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# DESIGN OF HYDROSTATIC LEVEL SYSTEM FOR THE APS-U STORAGE RING*

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*Abstract*

A Hydrostatic Leveling System (HLS) has been designed for the Advanced Photon Source Upgrade (APS-U) storage ring (SR) to characterize the relative floor motion along each Insertion Device Front End (IDFE) and the global floor motion of the SR tunnel. 3 HLS sensors will be installed alongside each IDFE. Two sensors will be mounted near the ID Beam Position Monitors (BPMs), which are located at either end of the ID. The 3rd HLS sensor will be mounted near the Grazing-Incidence Insertion Device X-Ray BPM (GRID xBPM), about 20 meters away from the source point. In addition, there will be 1 sensor installed in each of the 5 sectors in Zone-F where there are no ID beamlines. The HLS water network along each of the 35 IDFEs and 5 sectors in Zone-F are connected via valves to form a global network around the 1.1 km SR tunnel. The HLS will measure the vertical floor displacement at a total of 110 locations. Combined with the highly stable BPM/xBPM stands, the HLS can better characterize the electron and photon beam long-term stability. The HLS design is based on a two-pipe system for easy installation in tight spaces. In this paper, we present the design of the HLS system and preliminary performance of the first article units.

## INTRODUCTION

Modern light sources have tight requirements of the beam stability. For example, the Advanced Photon Source Upgrade (APS-U) machine asks for an orbit stability [1] of 0.4 µm for short term (0.01 Hz – 1 kHz) and 1 µm for long-term (7 days). With careful design of the magnets, the supporting structure, Beam Position Monitor (BPM) electronics and the orbit feedback system, the short-term orbit stability can normally be achieved. However, the long-term stability is not obviously achievable even with the best modern electronics and feedback algorithms. The situation is even more complicated by comparing the stability of electron beam and photon beam. Long-term stability is affected by many factors including the mechanical/thermal stability of BPM/xBPM stands, BPM electronics long-term stability, utility system stability, ground motion, etc.

To achieve the long-term beam stability goals, all sources of mechanical motion of critical in-tunnel beam position monitoring devices must be carefully evaluated and appropriately addressed. This includes the effects of water and air temperature, as well as earth tides and diffusive ground motion. A Hydrostatic Leveling System (HLS) is designed to quantify this floor motion.

The fundamental principle of the HLS is that any fluid seeks its own level. Given two reservoirs set at the same height and connected by a pipe or tube, the fluid level in each reservoir will be at the same absolute elevation. This is determined by the balance between gravity and air pressure. For small systems, the absolute elevation can be relative to some reference such as mean sea level. For larger systems, the curvature of the earth and other gravitational effects need to be considered. Given a reference point, the relative level of the fluid will vary as the sensor is moved up or down with respect to all the other sensors. While any fluid can be used, water has the advantages of a low viscosity (allowing for relatively rapid movement between reservoirs), it is non-toxic, is easily obtained, and if treated with sufficient care there will be no growth of biota in the reservoirs or tubing [2]. Specifically, the HLS requires that the system use demineralized water treated with fungicide.

3 HLS sensors per Insertion Device Front End (IDFE) will provide the necessary ground motion measurement. There will be a total of 105 HLS sensors to cover the 35 IDFEs. An additional sensor will be installed in each sector in Zone-F where there are no ID beamlines. This allows a global HLS network to be formed with a total of 110 sensors around the Storge Ring (SR).

Figure 1 illustrates the current HLS design for a generic sector in the APS-U SR. The B:P0 and A:P0 BPMs are mounted on invar stands on either side of the ID. The Grazing-Incidence Insertion Device (GRID) X-Ray BPM [3] in the IDFE is mounted on a granite table. 3 HLS sensors are mounted on the floor near the B:P0, A:P0 and GRID X-ray BPM stands. Water and air pipes will connect the sensors at each location. The invar stands and granite table will exhibit very good thermal stability given the tunnel ambient temperature will be stabilized within 0.1° C. Thus, we can assume that any ground motion measured by the HLS will be directly related to the change in position of the BPM sensors and any relative height differences between the BPMs can be characterized.

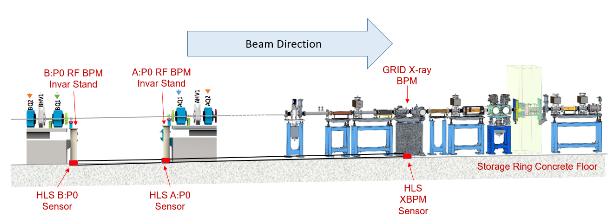


Figure 1: Hydrostatic Leveling System (HLS) for one of the APS-U IDFEs.

