CHARACTERIZATION OF SLOW ORBIT MOTION IN SPEAR3*

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Abstract

SPEAR3 is a third-generation synchrotron light source storage ring. The beam stability requirements are ~10% of the beam size, which is about 1 micron in the vertical plane. Hydrostatic level system (HLS) measurements show that the height of the SPEAR3 tunnel floor varies by tens of microns daily. We present analysis of the HLS data, including accounting for common-mode tidal motion. We discuss the results of experiments done to determine the primary driving source of ground motion. We painted the accelerator tunnel walls white; we temporarily installed Mylar over the asphalt in the center of the accelerator; and we put Mylar over a section of the tunnel walls.

INTRODUCTION

The Stanford Synchrotron Radiation Lightsource (SSRL) provides high energy photon beams to various users working along a 234-m circumference electron beam storage ring (SPEAR). Due to the sensitive nature of the users' experiments, it is essential that the electron beam and photon beam remain stable over long periods of time. However, challenges have arisen in maintaining the vertical stability of the beam due to movements of the ring floor. A Hydrostatic Levelling System (HLS) has observed the storage ring tunnel floor shift vertically on the order of tens of microns diurnally. Such movement has led to difficulties for SSRL users who need the incident photon beams to remain stable to ~1 micron.

The floor of SPEAR is composed of six sections, with four continuous concrete slabs forming the north and south arc, and two concrete blocks anchoring the East and West Pit. The accelerator is surrounded by a concrete tunnel. Most of the outside of the tunnel is not enclosed by a building, but is exposed to the outside temperature fluctuations.

In an attempt to determine the mechanism driving diurnal tunnel floor motion, we have tried three experiments. In the summer of 2008, the roof and walls of the storage ring were painted white. In June of 2009, highly reflective aluminum Mylar was installed on the asphalt that covers the ground in the middle of the ring. In July, the Mylar was also installed on the roof and walls of a portion of the ring, and fans were placed inside the ring to promote ambient temperature stability.

The reasoning behind all three experiments was the same: by finding ways to shield the ring and surrounding structures from cyclical temperature changes, we hoped to isolate the source driving tunnel floor motion. The white paint, and later Mylar, was intended to protect the concrete walls of the ring from radiative heating of the tunnel walls. The Mylar on the asphalt was intended to prevent outward expansion that might translate into vertical or rotational movement of the ring floor.

METHOD

Measuring System

The HLS, in brief, consists of a series of tubes half-filled with water placed on the concrete floor around the storage ring. Sensors placed at points around the ring measure the water level in reference to a central sensor. The data coming from one sensor shows the amount of vertical movement occurring at that point in relation to a sensor upstream of the East Pit [1]. SPEAR contains 28 sensors, with pairs of sensors placed upstream and downstream of points where photon beam lines move tangentially off from the electron beam.

Thermocouples (TC) placed at various locations inside and outside the ring provide data on temperature fluctuations taking place over any given period of time.

Data Analysis

Data from all three experiments was analyzed using one method, which consists of a simple outlier data filter, a planar extraction and spectral analysis.

When the entire SSRL facility, including the accelerator and photon beamlines moves as a rigid plane, the photon beams do not move relative to the experiments. It is only the deviations from co-planar motion that leads to motion of the photon beam relative to the experimental sample. For this reason, we are only interested in deviations from co-planar motion.

A code was written to calculate the best fit plane at each time using the coordinates of the sensors and the HLS readings at that time. The coordinate system for the HLS sensors is based on the major and minor axes (labelled X and Z, respectively) of the ellipse formed by SPEAR (Fig. 4). The function then subtracted the plane fit from the HLS data to give deviations from planar motion.

It is unclear whether the planar behavior of the ring can be extended onto the photon beamline floor. The beamlines extend tangentially from the ring and are placed on foundations that are distinct from the SPEAR tunnel. We are further expanding the HLS system on the beamline floor to better understand relative motion between the accelerator tunnel and photon beamlines.

As expected, the dominant frequencies seen in the planar slopes are those associated with tidal motion, 12-hour, 24-hour and 14-day periods. In order to calculate the theoretical tidal motion at SPEAR, the program Solid_UTC was used, which generates tidal shifts based on a solid Earth assumption [2]. An initial comparison of the best-fit slopes and theoretical tidal slopes shows that they are the same order of magnitude (Fig. 1). The best-fit slopes even approximate the 12-hour amplitude of tidal model within 14 percent, although the 24-hour and 14-day

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content does not seem to be correlated. It is known that ocean loading enhances earth tides in the vicinity of coastlines [3]. In the future, we hope to obtain an improved model of earth tides, including ocean loading, to compare to our fit planes. It does appear that much of the 24-hour period planar motion we are subtracting is not driven by tidal motion, which leads to concerns that the plane does not extend onto the photon beamline floor.

