Repeat Measurements Of SXU-001 At The End Of Production SXU Measurements

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Abstract

The LCLS-II SXR undulators are stored in building 81 after they are tuned and after the final data set has been measured. The storage area has only modest temperature control, so there is concern that the undulator calibration may change during their time in storage. In this note we document the repeat measurements made at the end of production SXU measurements of SXU-001 after it had been in storage for twenty months.

1 Introduction[1]

The LCLS-II SXR undulators are tuned and calibrated in the Magnetic Measurement Facility (MMF). The temperature in the MMF is stable at 20 ± 0.1 deg C. After calibration, the undulators are moved to a storage area with very modest temperature control. It must be verified that the temperature excursions in the storage area do not change the undulator calibrations.

The LCLS-I project experienced significant changes to the calibration of the undulators during storage[2]. Most of the undulators had to be remeasured and afterward handled with much attention to their ambient temperature. We wish to know as soon as possible if the LCLS-II project has similar problems.

LCLS-II undulator SXU-001 was initially calibrated as Dataset 1 on 8/11/2017. It was remeasured as Dataset 2 on 2/27/2018 after spending 6 months in storage. Essentially no change was seen in the undulator[3]. SXU-001 was the first undulator tuned and calibrated. After its initial calibration, some changes were made to the test plan. After Dataset 2, some shims were applied to improve the initial tuning and a new calibration was made according to the updated test plan. The new calibration was made in Dataset 3 on 3/1/2018. The undulator then went to storage for another 6 months. On 9/19/2018, Dataset 4 was taken

[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]Z. Wolf, Y. Levashov, E. Reese, "Undulator Changes Due To Temperature Excursions", LCLS-TN-08-8, September, 2008.

[3]Z. Wolf and Y. Levashov, "Repeat Measurements Of SXU-001 After Six Months In Storage", LCLS-TN-18-3, March, 2018.

and essentially no change was seen in the undulator [4]. The undulator then went to storage for another 6 months. On 3/7/2019, Dataset 5 was taken to see if the undulator changed during the latest 6 months in storage. Changes in the K value at the level of the tolerance were observed. Production SXU measurements were about to end, and SXU-001 would be measured again at the end of production. On 5/15/2019, Dataset 6 was taken and it essentially agreed with Dataset 5. This note documents the measurements made in Datasets 3 and 6 to look for any changes which may have occurred to the undulator in storage.

2 Measurement Requirements

In order to set a scale for the relevance of any changes to the undulator, we list the primary requirements that the SXR undulators must meet[5]. The undulator will be primarily tuned at a gap of 10 mm, but the requirements must be met for all gaps in the operating range of 7.2 to 22 mm.

1. The K value must be known to $\pm 3 \times 10^{-4}$ at all gap settings. The K value will be measured at a discrete set of gaps. A fit to the measured K value vs. gap data must allow K values at intermediate points to be known within the tolerance given here. This requirement sets the density of the measurements as a function of gap.
2. The phase shake in each undulator must be less than 5 degrees rms.
3. The total phase advance in the 4.400000 meter long cell must be known to ± 10 degrees.
4. The phase matching error at both the entrance and the exit of the undulator must be less than ± 7 degrees.
5. The first field integral of B_x and B_y must be within $\pm 40 \times 10^{-6}$ Tm. The second field integral of B_x and B_y must be within $\pm 150 \times 10^{-6}$ Tm^2.
6. The undulator temperature at which all measurements are performed must be 20.0 ± 0.1 degrees Celsius.

3 Measurement Results

3.1 Temperature During Storage

SXU-001 was stored with a temperature logger nearby recording the ambient temperature. Figure 1 shows the ambient temperature of the storage area. During the time of the temperature measurements shown in the plot, from 10/26/2017 to 3/18/2019, the ambient

[4] Z. Wolf and Y. Levashov, "Repeat Measurements Of SXU-001 After Twelve Months In Storage", LCLS-TN-18-8, October, 2018.
[5] H. D. Nuhn et al., "Undulator System Requirements", LCLS-II Physics Requirements Document LCLSII-3.2-PR-0038-R2.

temperature varied from approximately 15.0 deg C to 27.7 deg C. The temperature record for the previous 6 months is given in another note[6], and is very similar.

