

ANL and DESY Undulator Tuning Procedures

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Abstract

The ANL and DESY undulator tuning procedures are described. This information should be useful in formulating the undulator tuning procedures for the LCLS.

1 ANL Undulator Tuning Procedure

1.1 ANL Test Stand

Argonne National Laboratory (ANL) is building the undulators for the LCLS project at SLAC. The first LCLS prototype undulator was tuned at ANL on a test stand which has a 6 meter long granite table. The granite table guides a carriage which floats on an air bearing. A schematic diagram of a cross section of the test stand is shown in figure 1. The carriage is moved by a stainless steel belt which is driven by a motor. The carriage holds a set of stages which give x , y , and roll motion to a probe. The probe is held by a goniometer which aids in the alignment of the probe. The probe used at ANL at present is a two axis Hall probe made by the Sentron company. The two axis Hall probe measures both B_y , the vertical field, and B_x , the horizontal field. The analog voltage output of the Hall probe goes to an HP3458 precision voltmeter. The voltmeter readings are triggered by an encoder on the granite table, followed by a divider. The triggers determine the z positions at which the field is measured. The system gives B_x and B_y measurements as a function of z , the coordinate along the device.

The B_x and B_y measurements are used to compute the trajectory of an electron beam of given energy. The measurements are also used to compute the phase shift of the electron beam relative to light of a given wavelength. The goal of the undulator tuning procedure is to make the trajectory straight and to keep the electron motion in phase with the light. This is done by adding shims to correct small field errors in the undulator. The required shim strengths are calculated from the B_x and B_y measurements. The shims are placed on the undulator and the process is repeated until all errors are reduced to an acceptable level.

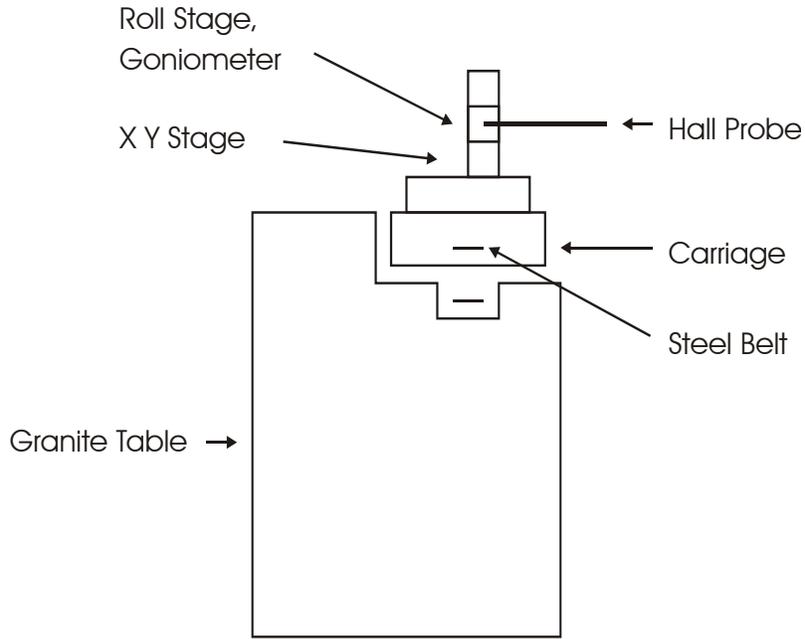


Figure 1: Schematic diagram of a cross section of the ANL test stand. The carriage holds stages which position the Hall probe. The carriage floats on an air bearing above the granite table. A steel belt driven by a motor is used to move the carriage.

ANL also uses a stretched wire system to check the overall integrals of B_x and B_y . The uniformity of the field integrals across the poles can also be measured.

The Hall probes are calibrated in a large magnet. Six NMR probes are placed on a stage and the one with the appropriate range for a given field value is moved next to the Hall probe. The Hall probe output can then be compared to NMR values over the entire range of operation of the Hall probe.