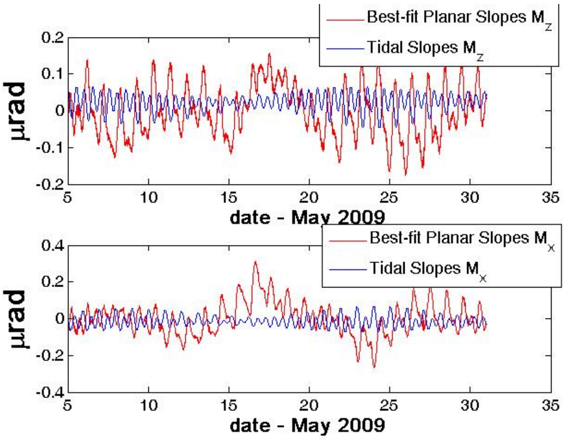

Figure 1: Slope of planar fit and simple tidal model.

After filtering and planar extraction, the power spectrum density (PSD) of vertical motion was calculated for each HLS sensor. Figure 2 shows an example.

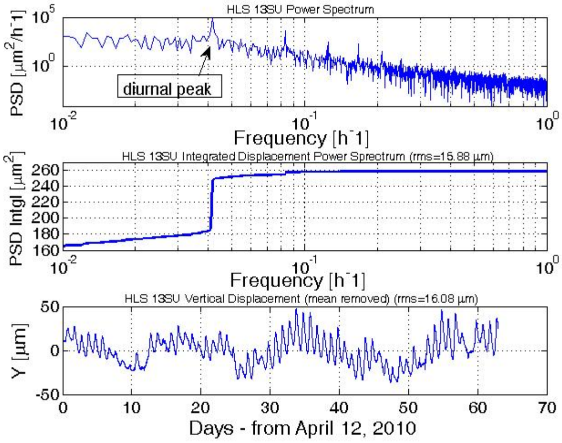

Figure 2: Measured motion on a single HLS sensor.

The biggest problem for synchrotron radiation experiments is movement of the photon beam on the time scale typical of data collection, ~1 hour, so it is the derivative of the vertical motion over ~1 hour that matters. Slow motion over the course of many days, even if it accumulates to relatively large amplitude, is not as troublesome as faster motion over the course of an hour. It's clear from the bottom plot in Fig. 2 that 24-hour period motion generates the greatest derivatives. For this reason, we used the PSD integral over the 24-hour peak as the relevant amplitude of motion for each sensor. We looked at how the height of this diurnal peak changed with each experiment.

RESULTS

Whitewash Project

During the summer of 2008, all the walls and the roof of SPEAR were painted with a white, titanium oxide based paint that also contained a Borosilicate glass additive. This yielded significant results, according to analysis of data from May 2008 (before paint) and May 2009 (after). The two months had nearly identical daily variations in outdoor temperature. However, the daily temperature fluctuation of the concrete roof was reduced by a factor of two with the white paint, and the internal ambient temperature fluctuation of the ring was reduced by 15 percent. The changes in diurnal motion at 20 sensors are shown in Fig. 3, with the sensors arranged in order as they would be seen in SPEAR.

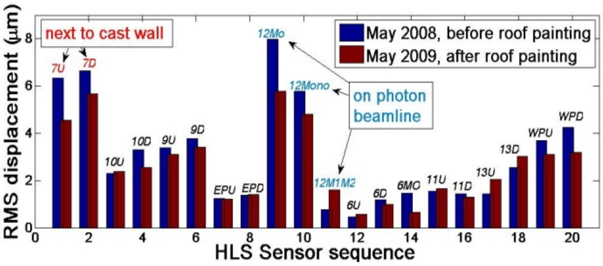

Figure 3: Diurnal motion reduction from white paint.

Four HLS sensors show relatively large motion in Fig. 3. The two in the middle are not on the accelerator tunnel floor concrete, but on a separate slab under BL12 photon beamline. The two sensors on the left of Fig. 3 are upstream and downstream of BL7 insertion device. In addition to seeing relatively large motion, these two sensors showed the most improvement with white paint.

We looked more carefully at the tunnel wall next to BL7, and we found that it is unique. This section of the inner wall was cast in place with a foundation extending 3 feet below ground, whereas the other sections of the surrounding arc are composed of concrete blocks that rest on the asphalt that covers the middle of the ring (Fig. 4). This led to the conjecture that temperature gradients across the wall caused buckling, which transferred forces to the tunnel floor.

There is a similar section of cast-in-place wall in the south arc. There are also cast walls around the east and west pits (top and bottom of Fig. 4). These east and west pit walls, however, are mostly inside buildings, so they do not see large temperature gradients across the walls.

We added 8 HLS sensors before the 2010 run, one of which we placed next to the cast-in-place south arc wall (sensor labelled 13SU in Fig. 4). Figure 5 shows diurnal motion including the new sensors. The new 13SU sensor next to the cast wall in the south arc has the largest motion.

