LCLS-TN-09-4

Undulator K Value Temperature Dependence

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Abstract

LCLS undulator SN27 was used to measure the temperature dependence of its K value. The results are presented. A linear fit gives $dK/K/dT = -4.3 \times 10^{-4}$ 1/C. This result is useful for correcting undulators in the tunnel whose temperature is different than the temperature used for tuning and fiducialization.

1 Introduction[1]

The LCLS tunnel has temperatures ranging from 19.6 C to 20.2 C along its length.[2] The K values were set and the undulators were fiducialized at 20.0 ± 0.1 C. Using the result presented below that $dK/K/dT = -4.3 \times 10^{-4}$ 1/C, the temperature variations cause the K values to change by up to $\Delta K/K = +2.2 \times 10^{-4}$ to -1.3×10^{-4} from the fiducialized values. The tolerance limit[3] is $\Delta K/K = 1.5 \times 10^{-4}$. The temperature of each undulator is measured and the K value is corrected for its temperature dependence. This note discusses measurements which determined the correction factor. The correction is made by horizontally translating the undulator, using the effect of the canted poles which makes the K value vary with horizontal position. Undulator SN27 was used for this study. We also determined whether the trajectories, phase, field integrals, etc. change with temperature and this data is presented.

In the middle of the test, the air conditioner in our laboratory broke, damaging the undulator. Such damage has been seen previously.[4] The temperature in the lab rose by 3 C for a day and a half, causing the damage. We are forced to break the measurements up into two data sets, before and after damage. Results are averaged over the data sets.

2 Measurements

In order to change the SN27 undulator temperature, we had to change the temperature of the entire lab. This necessitated extensive calibrations, since our measurement equipment changes with temperature. After the temperature was changed, a wait of two days was required before the undulator and granite measurement bench came to equilibrium. During this time, the air temperature was stable, so we could calibrate the hall probe. After the bench was in equilibrium, we had to re-align it, and we had to adjust the linear scale on the bench giving the z-position of the hall probe using an interferometer. The undulator was then aligned to the bench, the hall probe

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[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, private communication.

[3] H. D. Nuhn, et. al., "General Undulator System Requirements", LCLS Physics Requirements Document #1.4-001, rev. 4., April, 2008.

[4] Z. Wolf, et al., "Undulator Changes Due To Temperature Excursions", LCLS-TN-08-8, August, 2008.

was aligned to the undulator, and the measurements began. A full set of hall probe scans, long coil measurements, and a fiducialization was performed.[5] The undulator was moved to the CMM to complete the fiducialization. The CMM room stayed at 20.0 C, so CMM mechanical measurements at the various temperatures were not made. The process took about one week for each temperature setting.

The first measurement of the test was made at 20.0 C. The temperature was then set to 19.0 C, 19.5 C, and 20.5 C. These four points comprise the first set of measurements. After the 20.5 C measurement, we had an air conditioning failure in the MMF, and the air temperature of the lab rose slightly above 23 C. The duration of the temperature excursion was about a day and a half. The temperature of the undulator rose to 22 C. The undulator was damaged, as evidenced by a change in the gap. This is illustrated in figure 1 which shows the difference in the gap before and after the temperature excursion. After the air conditioner failure, a second set of measurements at 20.5 C, 21.0 C, 19.0 C, and 20.0 C was taken. The change in K with temperature is given for each of the two sets of measurements. Significant gap changes were not observed for any of the temperatures used in this test, indicating a damage threshold for temperature excursions somewhere between 1 C and 2 C.

Note that in the data which follows, all measurements were done along the beam axis, i.e. along a line with the specified K value. As the temperature changed, the position of the line changed. The canted poles make the field vary with horizontal position (x-direction). As the temperature changes, the field changes, necessitating a shift in x to get to the same K value. The line with the specified K value is the fiducialized beam axis at each temperature. Plots of the peak field at each pole are ideally the same at each temperature because the position of the measurements was adjusted to keep the fields constant. We did not build into our measurement system the capability to measure at the same x-position relative to the undulator each time the undulator was placed on the test stand. Measurements at fixed x-position relative to the undulator at different temperatures were not made, but calculations are presented which infer the results.

