NLCTA U33 Alignment Recommendations

This note contains some recommendations regarding alignment of the U33 undulator. SLAC may use different methods, of course.

For scanning, the purpose is to get the undulator parallel to the scanner motion. The Hall probe is a pseudo-electron beam. Mechanical alignment adjusts pitch, roll and yaw. Any x, y, z translation is handled by the scanner software. For x, y, z offsets we redefine Hall probe centerline. Range of motion in y is 150mm, x is 100mm and z is 2.5 m. The bench is 7m long but we recently modified the z-motion for ILC Damping Ring wiggler prototype tests which reduced the z-range. It is sufficient for the NLCTA tests.

# Mechanical alignment of undulator

## Use Enclosed High Pressure Grease

We have included a small amount of high-pressure grease with the undulator. This grease should be used on the ball end of the tooling balls and the bottom surface of the kinematic mounts. It will allow easy translation, elevation, roll, pitch and yaw adjustments with minimal chance of brinelling the kinematic mounts. Brinelling occurs when the local Hertz stress at point, line or circle contacts between the plate, V-groove or cone, exceed the yield strength of the material. Our engineering calculations confirm that for steel this will not occur for the 33mm or 55mm kinematic mounts under static loading conditions. However, if the horizontal mounting plate is moved by use of hammer taps and there is no grease on the tooling balls or bottom mount surface then it is possible that brinelling will occur because of a stick-slip motion. The grease insures smooth sliding. High pressure grease is used because the local pressure at the contact points is high. It is used extensively in bearings.

## Align V-groove for desired translation

The undulator has kinematic feet: cone, V and flat. The arrangement is shown in the drawing 1948-3000. The alignment of the V-groove shown in zone A6 assumes axial translation may be needed. It is more likely that transverse adjustments will be needed, i.e. along the x-axis. Then the V-groove should be oriented along x, not z.

## Use precision levels on horizontal plate

We have tried to align the magnetic centerline parallel to the horizontal plate. This was confirmed with precision levels on the horizontal plate and lower jaw strongback. The pitch and roll of the horizontal plate were adjusted with a Brunson 187 with 1 arc-second null indication using a split bubble system. During magnetic field scanning we did not need to make any further adjustments to the level. As a point of reference, 1 arc-second is 5 microradians or about 2.5 microns in the 20” horizontal dimension. We placed the level at the center. We do know that the horizontal plate has a flatness of about 0.001”, so moving the level will give different readings. Even if there is a 0.002” end-to-end misleveling, the  is 1.000045315 and B would change by 0.267 gauss. It would be surprising if this had an impact on performance.

## Use inside micrometers or a precision spacer between the horizontal plate and the scanner granite

When the undulator was scanned we used a precision ground rod and moved the horizontal plate to achieve a uniform spacing. This was confirmed with inside micrometers between the plate and our scanner. Depending on the details of the SLAC scanner this may or may not be possible. Essentially we are insuring that the magnetic centerline is parallel to the trolley motion by adjusting the undulator yaw.

## Alternative leveling uses scanner trolley

An alternative leveling and alignment method is to mount micrometers on the scanner trolley itself. We used this method on a scanner we built and delivered to NSRRC in February of this year. It had provisions on the trolley for attaching micrometers. Our older trolley does not have them and there wasn’t enough time to add this feature. (We would also have to re-align the trolley sub-plate in addition to adding threaded inserts into its granite vertical plate.)

## Notes and comments on Hall probe scanning

Because only one beam can be moved, whenever any change is made to the gap, the centerline shifts by 0.5\*dgap. Therefore, set the gap first using the fiducialization data. If gap adjustments are made, the scanner vertical probe offset needs to be adjusted. If this is not done then the peak field will increase by . This is quadratic. A 1 gauss change requires a 0.2mm gap change.