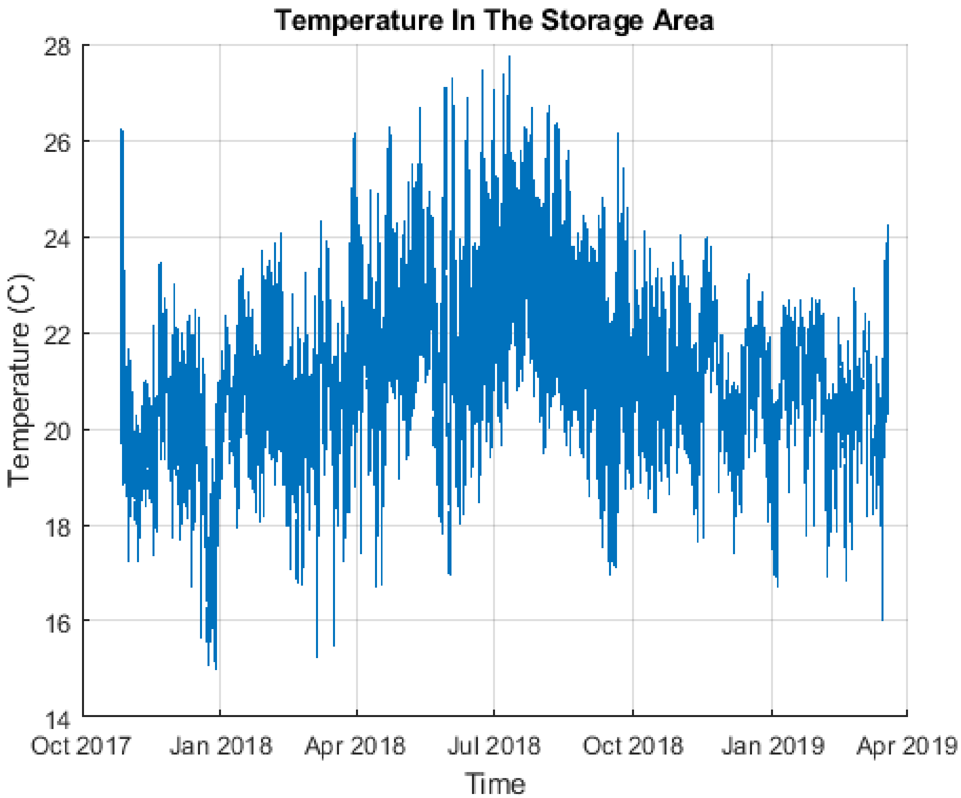

Figure 1: Ambient temperature in the storage area.

3.2 Measurements At The Tuning Gap

The Dataset 3 measurements of SXU-001 were made on 3/1/2018 and the Dataset 6 measurements were made on 5/15/2019. Measurements were made at many gaps, but in this section we compare measurements at the 10 mm tuning gap. The undulator temperature during the 3/1/2018 measurements was 20.11 deg C and the undulator temperature during the 5/15/2019 measurements was 20.02 deg C. Figure 2 shows a comparison of the B_y peak field measurements through the core of the undulator. The difference in the peak fields is shown in figure 3. The difference is about 3.5 Gauss, which is 3.0×10^{-4} of the average peak field.

The K value on 3/1/2018 was 4.244130, and the K value on 5/15/2019 4.245487. The relative change in the K value is 3.2×10^{-4}. The undulator gap was different for these two measurements, however. The gap on 3/1/2018 was 10.0012 mm, and the gap on 5/15/2019

[6] Z. Wolf and Y. Levashov, "Repeat Measurements Of SXU-001 After Twelve Months In Storage", LCLS-TN-18-8, October, 2018.

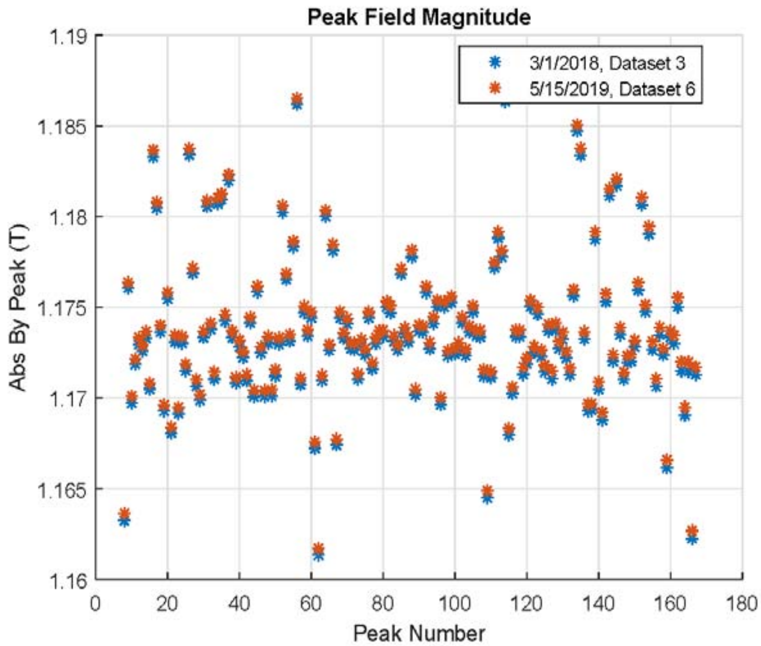

Figure 2: B_y peak fields for the measurements before and after the latest fourteen months in storage.

was 10.0005 mm. The 0.7 μm gap decrease in Dataset 6 accounts for 1.1×10^{-4} of this change. So the difference in K value still to be accounted for is 2.1×10^{-4}. A further discussion of the change in K value between datasets is presented below when the gap dependence of the K value is presented.

