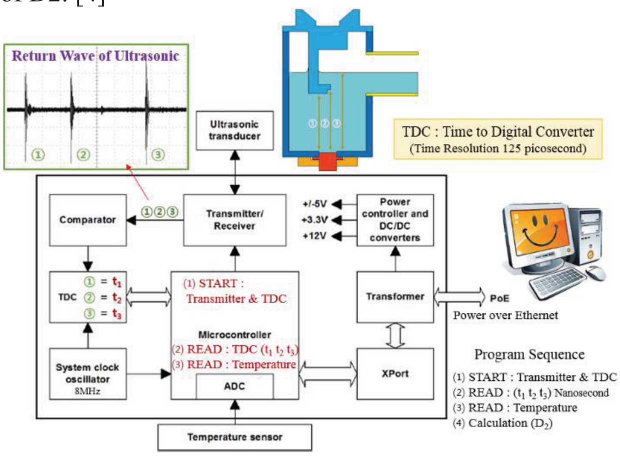

Figure 9: Block diagram of the ULSE Electronics.

The resolution for measuring the distance of HLS is determined by the sound velocity in water and TDC of an electronic circuit. The sound velocity is determined by the temperature of water and the time resolution of TDC is determined by a system clock 8MHz. Like Figure 10, the resolution for measuring the distance of BINP HLS is about 0.2μm.

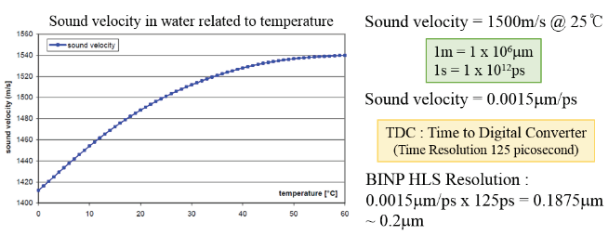

Figure 10: Resolution for measuring the distance of BINP HLS.

PAL-XFEL BUILDING FOUNDATION

The purpose of installing HLS is to continuously survey the vertical changes of a building and its foundation and record any changes. To analyse and understand the results of HLS measurement, people should know about the conditions of the building and its foundation. Conditions regarding the creation of the foundation of a PAL-XFEL building are shown in Figure 11. After deciding to construct a building at an altitude of 62 meters, earth at the altitude of 62 meters or higher was removed completely. In order not to construct the building on a weak foundation, the earth of the weathered zone, a weak foundation, was removed completely. After this, the space of the removed weak foundation was replaced with concrete to maintain an altitude of 62 meters. It did not pour the foundation piles for the foundation for enhanced bearing capacity due to construction of a PAL-XFEL building on the bedrock. Transformation of the building floor is connected with subsidence and upheaval of the foundation. Zones where the foundation is expected to change vertically can be found through continuously measuring vertical changes of the building floor using HLS. Measurement data of HLS is used for aligning accelerators.

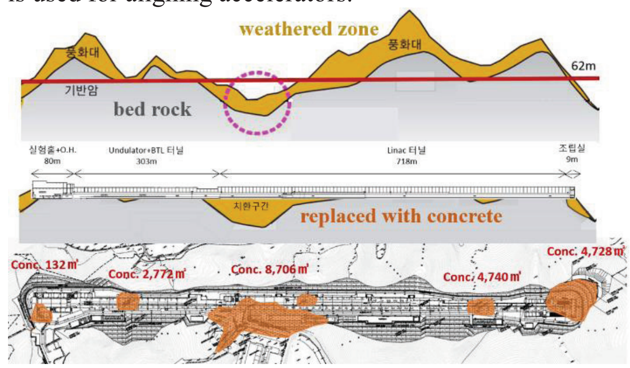

Figure 11: Conditions of creating the PAL-XFEL foundation.

BINP HLS TEST ON PAL-XFEL

Figure 12 shows the method of using BINP HLS and the result of testing ULSE 2 sets which was borrowed from BINP to learn about the operation. The tidal effect of the sun and moon could not be confirmed because of the changes in surrounding temperature (2.2 degrees). The tidal effect can be seen in HLS when the influence of surrounding temperature is less than the tidal effect.

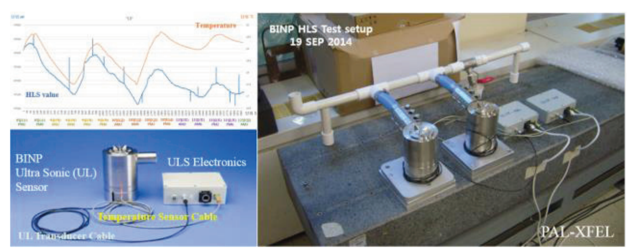

Figure 12: BINP ULSE Test on PAL-XFEL.

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