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The HLS that will be implemented for the APS-U will be a completely closed 2-pipe system in which there are two pipes connecting the reservoirs: 1 pipe filled with air and the other filled with water. In a two-pipe system, the piping can be flexible as long as the sensors are placed at the same absolute height. A 1-pipe HLS prototype system has been installed and tested at the existing APS tunnel [4-6]. It has been demonstrated that the 1-pipe HLS meets the technical specifications (50 nm resolution @0.01Hz, and stability of 500 nm for 1 week period). However, the 1-pipe configuration poses trip hazard especially at the duck-under locations (see more information in the mechanical design). The 2-pipe configuration is selected as the performance will be similar to a 1-pipe system, and they are widely used at other accelerator facilities [7-11].

## HLS MECHANICAL DESIGN

### *HLS Sensor and Stand*

Each sensor will be mounted to a reservoir and will require its own stand as depicted in Fig. 2. The reservoir will be filled with water and connects to the nearby reservoirs through the two bottom pipe fittings. The top pipe fittings will be connected to the air pipes. The capacitive sensor measures the water surface distance, this way relative water height difference, caused by floor movement, can be measured. The sensor shall have a minimum measurement range of 3 mm.

The stands consist of four drop-in anchors, 4 Invar 36 support rods, a SS platform, 3 tuning bolts, a central PEEK bolt, and fasteners. The Invar 36 threaded rods will be mounted to the ground using drop-in anchors for concrete. The platform will slide over the four threaded rods and be held in place using jam nuts as fasteners. This approach allows the HLS reservoirs/sensors to be mounted on the same level, even though the floor settled differently around the ring. The reservoir will be held in place by the central PEEK bolt. The bolt screws into a tapped hole on the bottom surface of the reservoir and a nut on the bolt is torqued against the platform. This creates a compression force against the tuning bolts holding thus holding the sensor in place. The 3 tuning bolts allow for accurate adjustment of the position of the sensor as there is some height variation of the SR concrete floor. To protect the sensor, a cover which encloses the sensor will also be mounted to the platform.

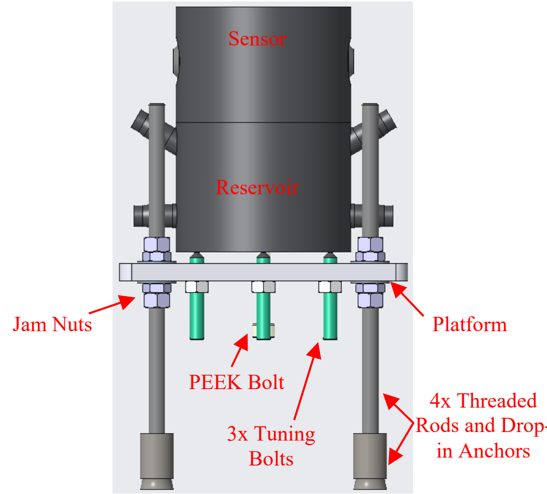


Figure 2: HLS sensor/reservoir and its stand.

It is understood that even in a near constant temperature in the SR tunnel, the stand will experience some thermal expansion which may impact the measurements by the sensors. To reduce the potential of thermal expansion influencing the measurements, Invar 36 was chosen for the threaded rods because of its strong thermal stability.

### *HLS Piping and Duck-Under Ramp*

The piping for the HLS will route along the floor inside of a standard slotted hole aluminum Unistrut backed with plastic bars to keep the piping relatively level throughout the network. The Unistrut will be mounted to the concrete floor.

The open spaces underneath the QMQ bridges (QMQ is a module formed with two quadrupole magnets and on dipole M2 magnet) along each IDFE will be used as a duck-under and allow people to pass underneath the SR girders to gain access to the FEs (see Fig. 3). Because the pipe channel will route directly along these openings, a ramp will be installed to protect the pipes while mitigating the risk of someone tripping over the channel. The low angled ramp will have an opening through the center for the pipes to pass horizontally through. There will also be a polyurethane foam backing through the center of the ramp to any absorb any disturbances that might occur when someone steps on the ramp. The foam will be held in place using a polyurethane glue such as Gorilla Glue or equivalent. The surfaces of the ramp will have anti-slip tape on them for extra grip. The ramp will mount to the ground.

Generally speaking, the HLS water network along the IDFEs will be connected to the HLS water network of the following sector using a straight valve. The straight valves can be opened to form a global network or closed to divide the global network into isolated local networks.