A comparison of the second B_x field integral is shown in figure 4, and a comparison of the second B_y field integral is shown in figure 5. The second field integrals are proportional to the beam trajectories. In both cases, the changes are small.

The phase errors at the tuning gap for the two data sets is shown in figure 6. The difference is insignificant.

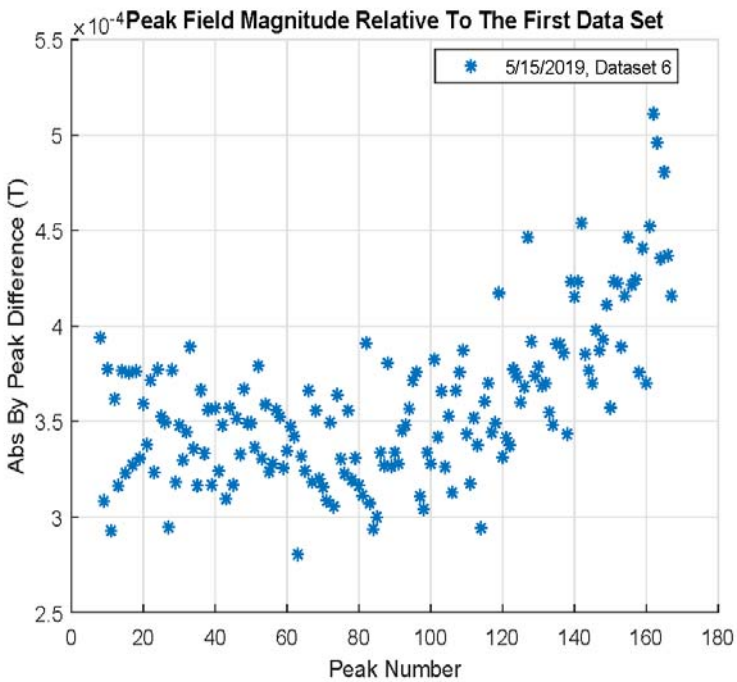

Figure 3: Difference in the peak fields.

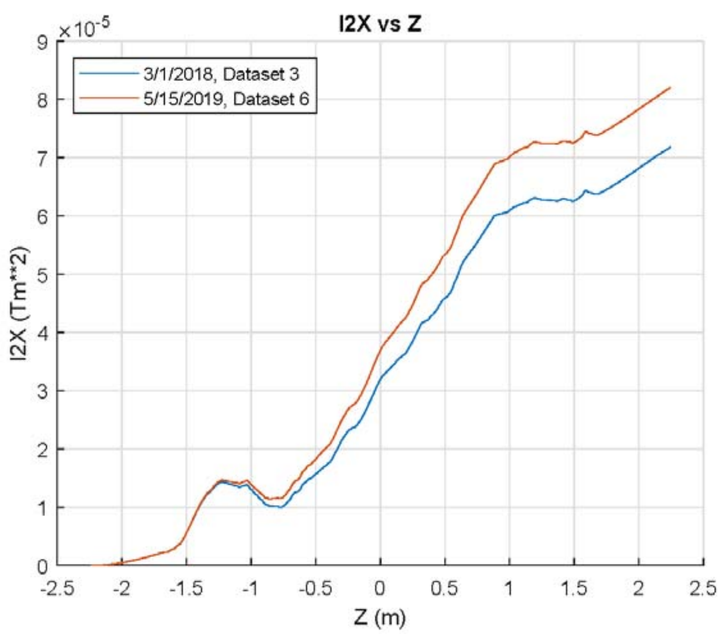

Figure 4: Comparison of the second integral of B_x.

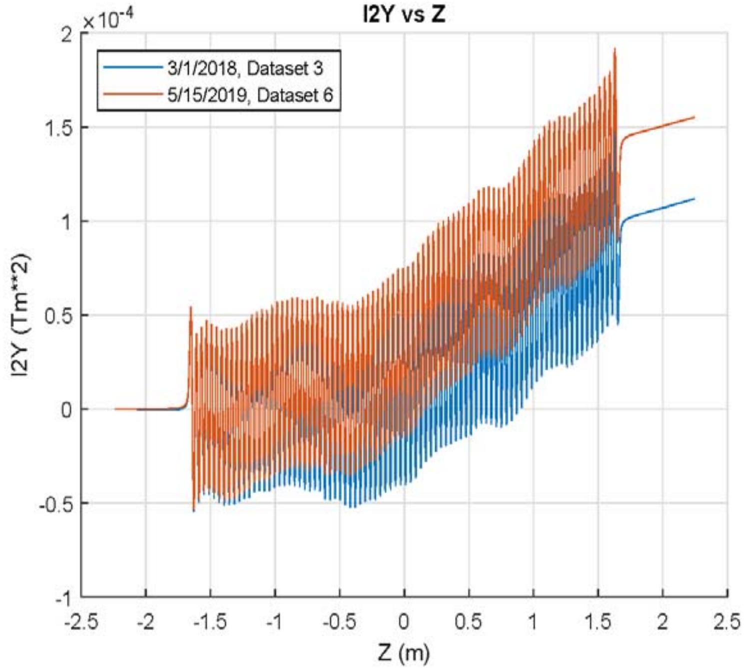

Figure 5: Comparison of the second integral of B_y.

