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PEP-II IR-2 Alignment

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This paper describes the first results and preliminary analysis obtained with several alignment monitoring systems recently installed in the PEP-II interaction region. The hydrostatic level system, stretched wire system, and laser tracker have been installed in addition to the existing tiltmeters and LVDT sensors. These systems detected motion of the left raft, which correlated primarily with the low energy ring (LER) current. The motion is of the order of 120 micrometers. The cause was identified as synchrotron radiation heating the beampipe, causing its expansion which then results in its deformation and offset of the IR quadrupoles. We also discuss further plans on measurements, analysis and means to counteract this motion.

1. INTRODUCTION

The PEP-II interaction region (IR) provides head-on collisions of the LER (Low Energy Ring) and HER (High Energy Ring) e+ and e- beams [1]. The need to separate the beams after collision requires that the beams have complicated curved trajectories in the IR shaped by dipole magnets that in turn cause synchrotron radiation, part of which shines onto the LER and HER vacuum chambers causing its heating (see Figure 1).

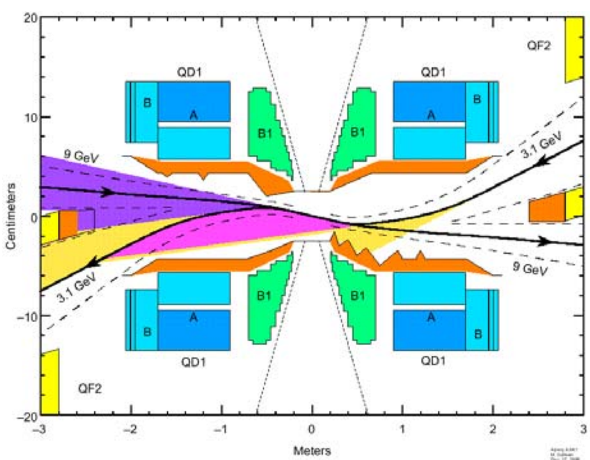

Figure 1: Schematics of PEP-II interaction region with synchrotron radiation fans from LER beam (picture courtesy Mike Sullivan).

Variations of the electron and positron currents cause varying heating of the vacuum chamber and its varying distortion. Due to tight space constraints, the vacuum chamber fits tightly into the aperture of near IR quadrupoles, therefore distortion of the vacuum chamber translates into motion of the IR magnets and motion of the rafts which support them. As a result, the Q1 quadrupole magnet which is shared between LER and HER, and septum quadrupoles Q2 (in LER) and Q4 and Q5 (in HER) which are supported from IR rafts, may all move. The Q1 and Q2 are separated by bellows, so Q1 may not necessarily move.

Early indications of IR quad motion were obtained with tiltmeters and LVDT sensors, which however were not giving sufficiently detailed information. In order to improve understanding of IR magnet motion, three additional motion monitoring systems were installed in IR2 in August of 2003: the hydrostatic level system, the stretched wire system, and a laser tracker.

2. IR2 MOTION

2.1. Motion Monitoring Systems

The Hydrostatic Level System (HLS) installed at IR2 was composed of HLS sensors [2] developed by Novosibirsk Budker Institute of Nuclear Physics for studies of slow ground motion for the Next Linear Collider (NLC) and for use as alignment monitoring tool at the Linac Coherent Light Source (LCLS). Figure 2 shows the HLS system installed at the SLAC sector 10 alignment laboratory. Similar systems were installed in the Fermilab Main Injector tunnel, with 20 sensors spanning over 300m, and in the near Fermilab deep dolomite Aurora mine. These HLS systems provided comparative data on slow ground motion in different geological locations [3].

Figure 2: Hydrostatic Level System installed in the alignment laboratory at SLAC for NLC slow ground motion studies. The HLS sensors from this system were installed at PEP-II IR. The test device shown in the right hand corner allowed controllable micrometer variation of the water level, for calibration tests and water dynamics study. An insert in the left bottom corner shows cross-section of the sensor.