Several upgrades to the test stand are planned. A very important upgrade involves the trigger signals from the linear encoder. At present, only one signal phase from the encoder is divided down to provide the trigger signal. After the upgrade, both phases from the encoder will be used so the direction of motion will be known. This should largely eliminate false triggers from mechanical noise.

1.2 Tuning Procedure

1. *Initial alignment of the undulator.* Ceramic gage blocks with a scribe line in the center are placed on poles at each end of the undulator. Poles are

chosen for a good fit of the gage block. The gage blocks can be moved on the poles to make sure the poles are horizontal and that the undulator has no roll. The Hall probe holder also has a scribe line on it giving the approximate position of the Hall elements. The undulator is adjusted until all scribe lines are at the same height. This gives the initial y and pitch alignment of the undulator. The x alignment is not as critical and is done by eye moving the carriage along the undulator.

2. *Precision alignment of the Hall probe to the undulator.* Both the B_x and B_y Hall probes are in the same package and both need precision alignment. The first step is to move to a pole and adjust the angle of the probes using the goniometer until the B_x signal is zero. One can then do a scan to make sure the average B_x is near zero and the main undulator field is not giving a B_x signal due to misalignment. These small angle adjustments cause a cosine error in the B_y measurement, which is negligible. The next step is to adjust the y value of the B_y probe. Scans are done with the probe at several y positions. The effective B_y is recorded and the y value which gives the smallest effective B_y is determined. The probe is then set to that y value.
3. *Straighten the trajectory in x .* The trajectory in x is calculated from the second integral of the B_y measurements. Wherever there is a significant change in slope, a shim is added to give the beam a kick to straighten the trajectory. The shims used at ANL for the LCLS prototype only weaken the field at a pole. (Other types of shims which strengthen a pole are used on other undulators, typically with a larger gap.) If weakening a pole gives a kick in the right direction, fine, otherwise a shim is added to the next pole (of opposite polarity).
4. *Minimize phase errors.* The phase error is calculated from the B_y measurements. Steel shims are added on top of the magnets to reduce the strength of two neighboring poles. This reduces the phase shift. Steel shims are added to two neighboring poles to increase the phase shift. The phase error signature also indicates if there is a taper to the undulator, in which case, the gap of the undulator may need to be shimmed as a function of z .
5. *Straighten the trajectory in y .* The trajectory in y is calculated from the second integral of the B_x measurements. The trajectory is straightened by adding shims that produce a horizontal field, giving vertical kicks to the beam. The procedure is very similar to the procedure used to straighten the trajectory in x , but with a different style of shim.
6. *Check.* This procedure can be iterated as necessary in case there is some cross talk between the shims.

2 DESY Undulator Tuning Procedure

2.1 DESY Test Stand

The Deutsches Elektronen Synchrotron (DESY) laboratory has a sophisticated undulator measurement laboratory which is presently measuring undulators for the FEL in the Tesla Test Facility. The DESY test stand uses a 12 meter long granite table which guides a carriage floating on an air bearing. A schematic diagram of the DESY test stand is shown in figure 2. The design of the test stand is similar to the ANL test stand, but with several improvements. The carriage is guided by the granite table on three sides instead of two for better stability. The belt drive is replaced by a linear servo motor which allows the carriage to be accurately positioned at the micron level. The carriage holds a set of stages which give x and y motion to a probe. These stages hold an angle stage and a goniometer which are used for precision alignment of the measurement probes. Probe readings are triggered by linear scales with dividers. The divider circuit corrects for the direction of motion, preventing extra counts from mechanical noise.

The probes used at DESY are different than at ANL. B_y is measured with a Hall probe made by the F. W. Bell company. B_x is measured with a coil whose output goes to an integrator. The reason to use a coil is to avoid the planar Hall effect in the B_x measurements. (The newly available Sentron Hall probes used at ANL are largely insensitive to the planar Hall effect.) Both Hall probe and integrator analog outputs are sent to an HP3458 voltmeter which is triggered by a linear scale with divider, as mentioned above.