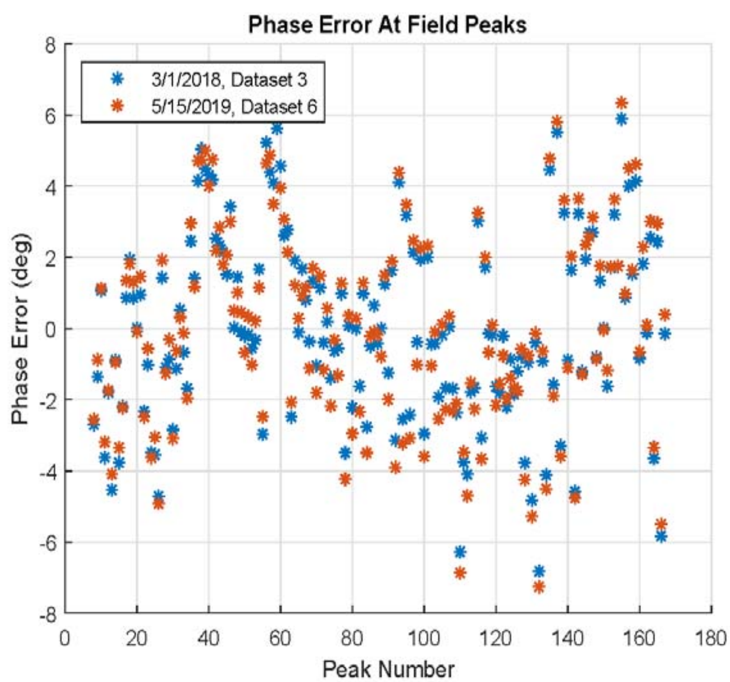

Figure 6: Comparison of the phase errors in the two data sets.

3.3 Measurements As A Function Of Gap

During each dataset, measurements were made at many gaps. In this section we summarize the changes in K value, phase matching, and field integrals as a function of gap.

3.3.1 K Value

Figure 7 shows the difference (Dataset 6 - Dataset 3) in K values as a function of gap. In order to account for small variations in undulator gap, the plot shows the Dataset 6 K-value minus the fitted Dataset 3 K-value at the Dataset 6 gap. The change in K is at the tolerance limit of 3×10^{-4} of its value. Possible reasons for the change in K value are due to gap changes, temperature differences, and Hall probe calibration changes. We discuss these possibilities in turn. We believe that the K value changes can be accounted for without assuming that the undulator changed during storage.

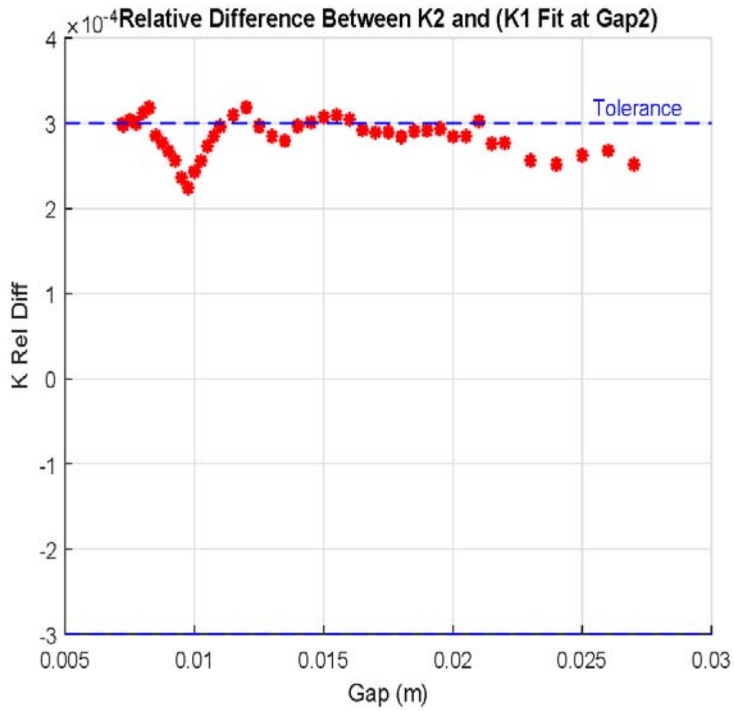

Figure 7: Difference in the K value before and after storage as a function of gap.

The undulator gap was measured with capacitive sensors at several poles. The sensors showed no significant change from one dataset to the next. Figure 8 shows the change in the gap measured at four poles, two poles at each end of the undulator, using capacitive sensors. The measured gap was 46.6 mm, which is outside the operating range of the undulator, but the change in gap from one dataset to the next is typically below 1 micron. It is believed that changes in the undulator gap, for instance due to encoder errors, are not responsible for the main changes in the K value. They can explain, however, some small changes in K value.

