# Repeat Measurements Of SXU-001 After Twelve Months In Storage

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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 of SXU-001 after it has been in storage for twelve 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 $20 \pm 0.1$ 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 to see if the undulator changed during the latest 6 months in storage. This note documents

[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.

the measurements made in Datasets 3 and 4 and looks for any changes during the last 6 months 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[4]. 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 $\pm 10$ degrees.

4. The phase matching error at both the entrance and the exit of the undulator must be less than $\pm 7$ 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 $20.0 \pm 0.1$ 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 3/16/2018 to 9/25/2018, the ambient temperature varied from approximately 15.5 deg C to 27.7 deg C. The temperature record for the previous 6 months is given in another note[5], and is very similar.

[4] H. D. Nuhn et al., "Undulator System Requirements", LCLS-II Physics Requirements Document LCLSII-3.2-PR-0038-R2.

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

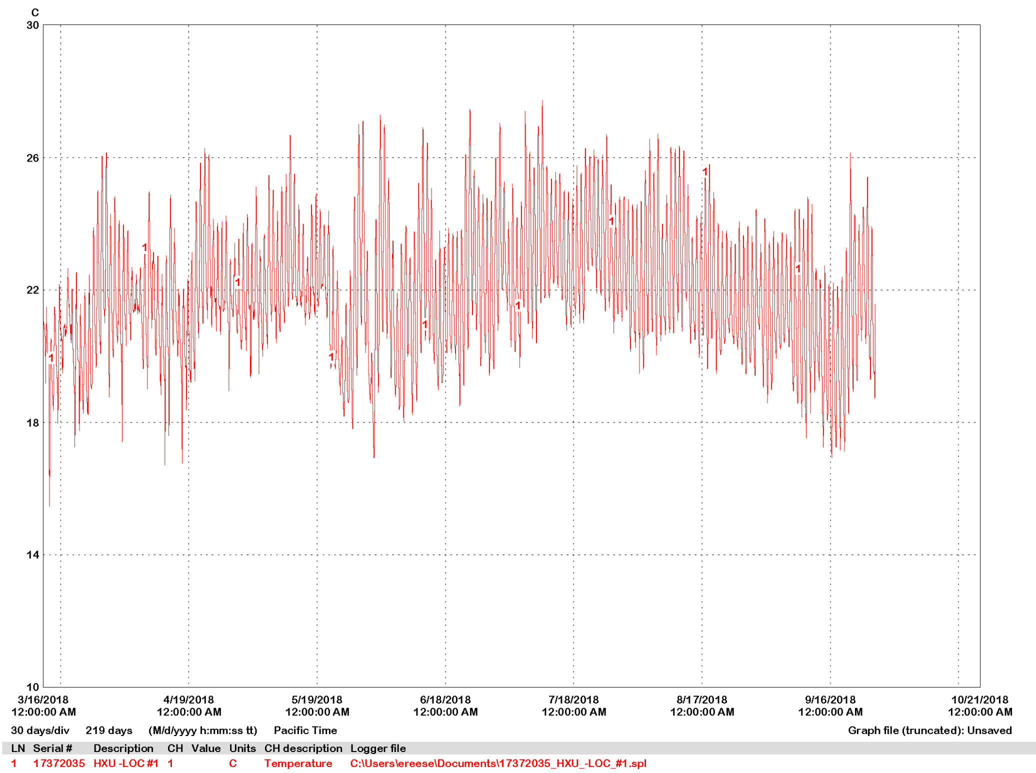


Figure 1: Ambient temperature in the storage area.

