Wire position system to consistently measure and record the location change of girders following ground changes

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Abstract. Several parts that comprise the large scientific device should be installed and operated at the accurate three-dimensional location coordinates (X, Y, and Z) where they should be subjected to survey and alignment. The location of the aligned parts should not be changed in order to ensure that the electron beam parameters (Energy 10 GeV, Charge 200 pC, and Bunch Length 60 fs, Emittance X/Y 0.481 μm/0.256 μm) of PAL-XFEL (X-ray Free Electron Laser of the Pohang Accelerator Laboratory) remain stable and can be operated without any problems. As time goes by, however, the ground goes through uplift and subsidence, which consequently deforms building floors. The deformation of the ground and buildings changes the location of several devices including magnets and RF accelerator tubes, which eventually leads to alignment errors (ΔX, ΔY, and ΔZ). Once alignment errors occur with regard to these parts, the electron beam deviates from its course and beam parameters change accordingly.
PAL-XFEL has installed the Hydrostatic Leveling System (HLS) to measure and record the vertical change of buildings and ground consistently and systematically and the Wire Position System (WPS) to measure the two dimensional changes of girders. This paper is designed to introduce the operating principle and design concept of WPS and discuss the current situation regarding installation and operation.

1. Introduction

As shown in Figure 1, the position of the components changes along with the changes in Girder and the location of the ground which a building stands on. When the position of the components moves out of the orbit of the electron beam due to changes in the ground, interaction between the electromagnet field of the component and electron beam also changes. If the frequency of the equipment is higher or the stronger the electromagnetic field or magnetic field, the greater the influence of changes in position.

In Korea, there is a saying that goes "It takes more than pearls to make a necklace." It means that no one will get the performance as he/she wants if he/she does not arrange and position all devices precisely even though each of the devices works well. In PAL-XFEL, the HLS and WPS are installed and operated to observe and record changes in the ground and building through continuous measurement and to quickly arrange devices in the region where significant displacement is shown [1].
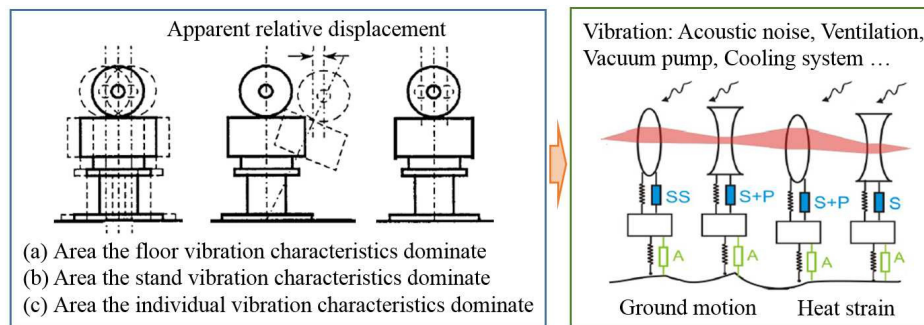
Figure 1. Three vibration patterns which generate relative displacement [2]

2. History of WPS to have used on the accelerator

In 1990, the concept of a wire measurement system was first introduced to observe the changes in the ground of a 10-km-long linear collider [3]. The method for transmitting the RF signal to the wire and comparing the strength of the RF signals at the Pickup which is the same as the beam position monitor (BPM) was also examined in 1993. In this case, impedance around a wire should be kept constant at 50 ohm to transmit the RF signal over a distance over 100 meter [4]. In 1995, the European synchrotron radiation facility (ESRF) succeeded in researching and developing a non-contact mono axe (1D) WPS sensor using carbon wire [5]. After that, FOGALE   Nanotech developed and commercialized the two dimension WPS2D sensor.

To establish and operate large scientific instruments including linear colliders, various sensors should be developed for the steady observation of changes in the position of the instruments as a result of changes in the ground [6]. Recently, the Compact Linear Collider (CLIC) studied the method for real-time measurement and recording of changes in the ground of instruments several kilometers in length by using WPS and HLS [7].