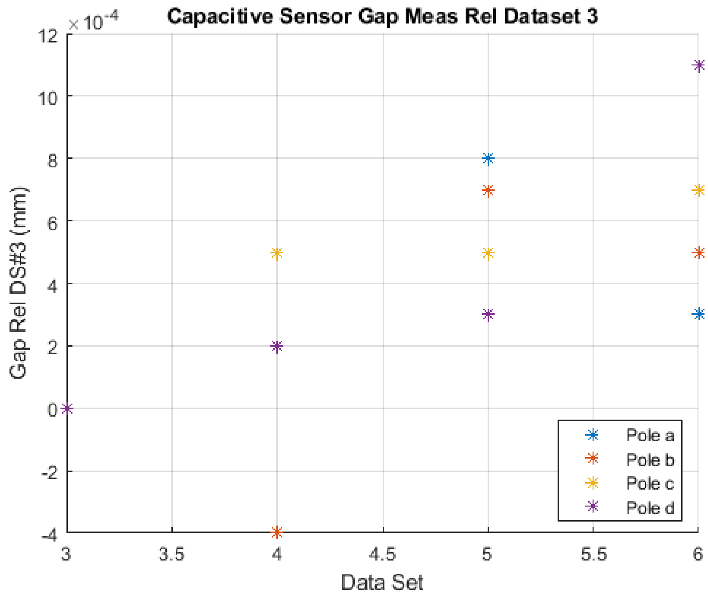

Figure 8: The change in undulator gap relative to dataset 3 is typically below one micron. A gap of 46.6 mm was used for these measurements.

The "V" shape in figure 7 appears to come from small distortions in the undulator gap that vary with time. Figure 9 shows the change in the absolute value of the peak field strengths relative to Dataset 3. The left plot is for 9 mm gap, and the right plot is for 15 mm gap. At 9 mm gap, the change in the absolute value of the peak fields at the exit end is larger than at the entrance end. At 15 mm gap, the entrance end change is larger. There appears to be a small uncontrolled taper in the undulator that changes with time. We believe this is responsible for the shape of figure 7. The shape is not due to temperature changes during the measurements since the magnet keepers only changed temperature by 0.02 deg C during the measurements for each dataset.

A temperature difference between datasets 3 and 6 may explain part of the 3×10^{-4} difference in K values. The temperature is 0.1 deg C cooler in Dataset 6 compared to Dataset 3. Nominally, this would make the undulator magnets increase in strength by $\Delta B/B = 1 \times 10^{-4}$, but the effect of temperature on the undulator K value has not been measured yet. The temperature difference likely explains some fraction of the K value difference.

We believe the majority of the K value difference between datasets 3 and 6 is due to Hall probe calibration drift. The Hall probe is compared against an NMR probe in a reference dipole magnet for every undulator that is measured. When the Hall probe calibration drifts by about 1/3 of the tolerance, the probe is recalibrated. Figure 10 shows the history of the comparison of the Hall probe to the NMR probe.

The Hall probe was calibrated on 4/18/2018 and this point is shown in the figure. We take this point as a reference to subtract out small differences in the Hall probe and NMR

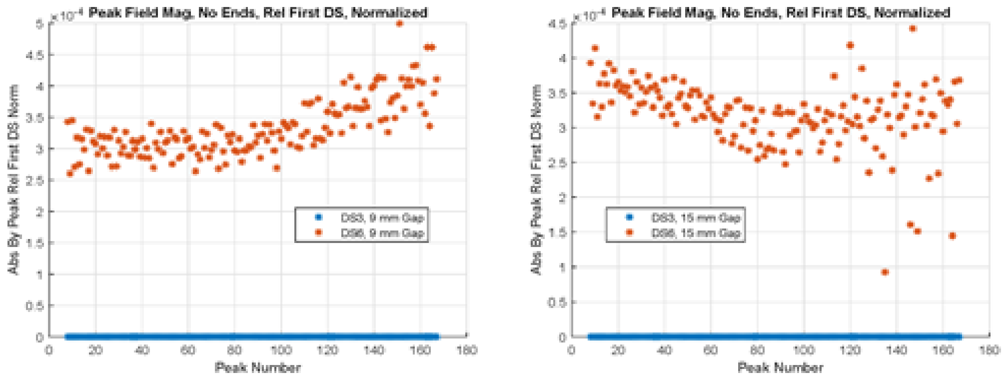

Figure 9: Difference in the absolute value of the peak fields, dataset 6 minus dataset 3, normalized to the dataset 3 peak fields. The left plot is for 9 mm gap, and the right plot is for 15 mm gap.

measurements due to the different locations that the probes measure at.

