A Problem With The HXU Full Gap Encoders

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Abstract

When making measurements on the first production LCLS-II hard x-ray undulator received by SLAC, we found that the residuals to the fit of K vs Gap were much larger than for the SXR undulators and outside the tolerance on setting K. An investigation led to the source of the problem being the full gap encoders. The present full gap encoders will not allow setting K within tolerance and they must be replaced. This note discusses these findings.

1 Introduction[1]

While making measurements on HXU-001, the first production hard x-ray undulator received at SLAC, it became apparent that the gap was not being set properly. The two encoder systems on the undulator, the full gap encoders and the half gap encoders, did not agree and the difference appeared random. In addition, the magnetic field in the undulator had large random tapers; and fits to the K value as a function of gap had residuals that far exceeded the K value tolerance. An investigation found that the full gap encoders were the source of the problem. Subsequent conversations with the encoder manufacturer by the undulator design team found that the encoders chosen did not have accuracy specifications that would let us meet our tolerances. The encoders need to be replaced. This note discusses the problem and how the errors affect the magnetic field in the undulators.

For the measurements presented in this note, the undulator gap was set using the full gap encoders. The control system reported the gap reading by the full gap encoders and also by the half gap encoders. The half gap encoders measure each strongback position relative to the girder. They measure at two different heights and are not appropriate for accurate gap measurements. Comparing the encoder readings and how each encoder system's gap values correlated to the magnetic field led to isolating the problem.

2 Requirements

The requirements for the hard x-ray undulators are specified in a Physics Requirements Document[2]. The requirement of interest for this note is that the accuracy for setting the K value is

$$\frac{\Delta K}{K} = \pm 2.3 \times 10^{-4} \tag{1}$$

[1]Work supported in part by the DOE Contract DE-AC02-76SF00515. This work was performed in support of the LCLS project at SLAC.

[2]H.-D. Nuhn, "Undulator System Physics Requirements Document", LCLSII-3.2-PR-0038-R3, June, 2017.

3 HXU Encoders

The hard x-ray undulators (HXU) have two sets of encoders. The full gap encoders measure the actual gap at the beam height. The half gap encoders measure the position of each strongback relative to the girder. The encoders on the upstream end are shown in figure 1. There is a similar set of encoders on the downstream end.

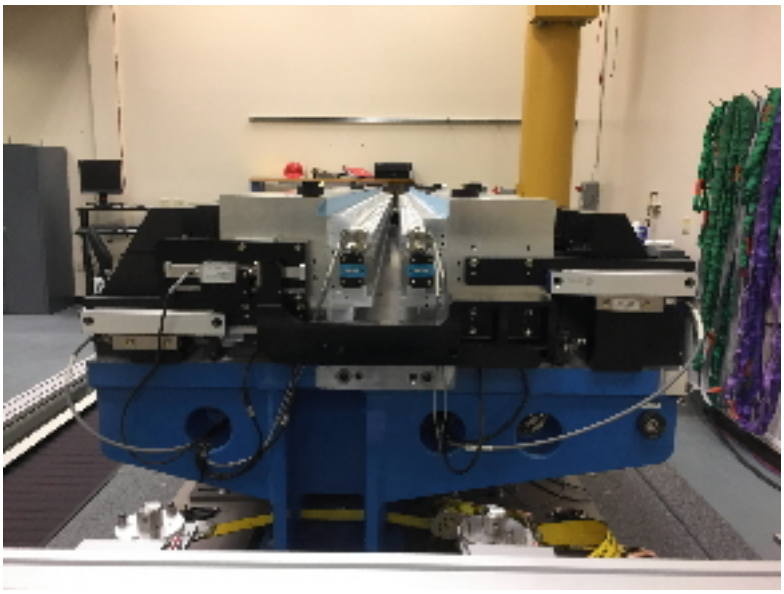

Figure 1: Photo showing the full gap encoder and the half gap encoders at the upstream end of HXU-017

A schematic of the encoders is shown in figure 2. Looking at the undulator from the upstream