3. Electrical characteristics of passive components used as sensors

We should know the characteristics of basic devices, such as resistors (R), condensers (C) and inductors (L) of electronic circuits regarding input power supply in order to design those circuits or to understand the response properties of designed electronic circuits. Input power supply is divided into DC and AC. Whereas the response characteristics of DC circuits can be simply understood by the relationship among the voltage, intensity and resistor, the response characteristics of AC circuits can be understood only after knowing three kinds of resistance components. In AC circuits, the resistor (R) is marked as a real number resistor and the condenser and inductor are marked as imaginary number resistors and called reactance. The condenser (C) is called capacitive reactance (X_C) and the inductor (L) inductive reactance (X_L). An important point is that resistance values of reactance are determined according to the frequency of AC power supply. Equation (1) shows how to calculate the resistance values of R-L-C passive components in relation to AC power supply [8].

$$V = I \cdot Z \tag{1}$$

where

$$Z = R + j \cdot X = \text{resistance } [\Omega]$$
$$X = X_C + X_L = \text{reactance}$$
$$X_C = \frac{1}{j \cdot \omega \cdot C} = \text{capacitor reactance}$$
$$X_L = j \cdot \omega \cdot L = \text{inductor reactance}$$

Various sensors using electric response characteristics of R-L-C passive components are used in diverse areas [9]. The operation principle of WPS sensors is to figure out changes in the X_C resistance values of condensers using AC power supply.

4. Working principle of WPS sensor

The working principle of the WPS sensor, which is to measure a distance in a non-contact way, is described in Figure 2. The capacitor AC voltage divider rule, which is widely used as a measurement of distance in various fields, is also applied to WPS. Voltage divider circuits may be constructed from reactive components just as easily as they may be constructed from fixed resistors, and just like resistors, a capacitive voltage divider is not affected by changes in the supply frequency even though they use capacitors which are reactive elements. WPS are used for measuring the displacement of the sensor with respect to a stretched wire, which serves as straightness reference. Horizontal and vertical movements can be measured with these sensors. The capacitive sensors have a working range of 10 mm for each axis with a resolution of minor 0.1 µm and a repeatability of about 1 µm with integrated electronics. The data acquisition rate can be up to 10 Hz. In addition to the sensor, the signal conditioning box and cables compose the calibrated sensor unit. It has two electrodes per axis facing each other, which makes a total of four electrodes. The sensor can be treated as a pair of double capacitors in a differential configuration. FOGALE sets and provides the Voltage AC frequency (4~10 KHz) of electronics. The first WPS have a frequency of 4 KHz and the other WPS have a frequency increased by 0.1 KHz steps.
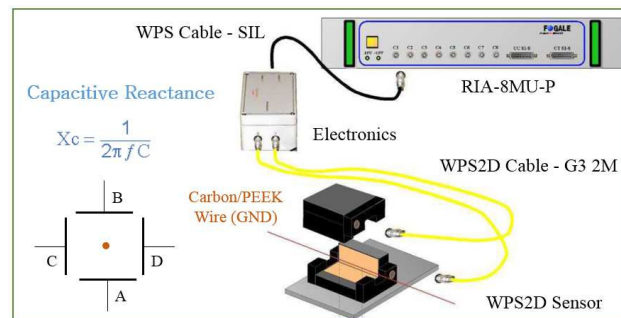

Figure 2. Working principle of WPS sensor

5. WPS reference: wire

The most important thing in the WPS system is a carbon wire which is used as a reference for measurement. As the post which is used to hold up a wire is installed on the ground, changes in the ground where the post is installed and the angle of the post should be measured regularly. Movement of the wire post means a change of reference. Carbon PEEK wire (diameter 0.4 mm, linear mass density 235 g/km) manufactured and marketed in Japan is used with 10~15 kg weights [5][10]. As shown in Figure 3, a precise wire stretcher PDL-WPS/15 provided by FOGALE was installed on the post and wire was connected to it. A wire protection duct is installed to prevent the wire from moving or shaking as a result of air generated from an air handling unit.

Figure 3. Wire stretched Post and WPS sensor support

To design the support for fixing the WPS sensor and fixed bracket, the wire sag should be calculated. The calculation formula provided by FOGALE Nanotech is shown in Equation (2) and Figure 4. In a measurement performed by PAL-XFEL, the wire sag was about 41 mm in relation to a 135 meter length and 12 kg load wire.

$$C(x) = \frac{\gamma\, g\, L}{2\, T}\left(1 + \left(\frac{h}{L}\right)^2\right)\left(x - \frac{x^2}{L}\right) \tag{2}$$

