# MODELING AND MEASUREMENT OF µ-METAL SHIELDING EFFECT ON THE MAGNETIC PERFORMANCE OF AN LCLS UNDULATOR*

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*Abstract*

In a previous paper [1], we presented results showing that the Earth's field might have a significant effect on the Linac Coherent Light Source (LCLS) undulator performance due to a large concentration of the field by the undulator poles. Based on the result of model calculation, we decided to shield the Earth's field by surrounding the undulator backing structure with a 1-mm-thick µ-metal sheet.

First, the effect of the shield was modeled using the code RADIA. According to the calculation, the shielding factor of a "C-shape" µ-metal shield was better than a factor of eight. Second, we measured the Earth's field shielding effect without an undulator. In our measurement laboratory, the vertical component of the Earth's field was about 0.5 gauss. It was suppressed down to smaller than 0.1 gauss with the shield. After these background measurements, we examined the effect of the shield with an undulator in place. The measurement results show very good agreement with the model calculation.

## INTRODUCTION

For the commissioning of the Linac Coherent Light Source (LCLS), beam-based alignment will be used to correct the offsets of quadrupoles and beam position monitors. This strategy works only when the field integrals in each undulator segment are small enough [2]. Undulator segments will be measured and tuned in the magnetic measurement facility (MMF) at the Stanford Linear Accelerator Center and then installed on the iron girders and moved to the LCLS tunnel. Several sources of errors are possible here. The first one is due to the difference of the Earth's field at the locations of MMF and tunnel. This difference is exaggerated by a concentration of the Earth's field by vanadium-permendur poles of the device. Another possible source of error is the existence of the magnetic elements, such as iron, used in the support system and other elements of the tunnel. Based on the computer simulations using a simple model in the RADIA code [3], we decided to use the µ-metal sheet to shield unwanted external field effect.

## EARTH'S FIELD MODELING

As shown in our previous paper [1], a seven-period undulator model with a large surrounding solenoid was used for simulating the Earth's field effect. By using this simple model, we found that the averaged field concentration factor was about 2.4, i.e., a 0.5-gauss external vertical dipole field gave a 1.2-gauss dipole field in an undulator. The horizontal component of Earth's field was found to be well suppressed on the undulator axis.

Because a dipole field above 0.7 gauss in an undulator gives an electron trajectory excursion of more than 2 µm from the undulator axis, this unwanted field needs to be suppressed or corrected. Figure 1 shows the model used for the calculation of shielding effect of µ-metal. The B-H curve of CO-NETIC sheet [4] was assumed for the calculation.

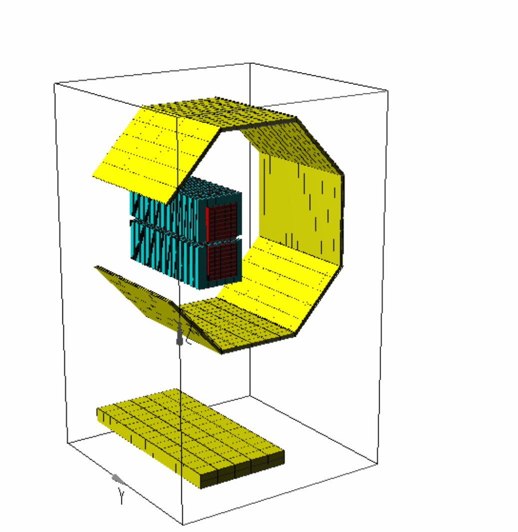

Figure 1: A µ-metal shield model used for the calculation.

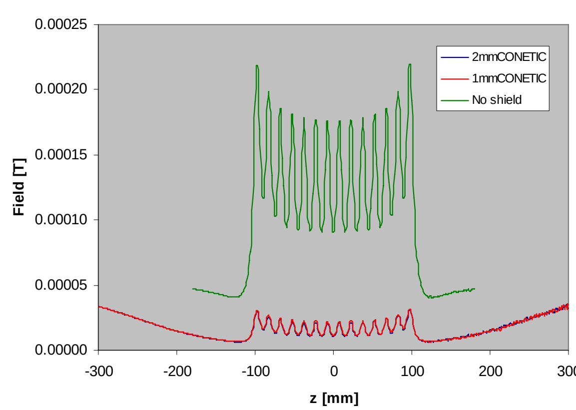


Figure 2: Summary of calculated results.