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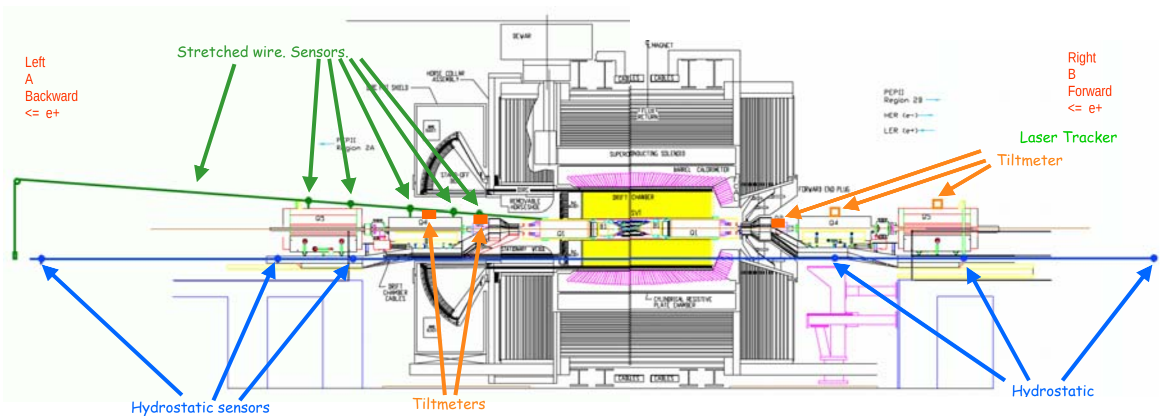

Figure 3: PEP-II IR scheme with hydrostatic system, stretched wire and tiltmeters (drawing courtesy Stuart Metcalfe).

The resolution of Budker INP HLS sensors is better than 0.1 micron and long term stability is one to several microns. The sensors are based on electrical measurements of the capacitance which changes when the gap between the electrode and the water level varies.

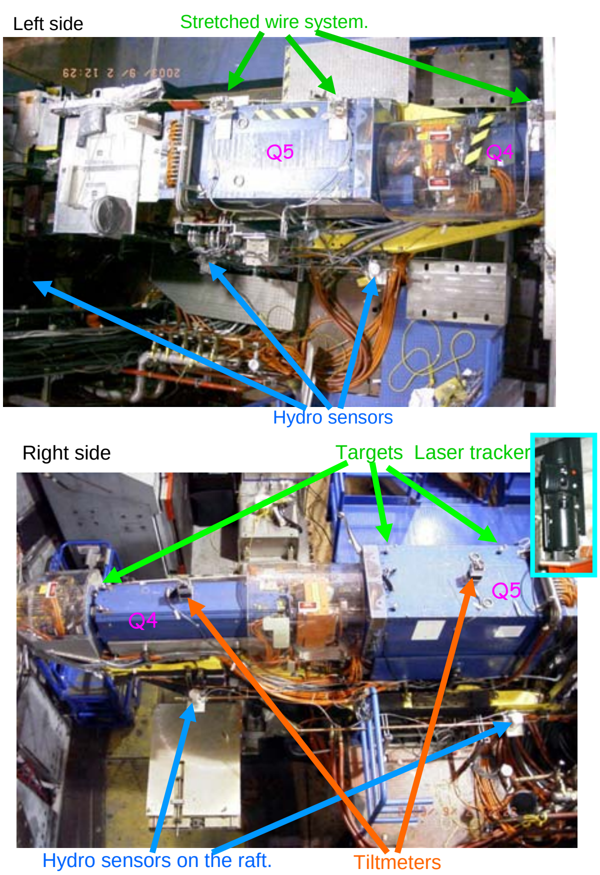

Figure 4: Photo of the left and right rafts supporting Q5, Q4 and Q2 magnets (part of Q2 is visible on the right side, under the plastic cover). Locations of hydrostatic sensors, stretched wire sensors (installed on the left side only), tiltmeters, laser tracker and its targets (installed on the right side only) are shown by arrows.

The HLS sensors are connected with a single pipe which shares water and air (in contrast with some older HLS sensors which had separate pipes for water and for air). Such 'half-filled' tube configuration ensures that the water level is determined by gravity only, and minimizes the sensitivity to temperature variation between sensors.