3 Trajectories and Phase vs Temperature

Figure 2 shows the peak field at each pole relative to the first data set at the various temperatures. The data were taken along the line of constant K, so at different x-positions. Ideally, the data would all be at zero. Note that the data marked "Set 2" all have deviations from zero with a periodic pattern. This is due to the damage from the temperature excursion mentioned above. The field deviations will introduce phase errors.

Figure 3 shows the x-trajectories at the various temperatures. There is essentially no change.

Figure 4 shows the y-trajectories. Again, there is no significant change. Differences are primarily due to the hall probe offset correction done with the long coil measurement. This was described in a previous note.[6]

Figure 5 shows the phase relative to the first data set. Errors in the K value are not included in this plot. Notice the periodic pattern in the "Set 2" data. This is due to the damage from the temperature excursion. The phase changes are well below the 10° tolerance and are noted for interest.

Figure 6 shows the phase relative to a nominal 1.5 $\mathring{A}$ radiation wave and relative to the first data set. Errors in the K value are included in this plot. The periodic pattern in the "Set 2" data is evident.

Figure 7 shows the K value of each data set relative to the first data set. It shows that at each temperature, K was set to the same value. (The undulator was fiducialized to the same K value.)

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[5] Z. Wolf, et al., "LCLS Undulator Test Plan", LCLS-TN-06-17, December, 2006.

[6] Z. Wolf, Y. Levashov, "Reference Undulator Measurement Results", LCLS-TN-09-3, August, 2009.

Figure 8 shows the phase in the cell relative to the nominal 1.5 $\mathring{A}$ radiation wave and relative to the first data set. A cell is a 3.656 m length centered on the undulator. K deviations cause phase errors in the cell since it is relative to the nominal radiation wave. As long as one moves to the proper K value at the different temperatures, there is essentially no change to the phase in the cell.

4 Field Integrals

Figure 9 shows the field integrals as a function of x-position at the various temperatures. The field integrals were measured with a long coil. The spread in the measurements is similar to what was seen with the reference undulator.[7] The field integrals show no significant change with temperature. The spread in the second integral of B_y measurements at the various temperatures is slightly larger than for the other field integrals, but remained well within the 50 μTm^2 tolerance.

5 Beam Axis Position

Figure 10 shows the change in the fiducialized beam axis horizontal position relative to the undulator tooling balls at the various temperatures. The original 20.0 C beam axis position is the reference for the changes. The first data set, shown in red in the figure, show a linear variation of beam axis position with temperature with a slope of $dx/dT = -540$ μm/C. After the first measurement at 20.5 C and the temperature excursion, a second measurement at 20.5 C was made which showed a -155 μm change in beam axis position. The second 20.5 C measurement started the second data set, which is shown in blue in the figure. The second data set show a linear variation of beam axis position with temperature with a slope of $dx/dT = -594$ μm/C. The average of the two data sets gives $dx/dT = -567$ μm/C. This result tells how the fiducialized beam axis position changes with temperature. Equivalently, it tells how to move the undulators horizontally to correct for temperature changes.

The figure also shows that if a nominal variation of K with x of $dK/dx = 2.64$ 1/m due to the canted poles is assumed, and if we divide by the K value giving a fractional change in K with x-position $dK/K/dx = 0.758$ 1/m, then we calculate using the slopes $dK/K/dT = -4.09 \times 10^{-4}$ 1/C for the first data set and $dK/K/dT = -4.50 \times 10^{-4}$ 1/C for the second data set. The average of the two data sets gives $dK/K/dT = -4.30 \times 10^{-4}$ 1/C.

The variation of K with x due to the cant angle was measured at each temperature. A typical measurement is shown in figure 11, which is for 20.0 C. The data fit a straight line with slope $dK/dx = 2.63$ 1/m and $dK/K/dx = 0.754$ 1/m. The dependence of the slope on temperature is shown in figure 12. The variation of dK/dx with temperature is evident, although there is some scatter.