### 3.2 Measurements At The Tuning Gap

The Dataset 3 measurements of SXU-001 were made on 3/1/2018 and the Dataset 4 measurements were made on 9/19/2018. 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 9/19/2018 measurements was 20.09 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

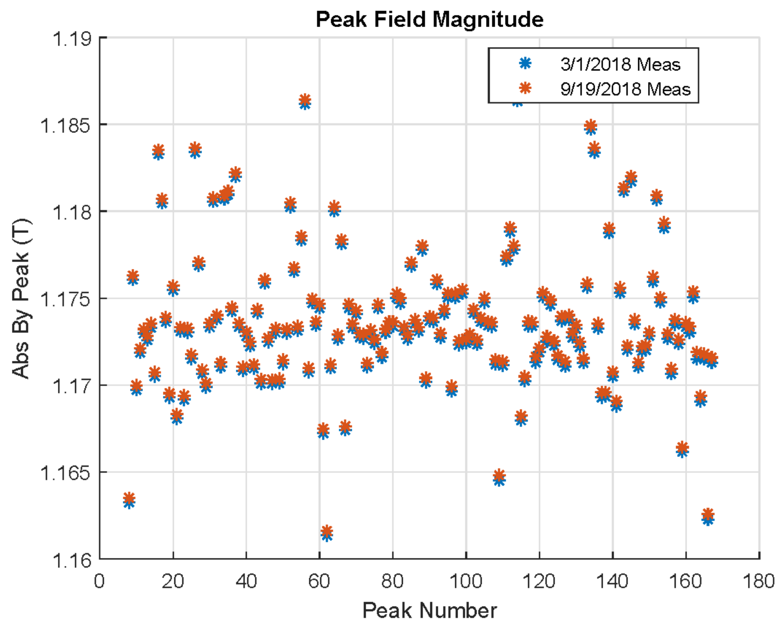


Figure 2: $B_y$ peak fields for the measurements before and after the second six months in storage.

shown in figure 3. The difference is about 2.6 Gauss, which is $2.2 \times 10^{-4}$ of the average peak field. The K value on 3/1/2018 was 4.244130, and the K value on 9/19/2018 was 4.245063, a relative change of $2.2 \times 10^{-4}$.

It should be noted that the Hall probe was calibrated on 4/18/2018 and after the calibration, the K value of the reference undulator increased by $\Delta K/K = 9 \times 10^{-5}$. A significant fraction of the relative change in K in SXU-001 is likely due to this Hall probe calibration, and not a change in the undulator. All changes mentioned are within the specification.

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.

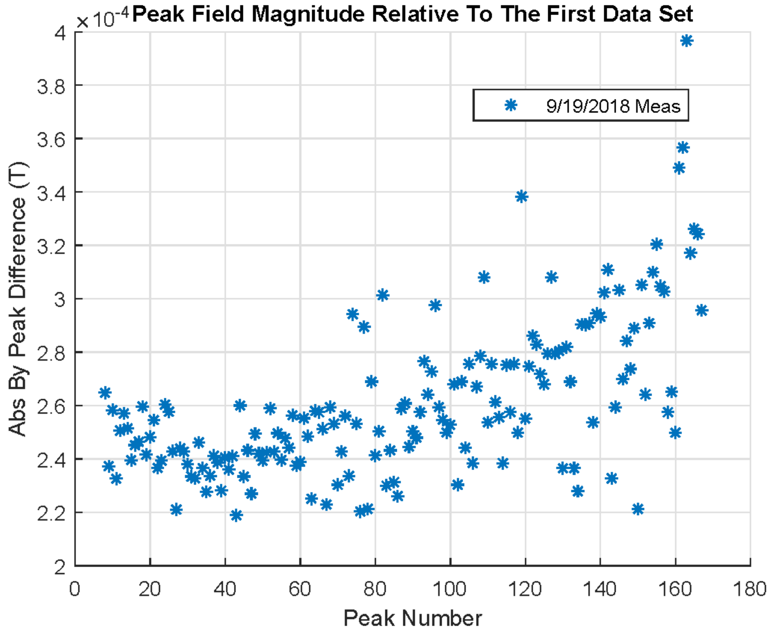


Figure 3: Difference in the peak fields.