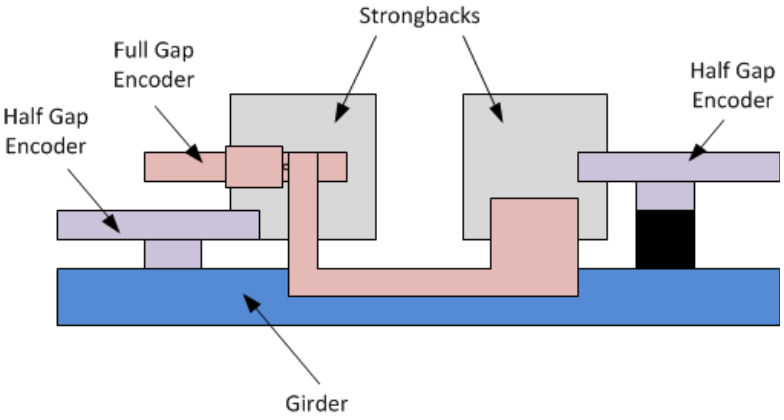

Figure 2: Schematic of the hard x-ray undulator and its encoders.

end, there is a half gap encoder on the right strongback. It is at the beam height. There is also a half gap encoder on the left side. It is at the bottom of the strongback. The half gap encoders do not measure the gap and they measure at different heights. The left encoder reading

can be significantly different than a reading at the beam height if the strongback has roll. Both half gap encoders measure relative to the girder so that girder deformations which affect the gap are not measured by the half gap encoders. The girder deforms when the magnetic forces on the strongbacks are large and bend the girder. For instance, a bend in the center of the girder affects the gap but is not seen by the half gap encoders.

The full gap encoder measures across the gap at the beam height. In principle, it provides a proper gap measurement. Of course, if the full gap encoders have errors, these will be reflected in the undulator gap when the control system uses the full gap encoders to set and read the gap.

4 Gap Measurements By The Full And Half Gap Encoders

There is a significant difference in the gap measurement by the full gap encoders and the value given by the sum of the half gap encoders. The plot in figure 3 shows the difference between the full gap encoder reading and the sum of the half gap encoder readings plotted as a function of gap. The

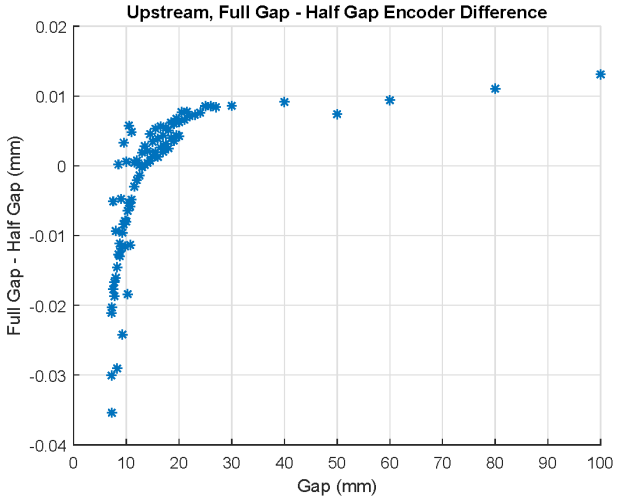

Figure 3: Difference between the full gap encoder reading and the sum of the half gap encoder readings as a function of gap.

plot shows a significant difference in the two gap measurements, over 30 μm, at small gap. This is due to the girder bending and the strongbacks rolling due to the magnetic forces. This is expected since the half gap encoders do not accurately measure girder bending and strongback roll, so their sum should not give the true gap at the beam height. A smooth difference in the full gap and half gap readings in the plot is expected.

In addition to the smooth trend in the plot, however, there is significant noise in the points. The noise is large, indicating a problem in one of the encoder systems. The noise is the source of the problems which are the subject of this note.

5 K vs Gap

The measured K value of the undulator as a function of gap is shown in figure 4. The full gap encoders were used by the control system to set the gap, and the measured gap comes from the full gap encoders. Also shown in the plot is a spline fit to alternate points. The spline fit goes through

the points used in the fit. The residuals of the points not used in the fit give an estimate of how well the fit interpolates between the measured points.

