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ACCURATE MEASUREMENTS OF UNDULATOR PARTICLE BEAM ENTRANCE/EXIT ANGLES USING IMPROVED HALL PROBES AND CALIBRATION PROCESS*

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Abstract

The Advanced Photon Source Upgrade (APS-U) undulator requirements were changed from the first and second field integrals to the entrance and exit angles of the particle beam. This gives the user the best radiation view angle via the storage ring closed orbit correction system.

SENIS HALL PROBE BEFORE IMPROVEMENTS

An issue regarding the general question of the accuracy of Hall probe measurements has been unclear until recently. Calibration of the probe and measurements of the undulators are done under quite different conditions. Calibration is done at rest with a stable field, and measurements are done on the fly in a high-gradient field. It is quite obvious that one cannot expect exact accuracy of the field obtained in this case. It is not difficult to find the difference: just measure the field of the device on the fly and at rest at a few points.

An extensive test of the Senis 2-axis Hall probes was done at the Advanced Photon Source using a 33-mm period undulator A device and the calibration system [1]. In addition to these general considerations, we recently found that the LCLS-II prototype undulator measurement results collected at the APS and at SLAC are different, and an investigation of this issue was performed. It was found that peak field results are speed dependent. To identify the reason for this difference, measurements of the undulator A device using a Senis 131-15 two-axis Hall probe were performed.

Figure 1 shows the difference between magnetic field scans performed at different speeds. It shows that the main difference occurs at the regions with strong field gradient. One of the possible sources of the errors we described earlier is Faraday's law, which states that the electromagnetic force (EMF) through the wire loop is given by the rate of change of the magnetic flux. It allows us to assume that the reason for this effect is due to some inductance and capacitance components in the vicinity of the Hall probe sensor.

The results of speed dependence for a 35-cm-period xLEAP-II wiggler are shown in Fig. 2. The speed dependence for such a device with a long period is very small. The difference between high speed and low speed can be seen only at the locations with sharp field change.

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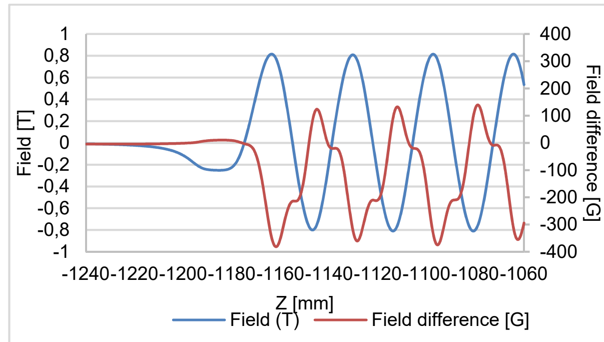

Figure 1: Magnetic field vs Z for a 33-mm period undulator A device (left scale) and the difference of the field measured at scanning speeds of 150 mm/s and 50 mm/s (right scale).

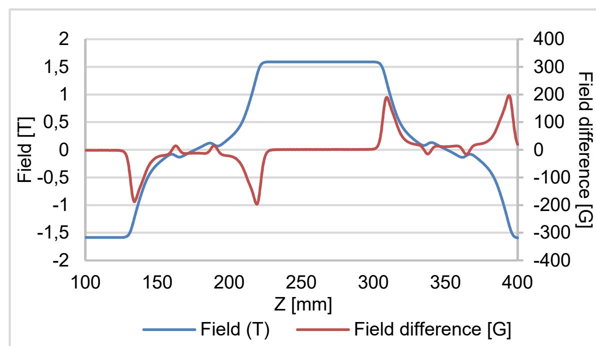

Figure 2: A 35-cm-period xLEAP-II device. Blue curve: B_y field; red curve: difference of the field measured at scans with speeds of 100 mm/s and 20 mm/s.

The integral of the field difference for different speeds is very close to the locations with strong field change. This statement proves our conclusion that this effect is due to the existence of inductance and/or capacitance at or near the sensor.

SENIS HALL PROBE AFTER IMPROVEMENTS

The recent generation of Senis Hall probes features many very important improvements. One of them is the elimination of Hall sensors zero drifts (see Fig. 3).

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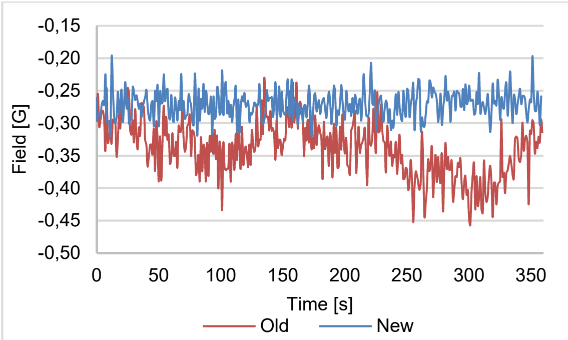

Figure 3: Zero drift comparison between the old and new Hall probe sensors. The old has a standard deviation of 0.05 G and the new 0.02 G.

The next improvements are elimination of the magnetic field speed dependence and planar Hall probe effect [2]. Even after all these improvements, to measure the entrance and exit particle beam angles with a high accuracy is of another challenge for the accuracy of Hall probe measurements. The most reliable tool used for field integral measurements is still a long stretched coil. The accuracy of Hall probe field integral measurements is not precise enough, and coil data are used (see Fig. 4).