A total of six HLS sensors were installed in IR2: two reference sensors in the left and right tunnels, and two sensors on each of the IR rafts. All the sensors were connected with half-filled pipe. In this way, this HLS system is able to determine vertical motion of each raft, as well as its slope along the beamline (also called pitch).

The stretched wire system installed at IR2 is a prototype system being developed for possible use at LCLS. It is based on induction sensors detecting motion of a copper-beryllium wire carrying AC current. A total of five two-plane sensors were installed on the left side quadrupoles Q5 and Q4 (two X-Y sensors on each magnet) and Q2 (one X-Y sensor). The wire with its one end was attached to the Q1 quadrupole and the other end was connected to a pulley fixture in the tunnel. Resolution of the stretched wire system is several microns.

The titlmeters measuring pitch (slope along the beam) and roll (rotation around longitudinal axes) were installed on both left and right side on Q5, Q4 and Q2 magnet (with the exception of the left side Q5). Though these tiltmeters were very sensitive to long term temperature variations, they have proven to be useful for detection of current induced motion of the magnets.

A laser tracker (SMX4500) was installed on the right side and mounted on the tunnel wall. It measures the 3D relative positions of Spherically Mounted Reflector (SMR) targets to an accuracy of about 20 microns with proper calibration and environmental compensation. Four SMRs were placed on both the Q4 and Q5 magnets, three on the raft and six around the building as control.

Signals from these systems were made available in the SLAC control program (SCP) for on- and off-line analysis.

Figures 3 and 4 show the schematics and the photos and of the PEP-II IR region. Locations of the installed sensors are shown by arrows.

2.2. Motion Data and Analysis

The newly installed IR motion monitoring systems allowed several important conclusions to be made about the amount and character of the motion. Figure 5 shows raw data measured by HLS sensors closest to the interaction point (IP) on the left (LRAFT Y1) and right (RRAFT Y1) sides.

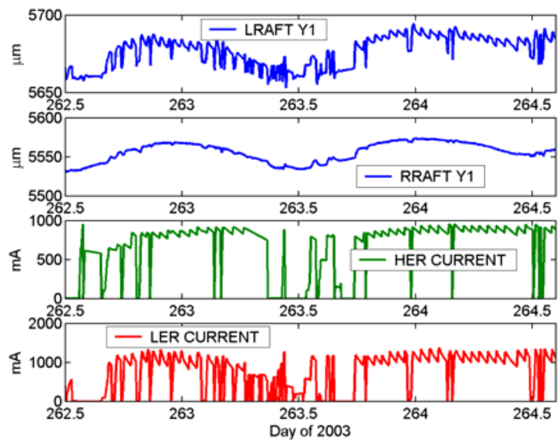

Figure 5: Raw signals from HLS sensors located most close to the IP on the left and right sides and the HER and LER beam currents.

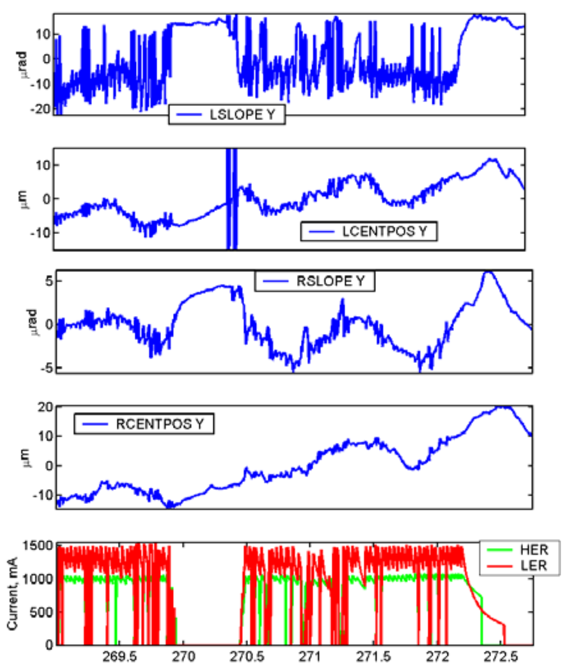

Figure 6: Data from HLS sensors converted into position of the raft central support point and its pitch. Horizontal axis shows the day of 2003.