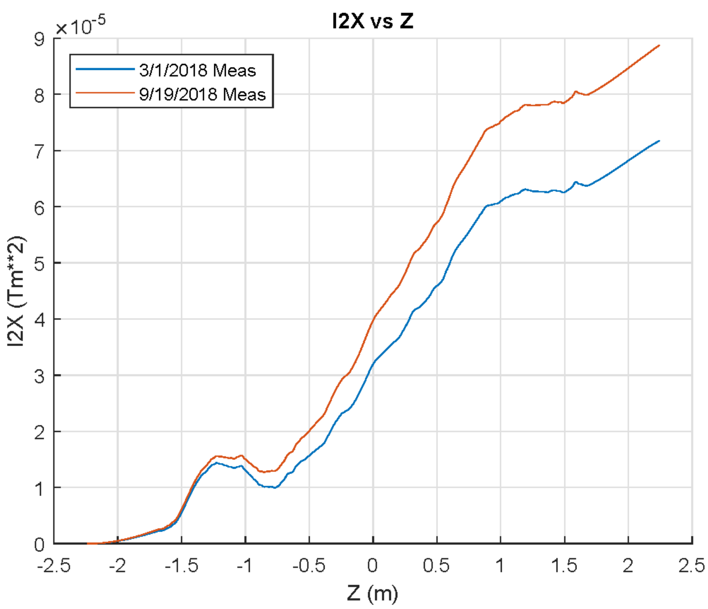


Figure 4: Comparison of the second integral of $B_x$.

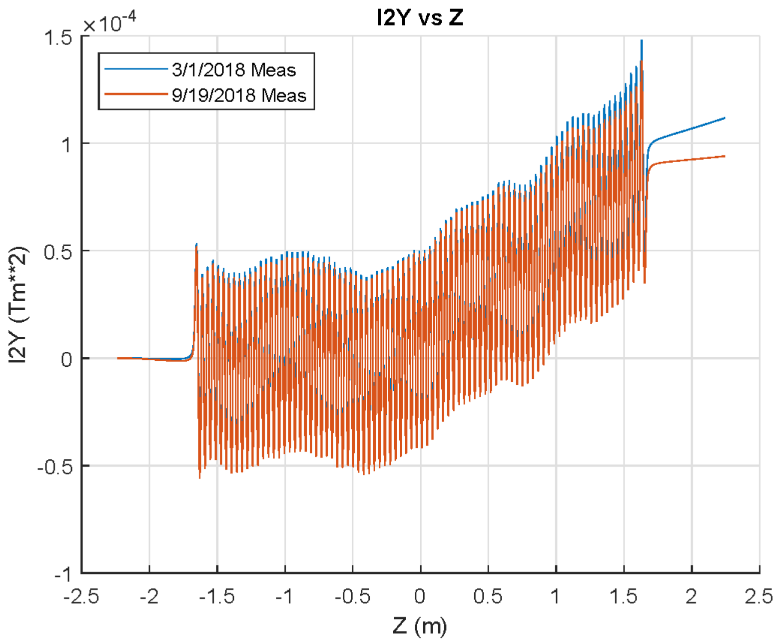


Figure 5: Comparison of the second integral of $B_y$.