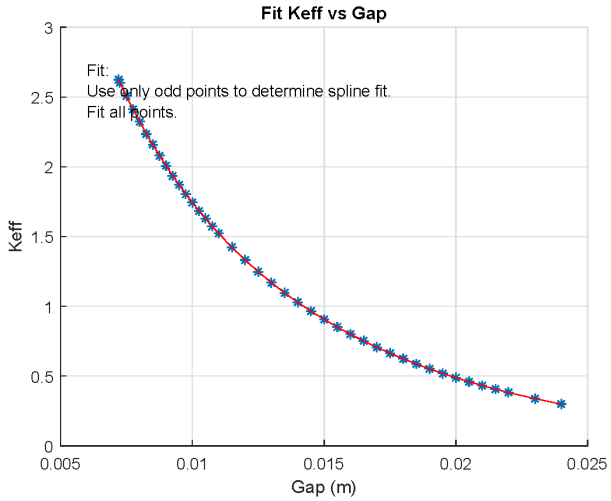

Figure 4: Plot of K vs Gap. A spline fit to alternate points is also shown.

The residuals to the fit of K vs gap are shown in figure 5. Note that the residuals far exceed the tolerance on K. This is a significant problem. The fit can not be used to set the K value of the undulator within tolerance.

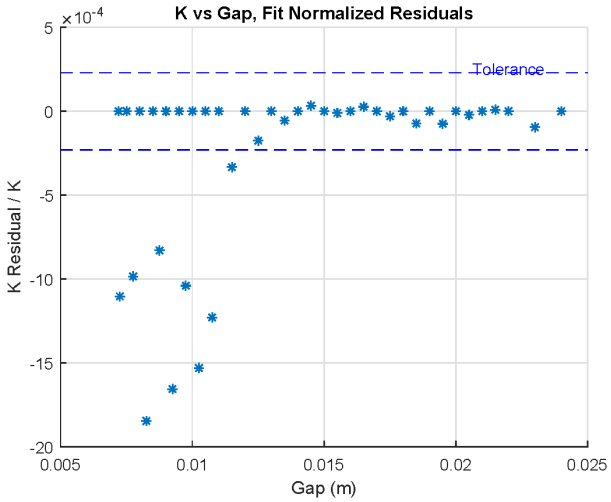

Figure 5: Residuals to the spline fit of K vs gap using alternate measurement points.

Now suppose we take the data from the previous measurements and fit K vs gap using the gap determined from the half gap encoders. When this is done, the residuals are an order of magnitude smaller than when the full gap encoders are used for the fit. The residuals using the half gap encoders are shown in figure 6. The residuals are only slightly larger than what we find for the SXR undulators.

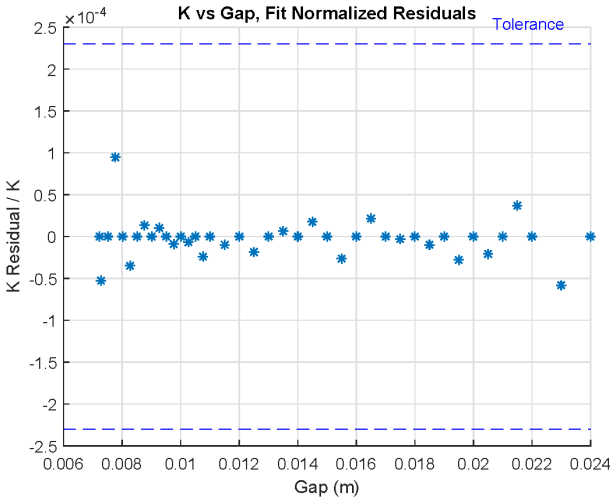

Figure 6: Residuals using the data from the measurements above, but using the half gap encoders to calculate the gap.

The fact that the half gap encoders give smaller residuals raises the suspicion that the full gap encoders have errors. The full gap encoders are likely responsible for the noise in the plot of the difference between the full gap encoders and the half gap encoders. The conclusion that the full gap encoders are the source of the noise is confirmed by correlating the taper in the peak fields to the taper in the encoder readings. This is done in the next section.

6 Field Taper

When the gap was set using the full gap encoders, there was taper in the magnetic field. This is illustrated in figure 7. The taper was random and was not correlated to the full gap encoder readings. This is illustrated in figure 8. Since the full gap encoders were used to set the gap, they report a taper on the micron level, essentially no taper. The field taper, however, is large and appears at random gaps.