One can clearly see that the hour scale motion is correlated with the beam currents and is happening primarily on the left side or the IR (the daily motion observed in the raw data is caused by tides and day-night temperature variation and should be ignored). Second, analyzing the pattern of the beam current and the pattern of the motion one can see that the motion is correlated primarily with LER current. This conclusion is consistent with the fact that LER synchrotron radiation is shining mostly onto the left side.

The HLS data were then analyzed in order to convert raw sensor readings into the relative position of the raft support point with respect to the tunnel floor, and into the slope (pitch) of the raft along the beam axis (the raft central support point is located approximately under the center of Q5 magnet, see Figure 2). One can see from Figure 6 that the position of the raft central support is rather stable – the daily variation is about five microns and the beam current induced variation is less than several microns. However, the slope of the left raft is changing significantly – variation of the slope angle is about thirty micro-radians which translate into a hundred microns over several meters of the raft length. In the following analysis it will be assumed that only the slope motion of the left raft is important, and all other motion will be ignored.

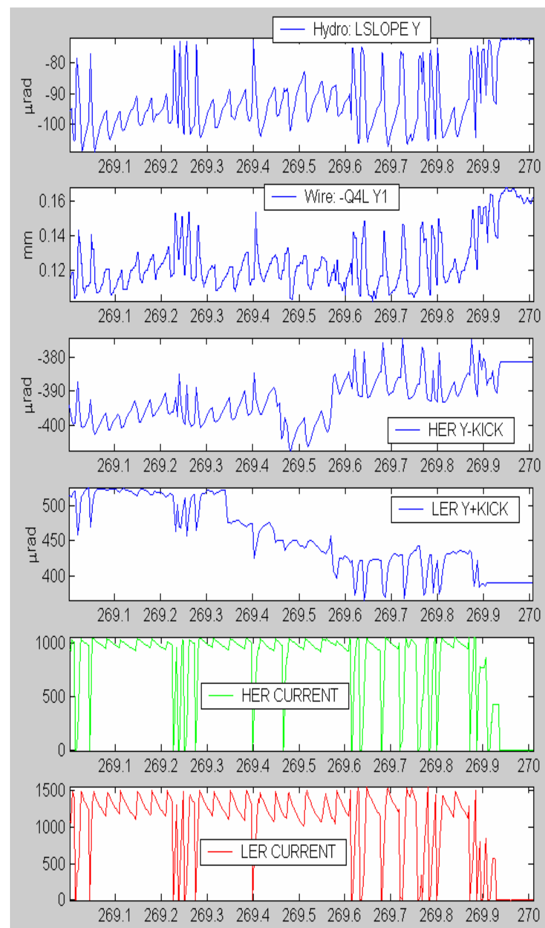

Figure 7: Slope of the left raft, signal of the stretched wire system, signals from the HER and LER orbit feedbacks, and beam currents. Horizontal axis shows the day of 2003.

The beam current dependent motion on the left side is also observed by the stretched wire system and tiltmeters, as well as seen in the orbit motion of the electron and positron beams. For example, Figure 7 shows the left raft slope, one of the signals from the stretched wire system (vertical, installed on Q4, closest to the IP), beam currents and the signals from the LER and HER orbit feedbacks (LER Y+ KICK and HER Y- KICK) that intend to stabilize the beam orbit through the IR region and keep the beam colliding. Clearly, there is very good correlation of all these signals with the LER current.

2.3. Reconstructed Magnet Motion

An attempt has been made to combine data from all the systems and reconstruct actual motion of the raft and magnets on the left side. The resulting model is shown in Figure 8 and the methodology is explained further below.