Figure 2 shows the summary of calculated results. The green curve represents the field change due to the 0.5-gauss external vertical field without a shield. In the central region, a field strength averaged over a half period is about 1.2 gauss. The red and blue curves are for 1-mm- and 2-mm-thick µ-metal shields, respectively. The

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averaged field was 0.156 gauss for a 1-mm sheet and 0.147 gauss for a 2-mm sheet, respectively. Based on these calculations, we decided to use a 1-mm thick sheet for better cost performance. (A sheet with a double thickness provides only 6 % better shielding.)

From these results, we find that the concentration (enhancement) factor by the poles in an undulator is 2.4, and the suppression (damping) factor by the μ-metal shield is eight.

## MEASURED RESULTS

The first and second articles of LCLS undulators were tuned in the magnetic measurement facility (MM1) at the Advanced Photon Source. Prior to the measurement, the background field along the measurement bench was measured with a moving coil. Figure 2 shows the Earth's field distribution along the z-axis.

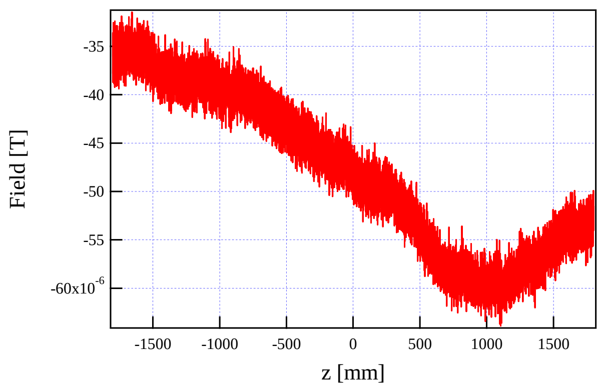


Figure 3: Earth's field distribution measured in MM1.

From this result, we can estimate the shielding effect by the μ-metal in an undulator based on the simulation result described in the previous section. Without the shield, the field, $B_y$, in an undulator due to the Earth's field is magnified by a factor of 2.4, i.e., $B_y = B_{EF} \times 2.4$. After applying the shield, the remaining field, $B_{yrem}$, is reduced by a factor of eight, i.e., $B_{yrem} = B_y/8$. Therefore, the signature of shield, $B_{sig}$, is: $B_{sig} = B_y - B_{yrem}$.

Figure 4 shows the signature of μ-metal shield. After measuring the undulator field without the shield, we can predict the field distribution with the shield by adding the shield signature to the raw data.

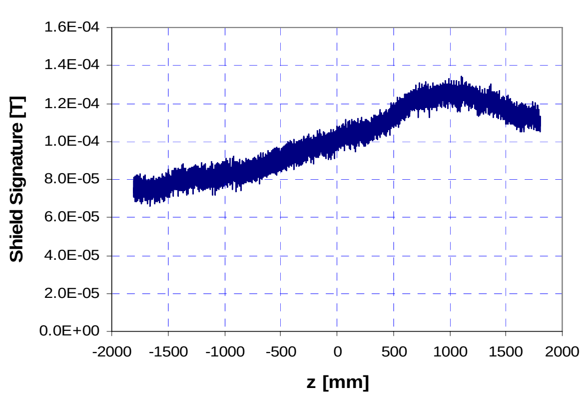


Figure 4: Signature of the μ-metal shield.

In Figure 5, the solid green curve is the second field integral of the raw data measured without the shield, and the blue broken curve is the prediction for after the shield is installed.