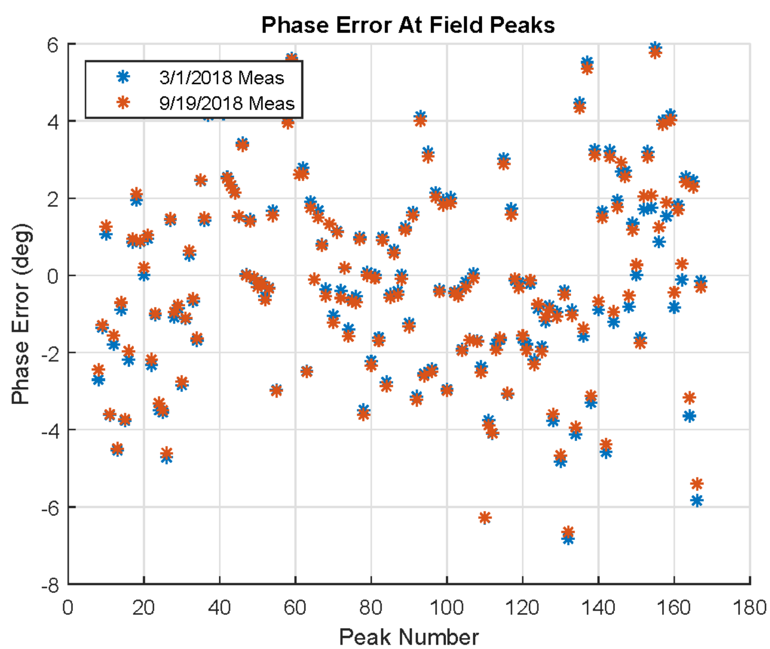


Figure 6: Comparison of the phase errors in the two data sets.

### 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 error, and field integrals as a function of gap.

The primary concern is that during storage the K value of the undulator might change. Figure 7 shows the difference (initial - final) in spline fits to the K values as a function of gap. The change in K is within the tolerance.

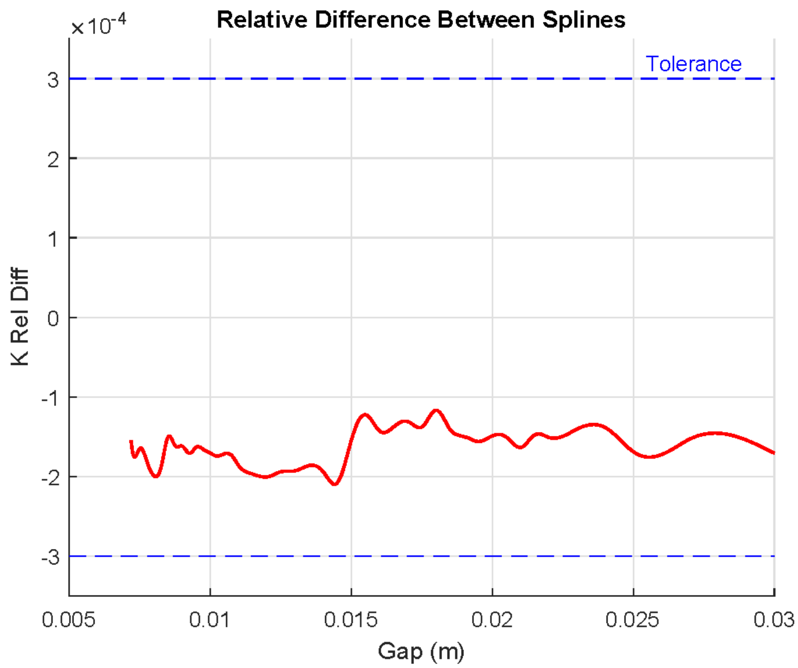


Figure 7: Difference in the K value before and after storage as a function of gap.

Changes in phase matching are also a concern. Figure 8 shows the difference (initial - final) in the spline fits to the cell phase as a function of K. The operating range of the undulator extends from $K = 1.4$ (gap = 22 mm) to $K = 5.8$ (gap = 7.2 mm). Figure 9 shows the difference in the spline fits to the phase matching error at the undulator entrance as a function of K. Figure 10 shows the difference in the spline fits to the phase matching error at the undulator exit as a function of K. In the operating range, the difference in all phase matching errors are small and well within the tolerance.

The field integrals remained fairly constant during the storage. The differences are most likely explained by changes in the straightness of our measurement coil. Figure 11 shows the measurements of the first integral of $B_x$. Figure 12 shows the measurements of the first integral of $B_y$. Figure 13 shows the measurements of the second integral of $B_x$. Figure 14 shows the measurements of the second integral of $B_y$. Changes in the field integrals are small and well within the tolerance.