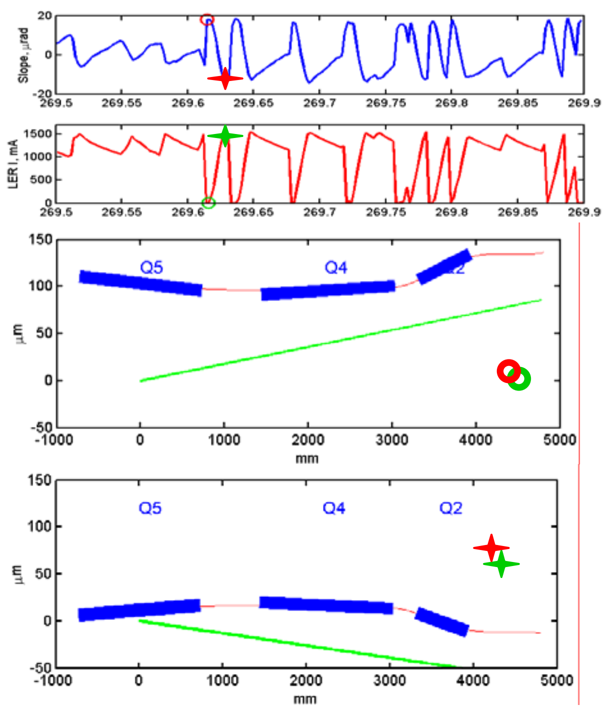

Figure 8: The left raft slope and LER current for the time interval used for magnet motion reconstruction, two top graphs (horizontal scale shows day of 2003). The bottom two graphs show reconstructed motion of the left side magnets for two extreme values of LER current. The green line indicates position of the raft and the blue boxes indicate positions of the Q5, Q4 and Q2 magnets (horizontal axis shows the distance along the beamline with respect to position of the central raft support).

According to the reconstructed motion model, when the LER beam current changes from the maximum (1.5A) to zero, the slope of the left side raft changes by about 30 micro-radians and the quadrupole magnets move by about 120 microns with respect to the tunnel. Moreover, the quadrupoles also move with respect to the raft by 50-100 microns and their pitch angle changes with most of the deformation occurring near Q2 (consistent with the fact that most of synchrotron radiation shines on this region, see Figure 1).

One needs to note, that since our three systems (hydrostatic level, stretched wire and tiltmeters) are measuring different things in different places, the presented reconstructed motion is necessarily based on many assumptions (for example that wire system pulley has no friction, and that all the wire sensors have the same calibration, and that the raft itself does not deform, etc.), some of which may not necessarily be proven entirely correct in the future. However, though further analysis may bring corrections to the details of the motion, the overall amount (a hundred of microns) appears to be doubtless.

2.4. Methodology of Motion Reconstruction

In order to reconstruct motion of the left side magnets, we first assumed that motion of the left raft is described by its slope only, measured by HLS sensors, and ignored the change of the raft support position.

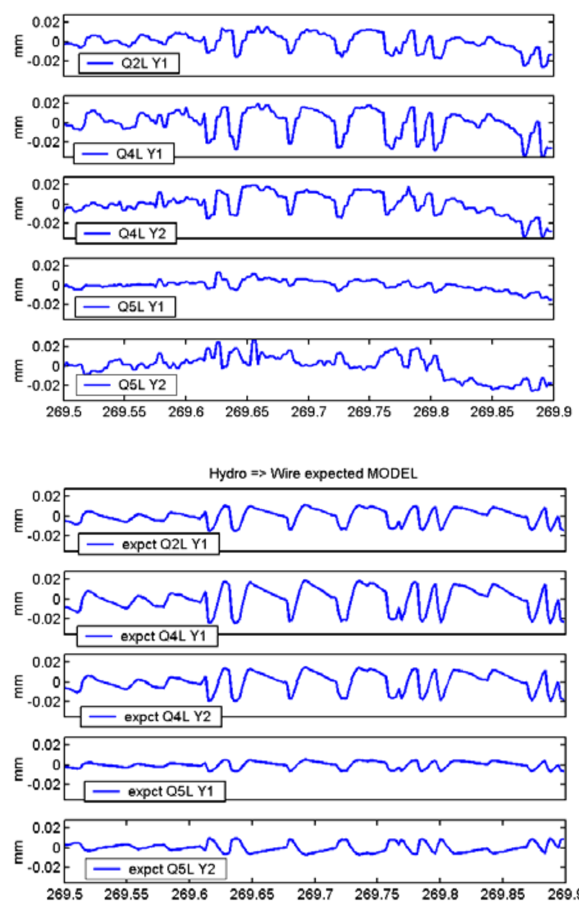

Figure 9: Measured (five top graphs) and modeled (five bottom graphs) signals of the stretched wire system corresponding to the reconstructed motion shown in Figure 8. Horizontal scale shows the day of 2003.