The comparison of the Hall probe and NMR probe measurements for datasets 3 and 6 are shown in the figure. Between the jump in the difference due to the Hall probe calibration and the normal drift in the calibration, datasets 3 and 6 were measured when the calibration had changed by about 2×10^{-4}. We believe this is the primary reason why the K values of datasets 3 and 6 differ. The remainder of the difference is due to the different undulator temperature.

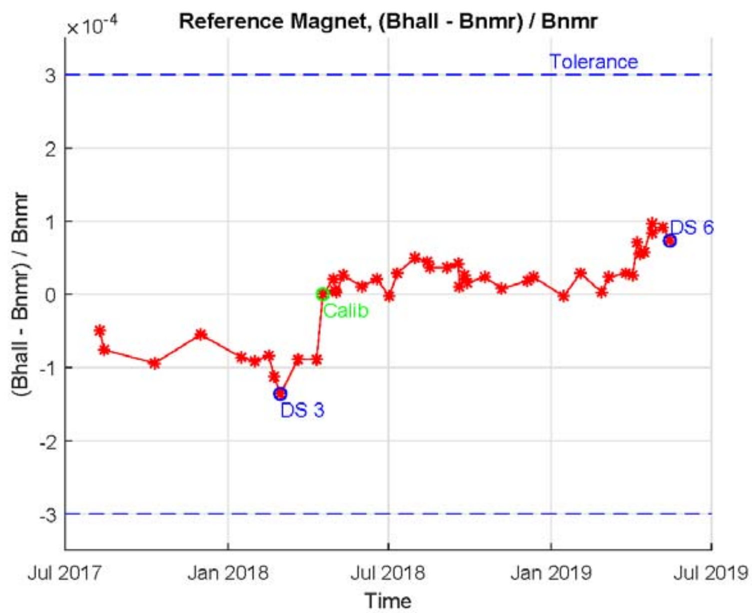

Figure 10: Comparison of Hall probe to NMR measurements of a reference dipole over time.

3.3.2 Phase Matching

Figure 11 shows the difference (Dataset 6 - Dataset 3) in the cell phase as a function of K. The measured K value for each dataset was used to calculate phase. The operating range of the undulator extends from $K = 1.4$ (gap = 22 mm) to $K = 5.8$ (gap = 7.2 mm). Figure 12 shows the difference in the phase matching error at the undulator entrance as a function of K. Figure 13 shows the difference in the phase matching error at the undulator exit as a function of K. The difference in all phase matching errors are below one degree and are well within the tolerance.

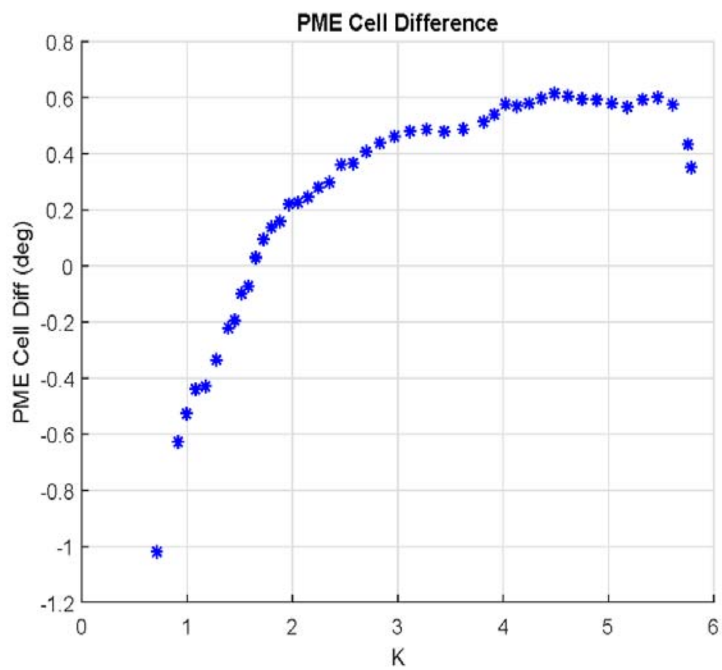

Figure 11: Difference in the spline fits to the cell phase as a function of K.

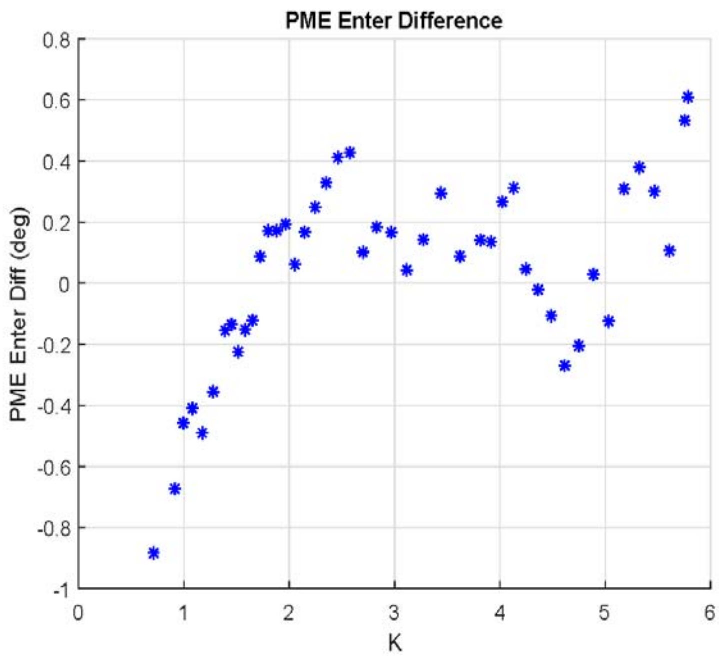

Figure 12: Difference in the spline fits to the phase matching error at the undulator entrance as a function of K.