The probe holder was leveled using a jig transit. We use a fine adjust tip/tilt stage to make adjustments of the probe holder roll and yaw. Roll is set by comparing the probe holder edges at 0 and 180 degrees. Rotating the probe holder 90 degrees and 270 degrees allowed us to check any yaw. Both yaw and roll was set to be < 0.001” in 10” which is the transit resolution. When the By probe is flipped, the probe center shifts in the vertical and axial direction. The vertical shift is handled by the scanner software which moves the probe vertically when it is flipped. The axial shift can be handled by the scanner moving the probe axially before starting acquisition of the flipped probe data or in the Hall probe analysis software. We used the latter approach for the 33mm undulator. They are equivalent. (The analysis code Hall.exe, always performs axial alignments, so having it done by the acquisition software mainly make pretty graphs.)

The By probe vertical alignment uses Hall probe scans, so the vertical center was roughly set. Fine adjustment of the By probe vertical center uses pole-by-pole fitting of the peak field to and linear regression of values. Poles 4 – 22 were used. We used scans at y=-0.5mm, -0.25mm, 0, 0.25mm, 0.5mm. This gave approximately a 25 gauss change. Probe peak field noise is about 0.1-0.2 gauss, so the SNR is sufficient. The linear term in the fit is pitch of the undulator relative to the scanner. It was small. The constant term was used to adjust the vertical probe offset. After adjustment the undulator was scanned again. The resulting vertical centerline error was about 1 micron.

The By probe horizontal alignment used the alignment cross on the probe. Prior to installing end poles we marked their centers. Then we rotated the By probe 90 degrees and aligned the horizontal cross to the pole centerline. This centerline is only known to an accuracy of about 50 microns. However, it is easy to see that since the 1st and 2nd integrals of the By meet specifications over a region of -4mm to +5mm and the specified transverse good field region is -2.5mm to +2.5mm, we would have to make a 1.5mm error in the horizontal probe location before it would matter.

As a note in passing, about 20 years ago we tried using a magnetic needle to find the magnetic center of a Group 3 DTM-141 probe. It was a design we got from LBNL. The centerline found by the needle had a very broad flat region so we have not used it since that time.

A different procedure was used for the Bx probe. The gap at the end pole was 10.7mm. A 5.35mm tall stack (3mm+1.3mm+1.05mm) of ceramic gage blocks was placed on the lower pole surface. The probe was vertically centered on the blocks. In the horizontal direction we used the scribe lines on the end poles. The Bx probe was moved until the surface of the ceramic plate lined up with the pole centers. Then the horizontal center was 1.45mm from that location, per Senis probe drawings.

Since the Bx probe alignment is less precise than the By probe, it might be argued that the skew multipoles are less accurate. This is true. However, we have performed skew dipole, quadrupole and sextupole shimming that eliminated skew quad and sextupole. The only statistically significant multipole is a skew dipole which is insensitive to either vertical or horizontal probe location.

Tuning and alignment scans acquired data with the probe moving in both directions, but certification scans acquired it with the probe moving in one direction. This is because there is a slight yaw between the two z-axis scan directions. It was also seen on the NSRRC air bearing, laser encoder scanner we delivered in February. While small, for the best quality certification scans we only collect data in one direction.

We performed a few scans with 0.002cm resolution. There were no statistically significant changes in the specified quantities: peak field, transverse rolloff, phase error, 1st or 2nd integrals. Therefore, since those scans contain 10X more data, we used the 0.02cm resolution. Note coarser resolution than this in not advisable. It could easily give inaccurate results.

Our lab is reasonably well temperature controlled: 1 degC. Sensor temperature variation was about 0.1 degC due to some thermal isolation created by the probe case and probe holder. The By field sensor had less than 0.01%/degC sensitivity variation (according to Senis calibration data). Our lab is close to the calibration temperature so no temperature compensation was used.

Skew field scans showed main field bleed thru. We removed it with software by subtracting a scaled version of the main field from the skew field data. The amount of correction was small and it did not impact skew 1st or 2nd integrals. Because of the presence of a non-zero cant, the normal field shows a dependence ofby Maxwell’s equations the skew field must be . For the 1st integrals this was confirmed with skew field scans at non-zero vertical displacements. A point-by-point test of this model has not been performed due to time constraints.