When the field taper is plotted against the taper reported by the half gap encoders, there is a strong correlation. This is illustrated in figure 9. The taper reported by the half gap encoders was up to 15 μm. The taper was real because it was in the magnetic field, and it was being accurately measured by the half gap encoders and not by the full gap encoders. The full gap encoders do not accurately correspond to the magnetic field. The full gap encoders are the source of the errors preventing accurate fits to the K value.

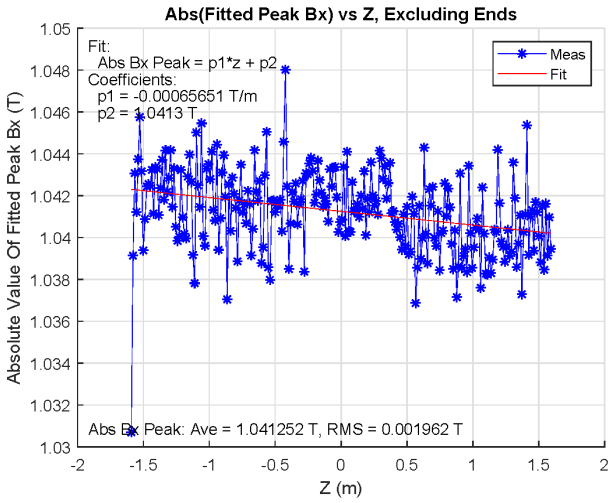

Figure 7: There was taper in the magnetic field when the full gap encoders were used to set the gap.

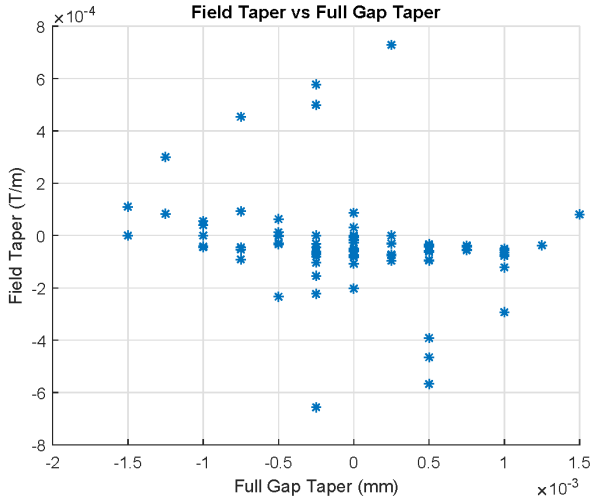

Figure 8: There is no correlation between the taper in the magnetic field and the taper from the full gap encoders.

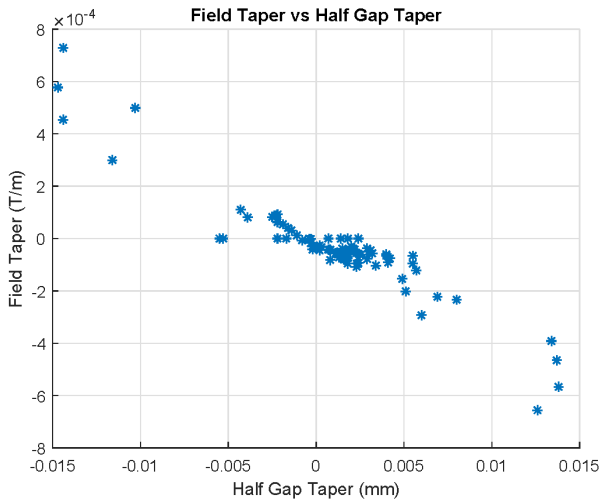

Figure 9: There is a strong correlation between the taper in the magnetic field and the taper reported by the half gap encoders.

7 Conclusion

The full gap encoders on HXU-001 do not give measurements that correlate with the measured magnetic field. When the full gap encoders are used to set the gap, the fit to K vs gap has residuals that far exceed the tolerance on K. The full gap encoder system will not let us set the K value within tolerance.

After these measurements, subsequent investigation showed that the problem is not unique to HXU-001. The undulator design team at LBNL contacted the full gap encoder manufacturer who confirmed that the accuracy of the chosen encoders is not sufficient for our needs. Interferometer tests on another spare encoder confirmed this. With insufficient accuracy, the full gap encoders must be replaced.

Acknowledgements
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