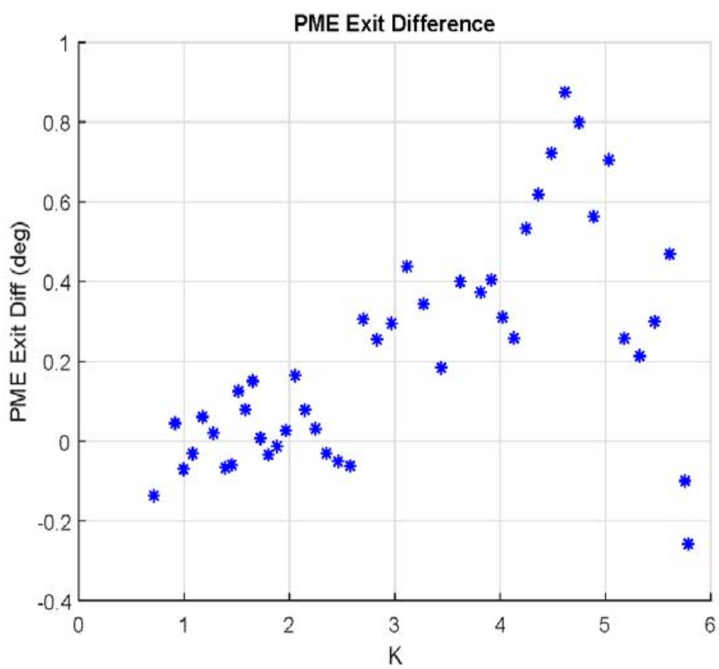

Figure 13: Difference in the spline fits to the phase matching error at the undulator exit as a function of K.

3.3.3 Field Integrals

The field integrals only changed a small amount during the storage. The differences are most likely explained by changes in the straightness of our measurement coil. Figure 14 shows the measurements of the first integral of B_x. Figure 15 shows the measurements of the first integral of B_y. Figure 16 shows the measurements of the second integral of B_x. Figure 17 shows the measurements of the second integral of B_y. Changes in the field integrals are small and well within the tolerance.

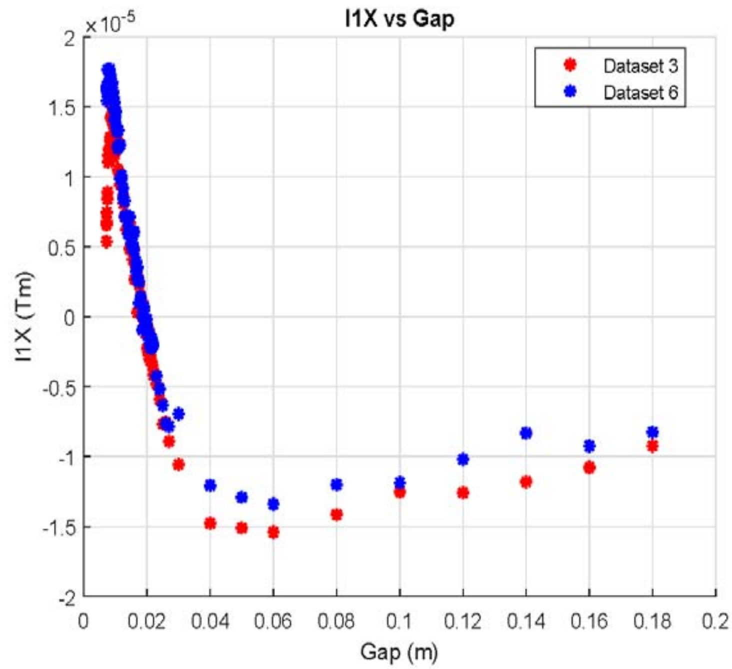

Figure 14: Comparison of the measurements of the first integral of B_x.