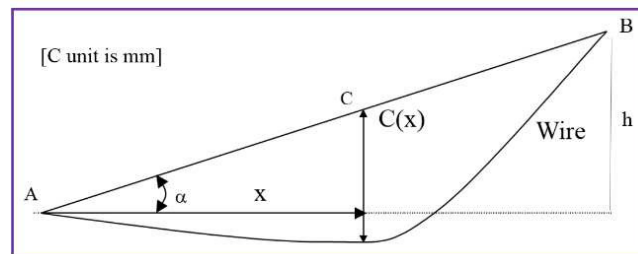$$\approx C_{carbon}(x) = 0.03 \times L^2(m)/T(kg)$$

where

γ : linear mass density
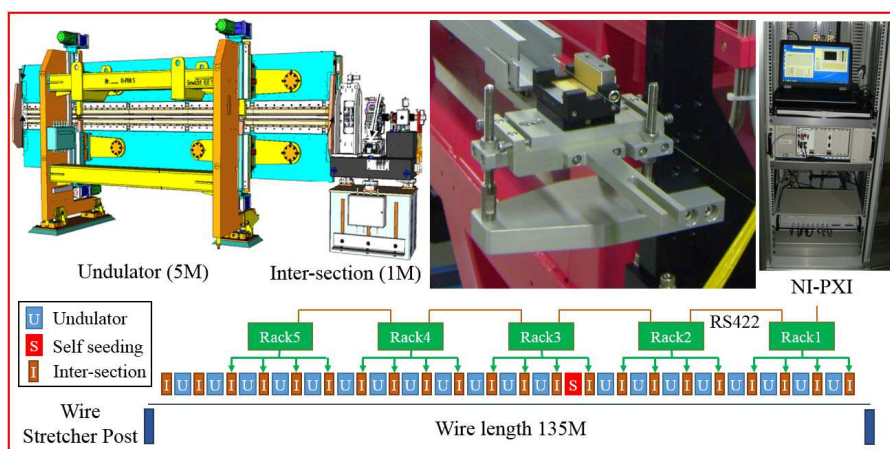g : gravity
L : horizontal distance between A and B
T : tension
h : vertical distance between A and B

Figure 4. Wire Sag calculation

6. Installation and operation of WPS

A WPS was installed in the inter-section girder of the hard X-ray undulator section as shown in Figure 5. A total of 40 WPS2D-B-10x10 sensors were attached to five RIA-8MU-P racks connected by RS422 communication cables. The length of the WPS2D Cable-G3 connecting electronics and a sensor was reduced to 2 meters, minimizing the cable length. The measurement area of WPS is +/- 5 mm, but the linearly measurable area is +/- 1.5 mm. When installing WPS sensors, WPS fixed brackets should be adjusted to make the WPS measurement value less than +/- 0.5 mm.

Figure 5. Location of WPS system installation and WPS fixed bracket

Data-acquisition PCs for WPS should be stably operated for a long time. For this, PXIe-8135 produced by National Instrument was selected. The program for measuring WPS was prepared with LabVIEW, which anybody can easily learn and program. The EPICS-type communication for storing WPS measurement values in the database used CA Lab, which was developed by the BEESY research center in Germany, after downloading it. The BEESY distributes CA Lab free of charge. Construction of data-acquisition PXI for WPS is shown in Figure 6 [11].
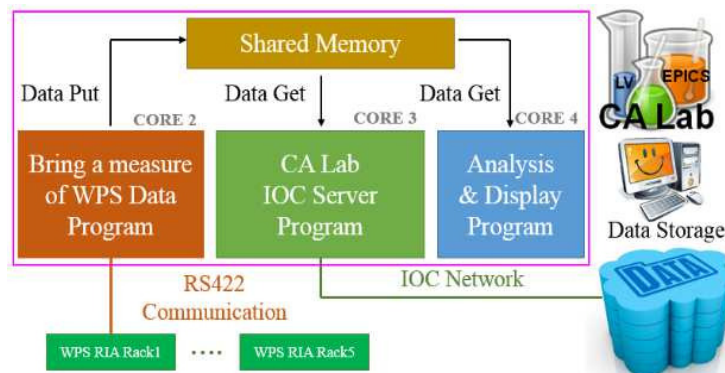