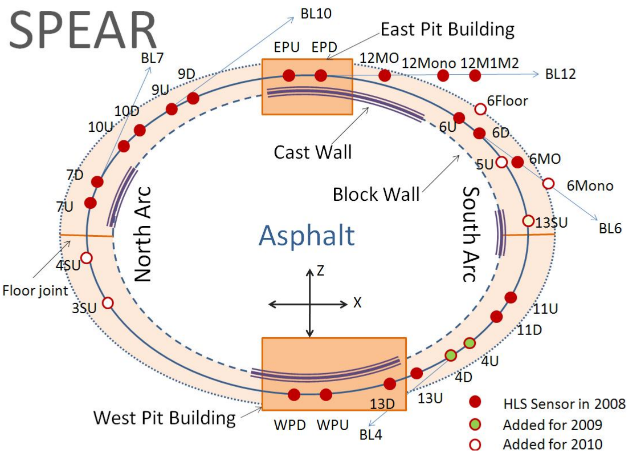

Figure 4: HLS sensors in SPEAR.

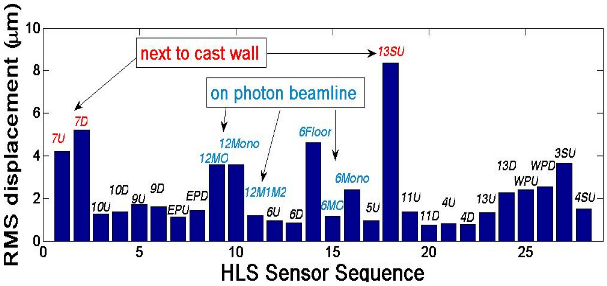

Figure 5: RMS 24-hour period motion 2010.

Figure 6 shows the motion of the 13SU sensor next to the cast-in-place wall compared to the sensors just upstream and downstream. The difference in the amplitude of the motion is dramatic and supports our belief that differential heating across the cast walls with foundations creates torque that moves the tunnel floor.

Figure 5 also shows that some of the sensors on separate concrete slabs along the beamlines show larger differential motion relative to the accelerator tunnel sensors. This problem will be investigated further with an expansion of the sensors on the beamline floor.

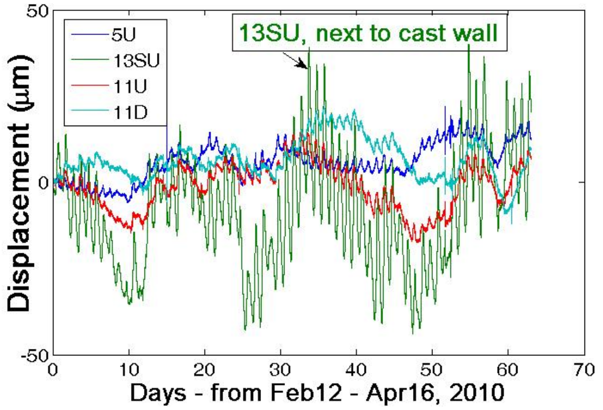

Figure 6: HLS sensor 13SU shows large motion.

Mylar on Asphalt

Putting Mylar over the asphalt in the center of SPEAR reduced the diurnal temperature fluctuations of the asphalt by nearly a factor or 6. Nevertheless, the HLS diurnal variation did not improve. Thermal expansion of the asphalt does not exert sufficient force to move the concrete tunnel floor.

Even the RF frequency variation in the SPEAR orbit feedback did not decrease with the installation of the Mylar, which suggests that the predicted asphalt expansion and storage ring circumference are entirely decoupled.

Mylar on Ring Roof and Walls

The results of the first two experiments prompted the installation of Mylar on the roof and walls of a section of SPEAR. It was hoped that the Mylar would reduce the temperature fluctuation of the roof by additional factors beyond the reduction caused by white paint alone. Unfortunately, the Mylar only reduced the outside wall temperature fluctuations by an additional 15% beyond the white paint, which was not enough to give a measurable change in the HLS.

CONCLUSION AND FUTURE WORK

Through the three experiments, we have concluded that the major driver of accelerator tunnel floor motion comes from differential heating across the concrete tunnel walls coupled to the floor through the wall foundations. We plan to insulate a section of the wall to validate our conclusion before proceeding to insulate the whole tunnel.

The method used to study data for this effort will also have to be re-evaluated, as the analysis expands to include not just the main storage ring, but also the beamlines and experimental floor. A more precise tidal calculator must be used to analyze and extract planar motion from the HLS data.

ACKNOWLEDGEMENTS

This effort would not have been possible without funding from the Department of Energy Office of Science and the SULI program at SLAC National Laboratory. Thanks to Steve Gierman, Ben Scott, Ann Trautwein, Domenico Dell'Orco, Tom Rabedeau, Ray Ortiz, Harvey Rarback, Jim Sebek, Bob Hettel, John Schmerge and the rest of the SSRL Accelerator Division for their helpful contributions.

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