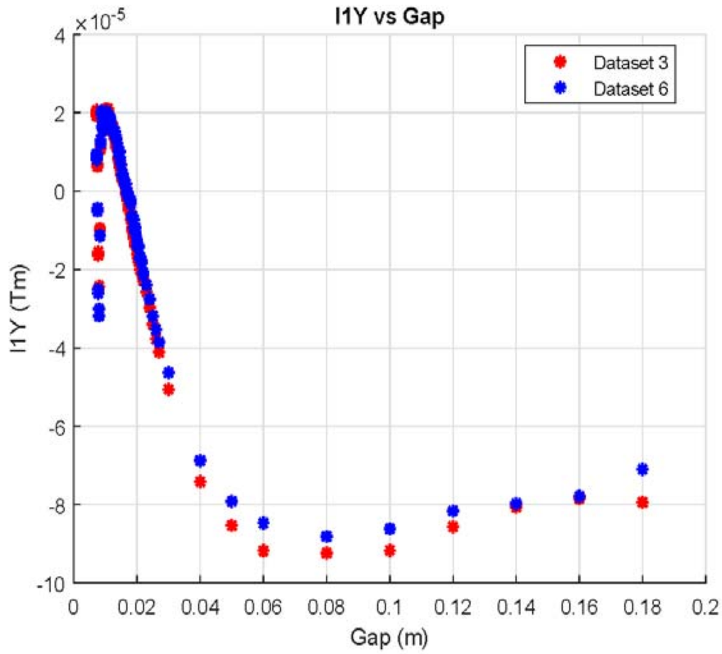

Figure 15: Comparison of the measurements of the first integral of B_y.

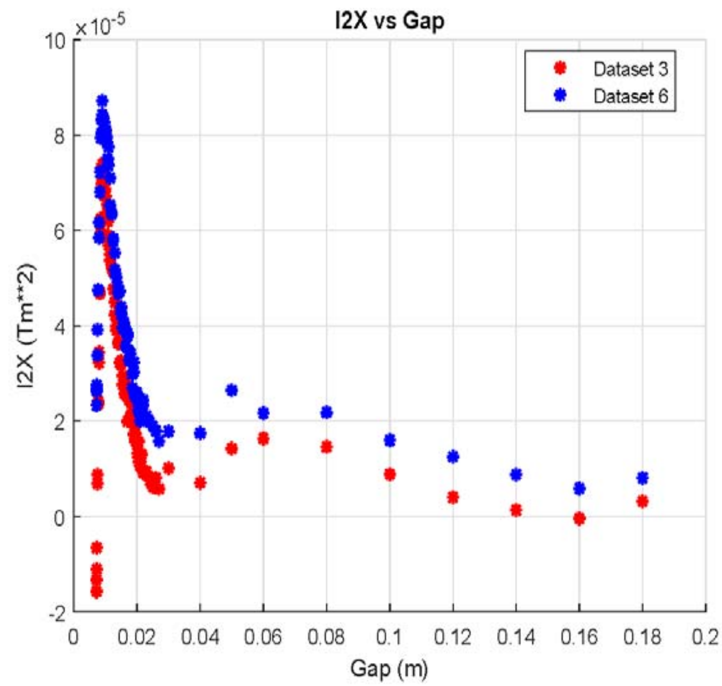

Figure 16: Comparison of the measurements of the second integral of B_x.

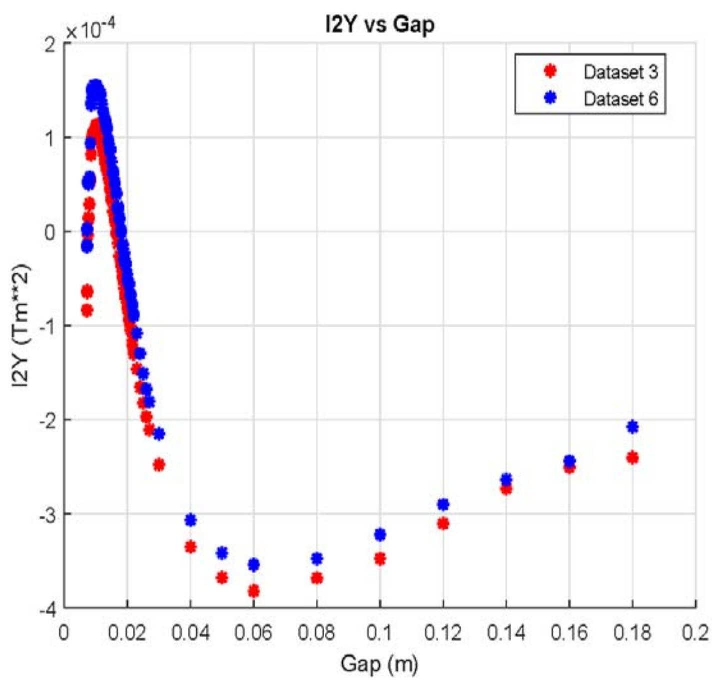

Figure 17: Comparison of the measurements of the second integral of B_y.

4 Conclusion

Measurements were made of SXU-001 at the beginning and at the end of the production SXU measurements. The K value changed at the tolerance limit, but the likely reason is a combination of the Hall probe calibration change and the colder temperature of this last dataset. Once the K value temperature coefficient is measured, the effect of temperature changes can be compensated for. All other quantities showed changes well within tolerance.

Acknowledgements
Many thanks to Heinz-Dieter Nuhn for valuable discussions about this note.