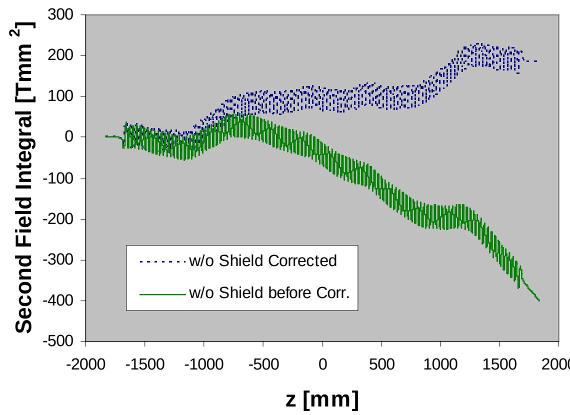


Figure 5: Second field integrals of raw data and corrected data.

Figure 6 shows the predicted second field integral and the integral measured after the shield was attached.

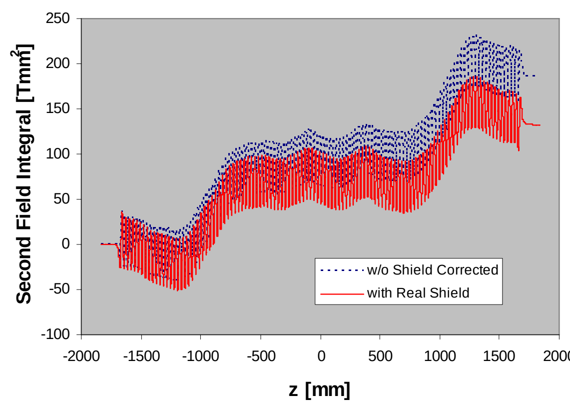


Figure 6: Second field integrals predicted from data without shield (blue broken line) and the data with the shield (red solid line), respectively.

The actual measured field data with the μ-metal shield is in good agreement with the corrected data based on simulation with a simple model.

## DISCUSSION AND SUMMARY

In the example shown in this paper, we applied additional trajectory shims and phase shims to straighten the trajectory and to reduce the phase error after applying the μ-metal shield. Also, we corrected the first and second field integrals by applying appropriate shims at the entrance and the exit ends of undulator. Figure 7 shows the trajectory after the final tuning with the shield. The net kick (corresponding to the first integral) and the net displacement (corresponding to the second field integral) are well below the tolerances as shown. Also, the trajectory excursion in the undulator is well below the tolerances (2 μm).

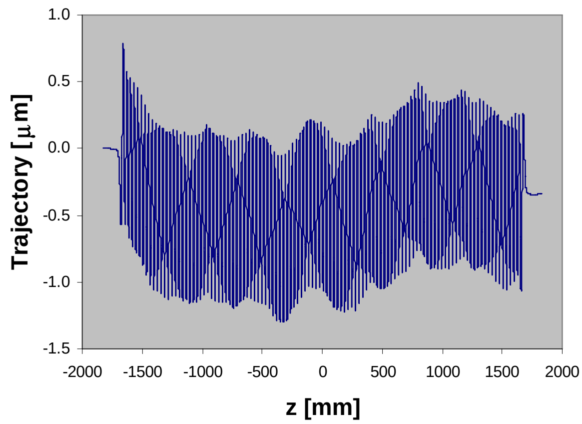


Figure 7: Trajectory of the first article undulator after final tuning.

In the example in this paper, we used the estimation procedures in a relatively early stage of the tuning process in order to demonstrate the effectiveness of this method. However, because the effectiveness of this method had been proven, we used it at the very end of the tuning process for the second article of LCLS undulators.

Here are the steps of the tuning procedures:

- Mechanically align an undulator to the Hall-probe measurement bench.
- Magnetically align the undulator axis to the Hall-probe.
- Set a proper gap by changing the thickness and/or the location of spacers (mechanical shims).
- Straighten the horizontal (x) trajectory by using trajectory shims.
- Minimize the phase errors by using phase shims.
- Straighten the vertical (y) trajectory.
- Apply shims to compensate multipoles.
- Apply μ-metal shield and do final measurements and tuning of field integrals.
- Do final fine tuning, if necessary.

## REFERENCES

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[3] O. Chubar, P. Elleaume, J. Chavanne, J. Synchrotron Radiat. **5**, 481 (1998).

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