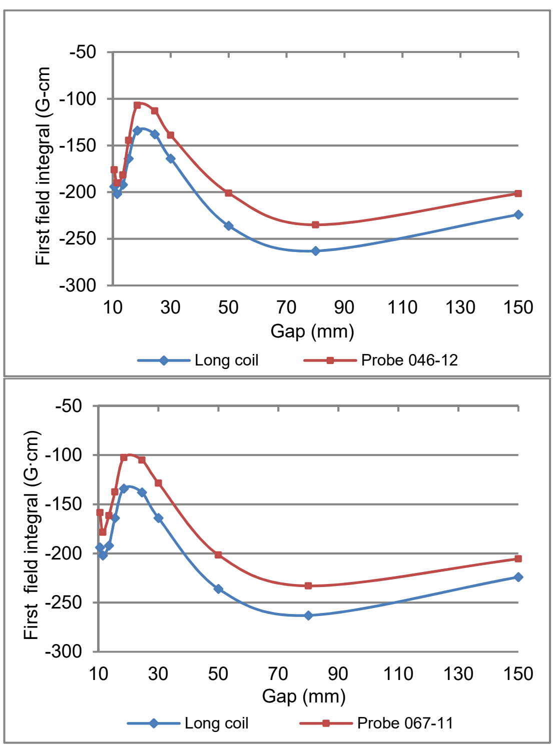

Figure 4: Comparison of different Senis Hall probes' first field integral data with that of a long stretched coil. 20 G-cm of the first field integral translate to 1-μrad angle for 6-GeV particle beam.

Recent requirements for the APS-U storage ring insertion devices, as mentioned above, have changed from field integrals to entrance and exit angles of the closed orbit of the particle moving through this device to better define the synchrotron radiation angles.

APS-U requirements for angle changes are shown in Table 1. To satisfy such requirements, the accuracy of angle determination must be at the level of ±0.5 μrad. To provide such accuracy, fine correction of the calibration table for the Hall probe was performed using long coil results as a reference.

Table 1: Entrance and Exit Angles (in μrad) Requirements for Two Independent (Canted) Ids Installed in a Straight Section

Entrance/ exit angles	Experiment gap range	Usable gap range	Full gap range
Horizontal	±3.9	±5	±10
Vertical	±1.25	±2.5	±10

The errors in the odd-numbered terms of Hall probe calibration coefficients have no effect on the end angles, only the even-numbered ones (symmetric components) have. While the even-numbered terms can be corrected by comparing the field integral measurements, of Hall probe and coil.

A short description of the procedure to correct the Hall probe calibration table is given below.

Step 1: Get the B-V curve of the Hall sensor $C_{ini}(V)$ from the regular calibration process with the help of a standard dipole magnet.

Step 2: Wipe out the symmetrical components in the B-V curve obtained in. Now only asymmetrical components remain in the new B-V curve, so we note the curve as $C_{asym}(V)$

$$C_{asym}(V) = \frac{C_{ini}(V) - C_{ini}(-V)}{2}.$$

Step 3: Measure an undulator over all gap ranges using the Hall sensor, keeping only the voltage data $V(g;z)$. With the help of the B-V curve obtained in step 2, translate the $V(g;z)$ in step 3 into the magnetic field:

$$B(g;z) = C_{asym}(V(g;z)),$$

$$J_{asym}(g) = \int_z B(g;z)dz.$$

Generate a symmetrical B-V curve $C_{sym}(V)$ with the help of a linear model regression algorithm, which satisfies:

$$J_{asym}(g) + J_{sym}(g) = J_{coil}(g),$$

where $J_{coil}(g)$ denotes the field integral measured by the long coil, and

$$J_{sym}(g) = \int_z C_{sym}\left(V(g;z)\right)dz$$

where B-magnetic field; V-Hall probe voltage; g- ID gap; z-ID longitudinal distance.

As a result of the improvements, it is now possible to achieve the required accuracy of Hall probe angles measurements of ±10 G-cm (see Fig. 5).

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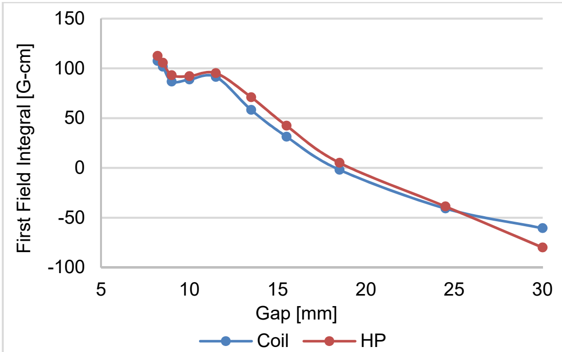

Figure 5: Comparison of the Hall probe and long coil first field integral measured results.

CONCLUSION

Recent improvements in Senis Hall probe parameters with the fine tuning of the calibration file with the long coil results allowed the achievements of the required accuracy of particle angle measurements moving through the insertion device with a Senis Hall probe.

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