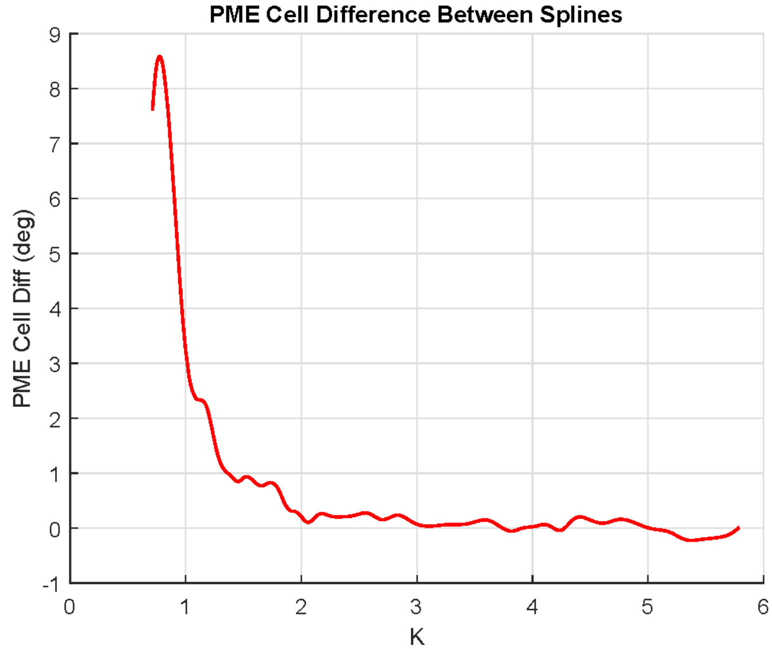


Figure 8: Difference in the spline fits to the cell phase as a function of K.

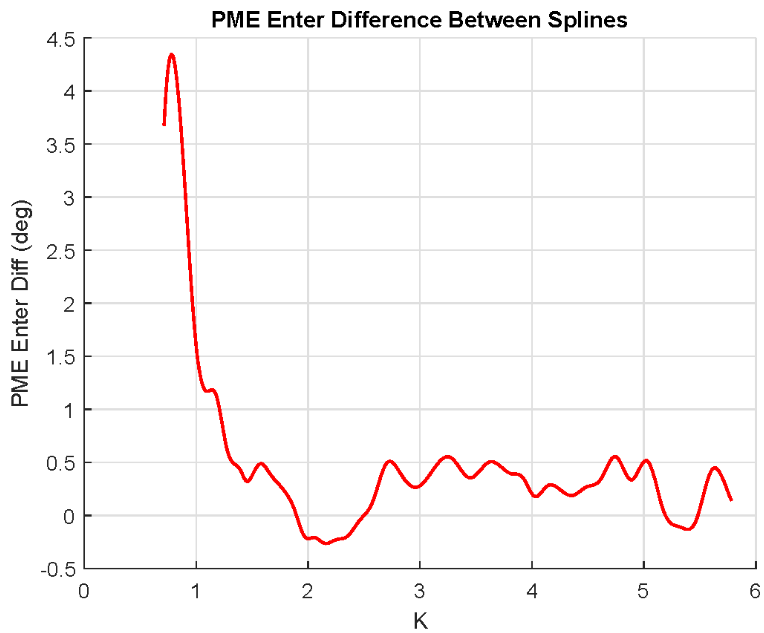


Figure 9: Difference in the spline fits to the phase matching error at the undulator entrance as a function of K.