The adjustments to tune the undulator are somewhat different than at ANL. The poles of the undulators are adjustable, so tuning the B_y fields is done by moving the poles. Thus, straightening the x trajectory and adjusting the phase are both done by moving the poles. The y trajectory is straightened using steel shims on the poles which are configured to give a horizontal field.

The Hall probe calibration system is similar to the ANL system. The NMR probes are not moved, however. They are placed in close proximity to the Hall probe in a large magnet with a small field gradient.

Several upgrades to the measurement system are underway at DESY. A two axis Sentron probe is presently being evaluated for the B_x and B_y measurements. A second axis is being added to the calibration system to accommodate the second probe. In addition, the multiple NMR probes of the calibration system are being replaced by a single NMR probe which uses flowing water. This will be a large simplification. In parallel with this work, a coil is being built which will accommodate the present Bell Hall probe inside it. This will save much setup and alignment time in the current configuration. Finally, a capacitive sensor system is being built which will allow precise monitoring of the pole positions during adjustments.

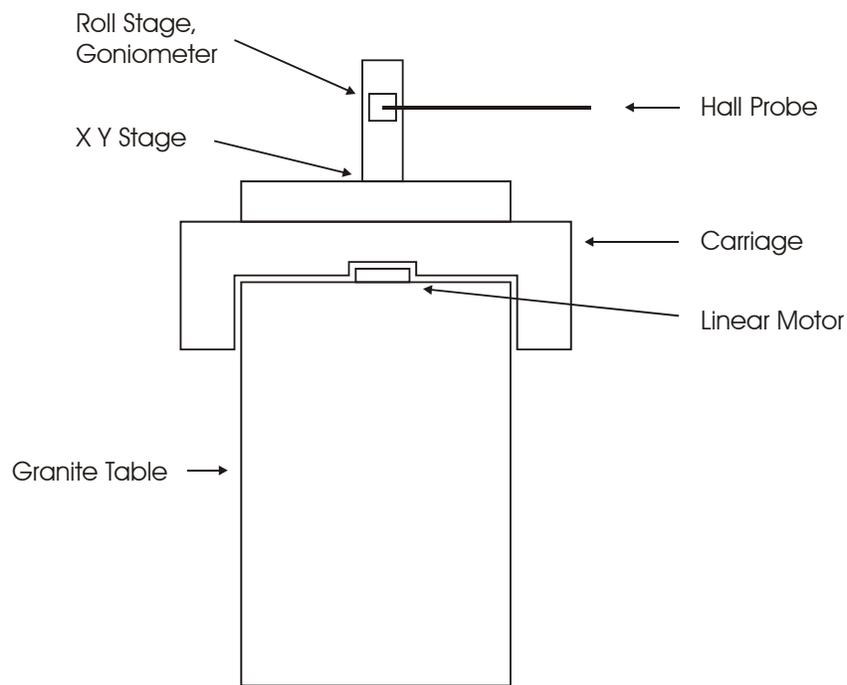


Figure 2: Schematic diagram of a cross section of the DESY test stand. The carriage holds a set of stages which position a Hall probe or coil. The carriage rides on an air bearing and is driven by a linear motor.