The first natural hypothesis to check was that the magnets are rigidly connected to the raft. The second hypothesis was to assume that there is some vertical flexibility between Q2 and Q1 (to which the wire is attached), since they are connected via a bellows. In the framework of our previously stated assumptions, however, both these hypothesis were found contradicting the measured data. So, it was concluded for the following analysis that a) there is additional motion of the magnets with respect to the raft, and b) the Q2-Q1 junction is rigid in the vertical direction.

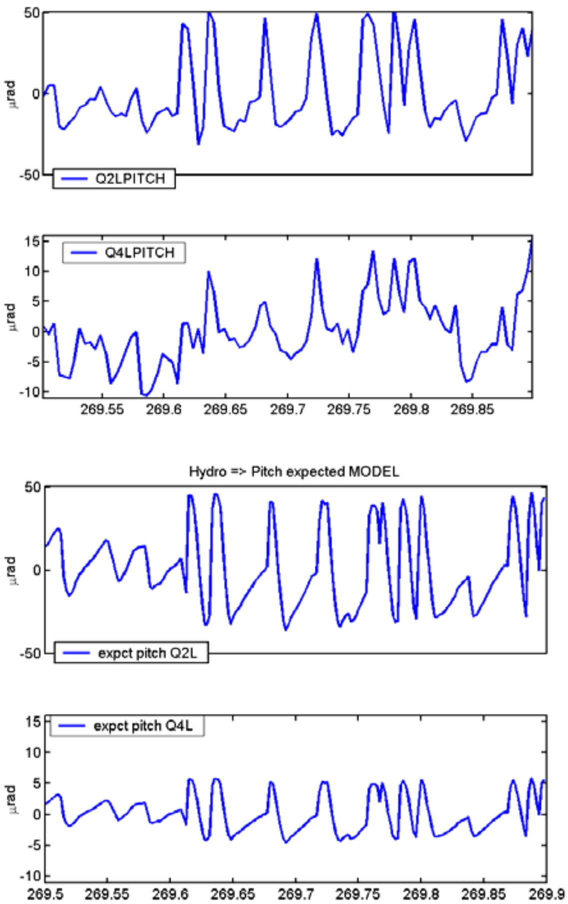

Figure 10: Measured (two top graphs) and modeled (two bottom graphs) signals from the left side tiltmeters corresponding to the reconstructed motion shown in Figure 8. Horizontal scale shows the day of 2003.

The additional motion of the magnets with respect to the raft was fitted in such a way that the modeled stretched wire and pitch signals would be consistent with measured quantities. The resulting comparison of the measured and modeled signals is shown in Figure 9 and 10. Note that the real wire signal is noisy, because of the limited resolution, and the real tiltmeter signal have slow drifts, which both should be ignored while looking only into the depth of the modulation correlated with beam currents. One can then see that the measured and modeled motions agree well.

3. SUMMARY

Alignment monitoring systems recently installed at the PEP-II IR2 allowed detection of hundred micron beam current dependent motion of the left side magnets. This motion is caused primarily by LER synchrotron radiation heating the left side vacuum chamber which then deforms and cause magnets and supporting raft to move when LER current varies. Preliminary analysis has shown that most of the deformation occurs in vicinity of the Q2 magnet. Our next steps would include modeling of the beam orbits and optimization of locations of the orbit corrector and of the feedback algorithms. One interesting possibility would be to use either the measured motion directly (e.g. the raft slope) or the beam current, appropriately filtered to take into account thermal delay, as a feedforward component of the orbit feedback. Possibilities of mechanical modifications of the IR region, to eliminate transmission of the vacuum chamber deformation into magnet motion, will be studied as well.

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