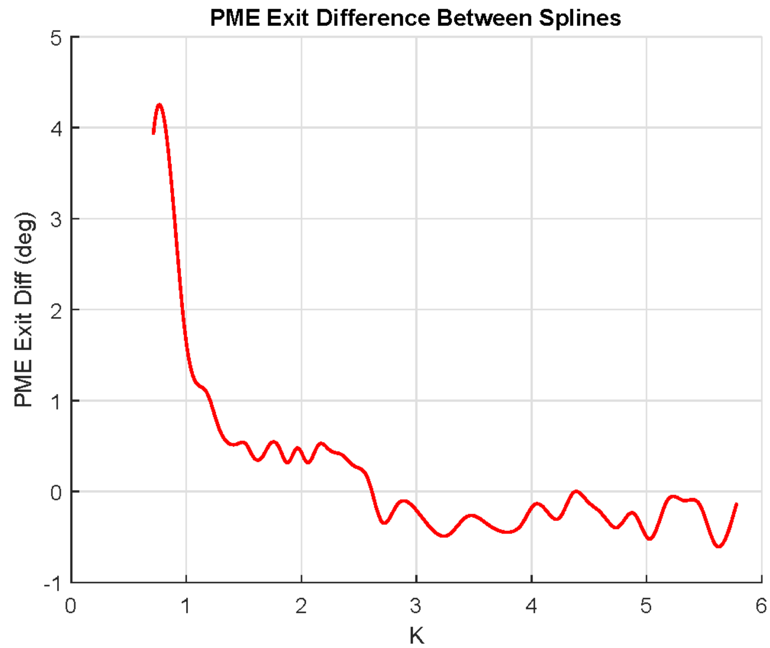


Figure 10: Difference in the spline fits to the phase matching error at the undulator exit as a function of K.

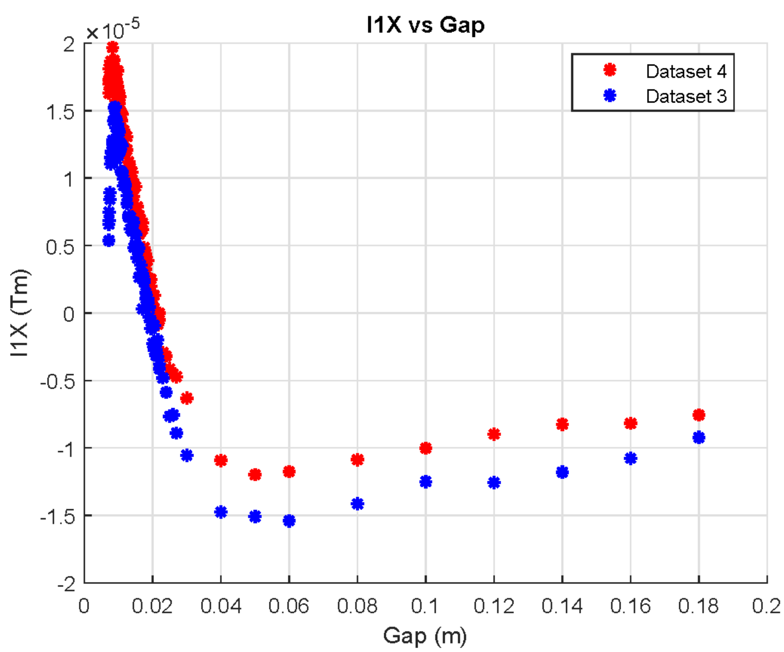


Figure 11: Comparison of the measurements of the first integral of $B_x$.

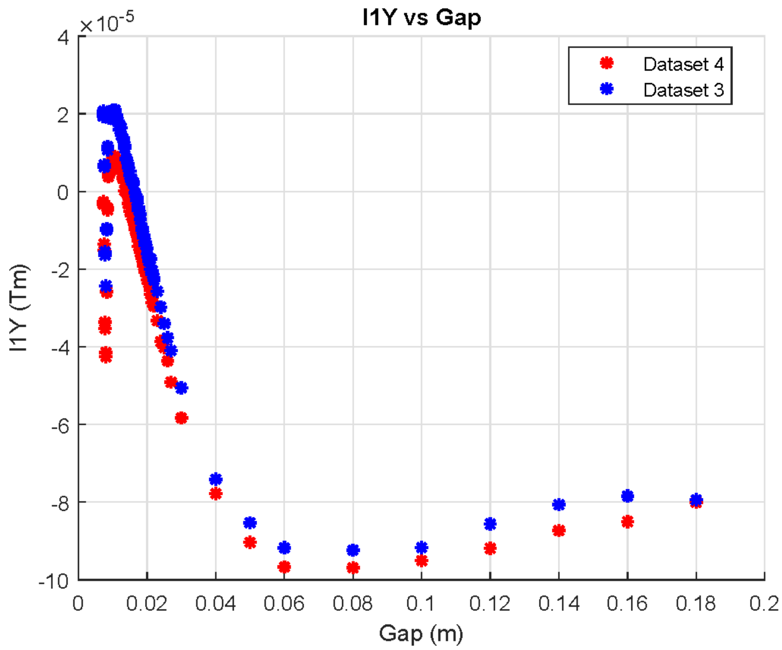


Figure 12: Comparison of the measurements of the first integral of $B_y$.