2.2 Tuning Procedure

1. *Initial alignment of the undulator.* The undulator is placed next to the test stand and aligned using optical surveying equipment to move it roughly into position.
2. *Precision alignment, vertical scans at each pole.* The Hall probe is sequentially moved to each pole and scanned up and down. B_y is measured as a function of y . This data is fit by a polynomial and the location of the minimum gives the center of the undulator at that pole. The center positions are plotted as a function of z . Any poles that are much different than the others are fixed. The average height and pitch of the undulator are determined. The undulator is moved to eliminate the pitch and make the average height have the desired value, say $y = 0$. This process is iterated. All future measurements are then done at $y = 0$.
3. *Precision alignment, horizontal scans at each pole.* The Hall probe is sequentially moved to each pole and scanned in x , the direction of the pole. B_y is measured as a function of x . The field is flat along the pole and drops off rapidly at the edges. The two points where the field has half the value that it had in the center are found, and the point midway between these two points gives the x position of the center of the pole. The x center positions are plotted as a function of z . Again, any poles that are much different than the others are corrected. The average x and the yaw of the undulator are determined. The undulator is moved to eliminate the yaw and make the average x have the desired value, say $x = 0$. This process is iterated. All future measurements are then done at $x = 0$.
4. *Measure and adjust the peak fields.* The Hall probe is scanned in z and B_y is recorded as a function of z . Each peak in the field is fit with a polynomial and the maximum values, the peak fields, are recorded. Using this data, the gaps between the poles are adjusted in an effort to get the peak fields constant and at the correct value along the undulator. This process requires several iterations with fewer poles needing adjustment each iteration.
5. *Repeat the vertical scans at each pole.* After the poles have been moved, the vertical scans are repeated to find the new center line of the undulator. The undulator is moved to the desired center line if required. At this point the alignment of the undulator is done.
6. *Correct the horizontal trajectory.* The horizontal trajectory is calculated from the B_y measurements. It is then straightened by first adjusting the poles at the end of the undulator so the trajectory enters straight and leaves straight. Poles in the center are then adjusted to make the rest of the trajectory straight. A software filter which integrates over one period is used in this analysis. Poles are adjusted until the output of the filter is

zero. The one period filter makes sure every period of the undulator gives no net kick to the beam. Thus the trajectory is straight. This process is iterated until the trajectory is within specifications.

7. *Phase adjustments.* Making the output of the one period filter zero in the previous step means that each period has been corrected to be identical to the others. This means phase errors in the body of the undulator have also been corrected. No further phase corrections are done in the body of the undulator. Typical RMS phase jitter using this approach is 6° , which is acceptable. The only phase adjustment left to do is make the total phase going through the device a multiple of 2π . The adjustment is divided between the two ends, so a phase shift of π is introduced at each end of the undulator. To do this, two poles are adjusted at each end of the undulator. This gives no net kick to the beam, but makes it travel an extra path length in its wiggle. In this way the phase is adjusted. Scans are made of the end regions only and the magnets are adjusted to give the desired phase shift of π . After this, the phase adjustments are complete.
8. *Set up the coil to measure B_x .* Up to now the main vertical field has been tuned. Now the imperfections causing horizontal fields have to be eliminated. The Hall probe used to measure the vertical field is removed and a coil is put in its place to measure the horizontal field. The coil is aligned vertically and horizontally using optical alignment equipment. The coil is adjusted until scribe lines on the coil match up with scribe lines on gage blocks (for the vertical) and scribe lines on the undulator (for the horizontal). The roll angle of the coil is adjusted by doing a quick scan and rotating the coil until the signal from the main field goes to zero. The output of the coil is sent to an integrator, basically giving the flux in the coil. The area of the coil is known, so the horizontal field can be calculated.
9. *Correct the vertical trajectory.* The integral of the coil voltage is measured as a function of z , giving B_x as a function of z . The vertical trajectory is calculated. Corrector kicks are calculated to straighten the trajectory. The corrections are implemented with special shims which give a horizontal field. The shims are placed in the undulator and the process is repeated until the vertical trajectory is a straight line at zero.
10. *Final checks.* At this point, the undulator is tuned. All shims are taken out and then glued back in place. A final measurement is performed. The Hall probe is then set up again and the vertical field is remeasured.

3 Conclusion

The tuning procedures used both at ANL and at DESY have been presented. The two labs use somewhat similar equipment and measurement techniques. These procedures can be a guide for setting up the LCLS measurement lab and

tuning procedures. Ideally, the LCLS would use the best of both the ANL and DESY hardware ideas and tuning techniques.

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