Figure 6. Construction map of a PXI server for WPS

7. Feedbacks for stabilization of PAL-XFEL beams

As various ways have been applied for the stabilization of beams regarding PAL-XFEL, electron beams and photon beams can move following a normal track even if the ground and building floor are changed. Figure 7 shows three methods applied to the PAL-XFEL system to minimize the orbit dispersion of electronic beams taking place due to various factors, including ground change. Beam orbit correction feedbacks are obtained using the strip-line BPM (S-BPM) and quadrupole electric magnetic for stabilization of electron beams in the linac section. In the undulator section, beam based alignment (BBA), a method to adjust the height of a magnet block that is an instrument of the 20 undulators using the screen-monitor and the cavity BPM (C-BPM), is applied. Regarding the beamline section, photon beams were always placed to be projected at the same place of the sample stage using a photon quadrant BPM (Q-BPM) and a mirror [12].
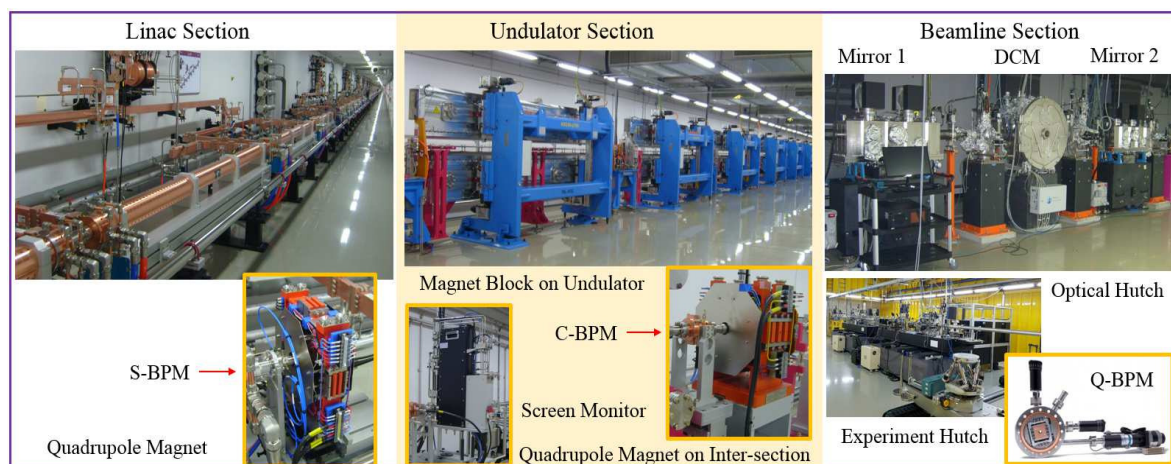

Figure 7. Way to stabilize FEL beams

The extent to which beams can be stabilized using beam stabilization feedbacks is limited. In consequence, the survey and alignment (S/A) team carries out an alignment procedure twice a year to

place all equipment at the correct three-dimensional location coordinates (X, Y, and Z) by adjusting their girders and supports based on the results of the measurement of changes in the ground and buildings.

8. Conclusion

By installing and operating WPS, changes in the position of Undulator Hall according to changes in ground can be measured in real time as shown in Figure 8. After detecting undulators that deviated off the alignment by more than 50 μm, operators of PAL-XFEL re-aligns 20 undulators by BBA method, it takes two to three hours, contributes to optimal performance of the undulator.
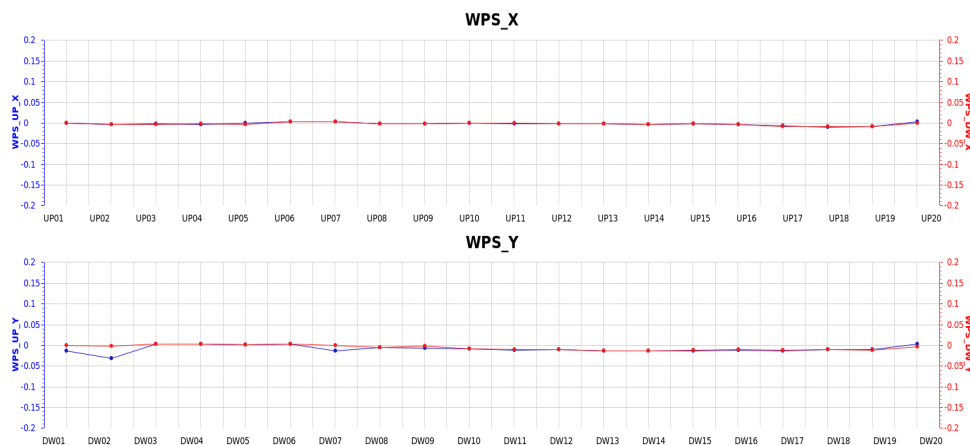

Figure 8. Real-time measurement of WPS

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