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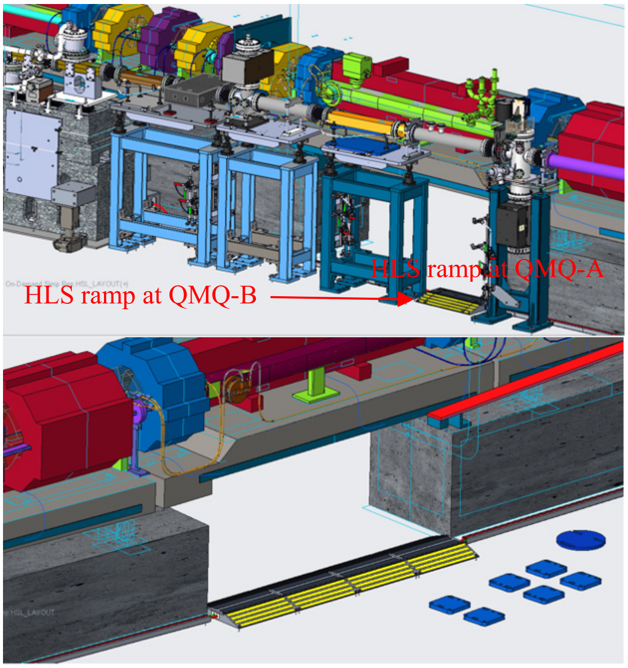


Figure 3: Duck-under at QMQ-B (top) and QMQ-A (bottom). HLS ramp mounted on the floor beneath the duck-under allows water and air pipes to pass through.

To form a complete loop around the SR, 1 additional sensor will be in each of the 5 Zone-F sectors. Ramps will also be used in these sectors in the same manner described above.

Because the water pipe will be completely filled with water in the 2-pipe system, ambient temperature and pressure changes will impact the water volume inside the network. This will impact the water level measurements inside the reservoirs. Therefore, the reservoirs should be equipped with a temperature sensor to measure the temperature of the water.

### *HLS Water Refill*

Although the system will be completely closed, there is still some evaporation and/or micro leakage that will occur and overtime the water level will decrease inside the reservoir. Before the water level falls below the measurement range of the sensors, the system will need to be refilled. Therefore, a refilling/purging station must be implemented to refill the water inside of the networks. To achieve this for a general sector containing an IDFE, the GRID X-Ray BPM HLS sensor from each sector will be connected to the B:P0 BPM HLS sensor of the following sector by a T-valve (or similar) as depicted in the valve schematic below (see Fig. 4). All valves will be opened during the manual refilling process and can be closed after that to have isolated HLS measurements for each IDFE.

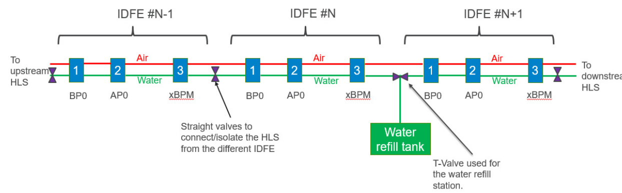


Figure 4: Gneral valve schematic for the HLS for sectors 1-35 containing IDFEs.

## HLS ELECTRONICS DESIGN

The HLS electronics shall be close to the pickups. Like other electrical systems in the APSU, the HLS electronics will be configured organized in double sectors: 6 HLS sensors (from two sectors) will have signals run to an electronics rack. The digitizer shall sample the HLS distance and temperature at 0.01 Hz rate or faster. The digitized HLS signal shall be integrated into the APS-U control system. The interface is RS232/RS485. The whole HLS system, with the electronics, shall be demonstrated with the required resolution and stability.

Signal cables and power supply cables connect the HLS sensor and mezzanine electronics. The cable length varies depending on the HLS sensor locations, and the maximum cable length can be more than 30 meters long. Figure 5 depicts the HLS electronics schematics.

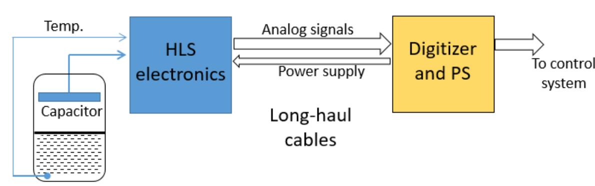


Figure 5: HLS electronics schematics.

## HLS PROCUREMENT STATUS

The HLS sensor/reservoir and electronics contract has been awarded to Fogale Nanotech [12] in April 2021. The first article units, including 5 HLS sensors and 1 electronics box has been fabricated and tested at the factory. Test results show that the resolution and stability both meet the requirements [13]. The first article units will be shipped to Argonne in September 2021.

EPICS drivers have been developed for the HLS electronics. These drivers have been tested with the first article units.

The HLS sensor stand has also been purchased and will be delivered in late Fall 2021. The refill station is currently being designed and its components will be ordered soon.

## SUMMARY

A hydrostatic level system (HLS) has been designed for APS-U SR to characterize the relative floor motion along each IDFE and the global floor motion of the storage ring tunnel. A 2-pipe system has been selected for ease of

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installation in tight spaces and to mitigate trip hazards. The HLS sensors and electronics have been ordered, and the first article units have been tested to be within the APS-U specification.

Components related to the HLS system, such as the sensor stand, have been purchased. Other components such as the refilling station are still being designed. All other components are being ordered or will be ordered soon.

The author acknowledges Fogale colleagues for fruitful discussion. Discussion with other accelerator facilities (Diamond, ESRF, SOLEIL, CERN) have been beneficial for the design.

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