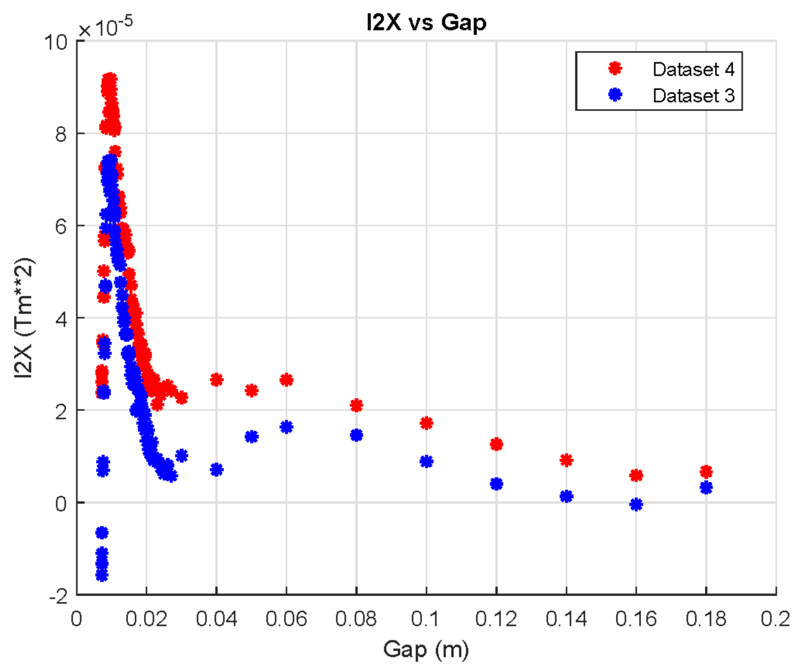


Figure 13: Comparison of the measurements of the second integral of $B_x$.

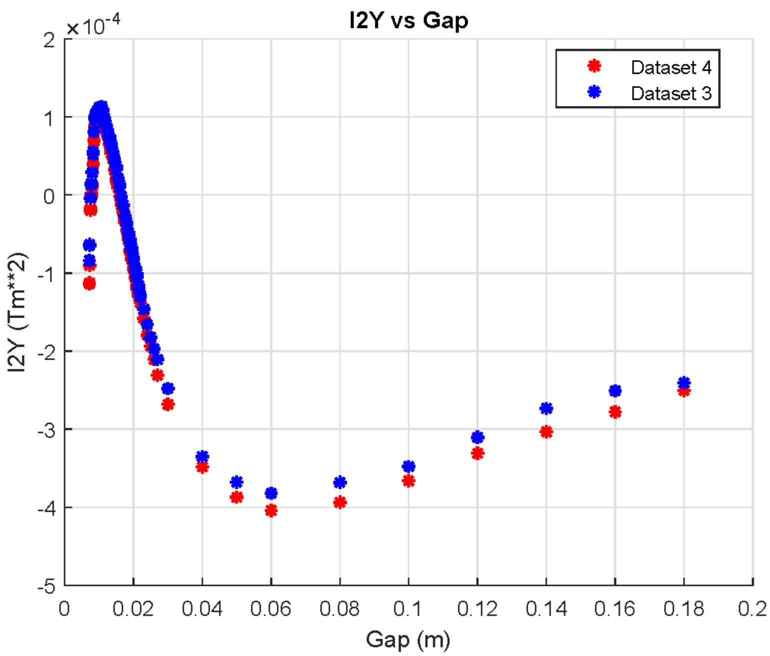


Figure 14: Comparison of the measurements of the second integral of $B_y$.

## 4 Conclusion

Measurements were made to SXU-001 after its second six months in storage. No significant changes were observed.

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