When the fiducialized beam axis position change Δx is multiplied by dK/dx for each temperature, the result is the change in K due to temperature at fixed x. Figure 13 shows the change in K as a function of temperature. Linear fits give $dK/dT = -1.44 \times 10^{-3}$ 1/C for the first data set, and $dK/dT = -1.57 \times 10^{-3}$ 1/C for the second data set. The relative change in K with temperature is $dK/K/dT = -4.13 \times 10^{-4}$ 1/C for the first data set, and $dK/K/dT = -4.50 \times 10^{-4}$ 1/C for the second data set. The average is $dK/K/dT = -4.32 \times 10^{-4}$ 1/C. This, in essence, agrees with a measurement from ANL which gave $dB/B/dT = -5.5 \times 10^{-4}$ 1/C for the change in the effective magnetic field in the gap with temperature.[8]

Figure 14 shows the change in the beam axis y-position at the various temperatures. The changes are within our measurement error. No temperature dependence of the y-position is observed.

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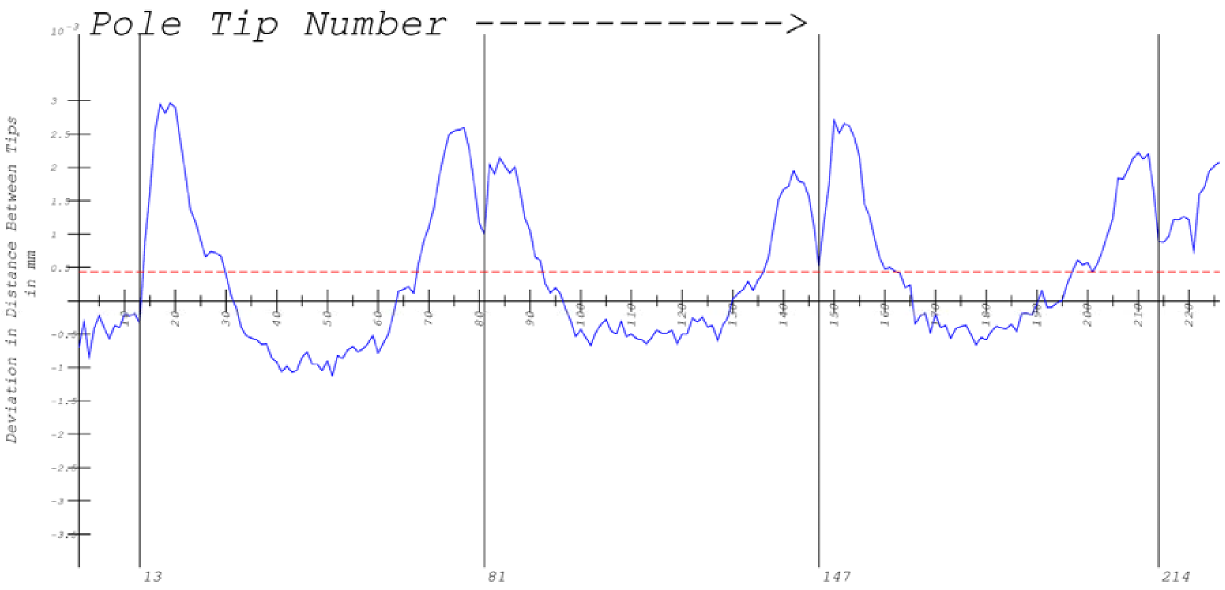
[7] Z. Wolf, Y. Levashov, "Reference Undulator Measurement Results", LCLS-TN-09-3, August, 2009.

[8] R. Dejus (editor), "LCLS Prototype Undulator Report", ANL/APS/TB-48, January, 2004, p. 52.

6 Conclusion

The temperature dependence of the SN27 undulator characteristics was studied. The trajectories, phase, field integrals, and beam axis y-position do not change with temperature over the 19 C to 21 C range of the study. The beam axis x-position (the line along which K is constant) does change with temperature at a rate of $dx/dT = -567$ μm/C. The K dependence on x in the canted poles was measured at each temperature. This allowed us to calculate the change in K with temperature at fixed x. The result is $dK/K/dT = -4.32 \times 10^{-4}$ 1/C.

List Of Figures



Average Deviation = 0.0004
Broken Red line is Average Value of Deviation
Vertical lines represent Magnet Sub-Assemblies
Deviation is the change in Gap width at the same YZ cross section (Dataset 0001 29-JUL-2009 (20.5 deg))

SLAC NATIONAL ACCELERATOR LABORATORY MMF GRE 45129	Deviation in Undulator Pole Tip Gap at 20.5 deg Between 29-JUL-09 Dataset and 06-AUG-09 Dataset	DATE:06-AUG-2009 UNDULATOR #27

Figure 1

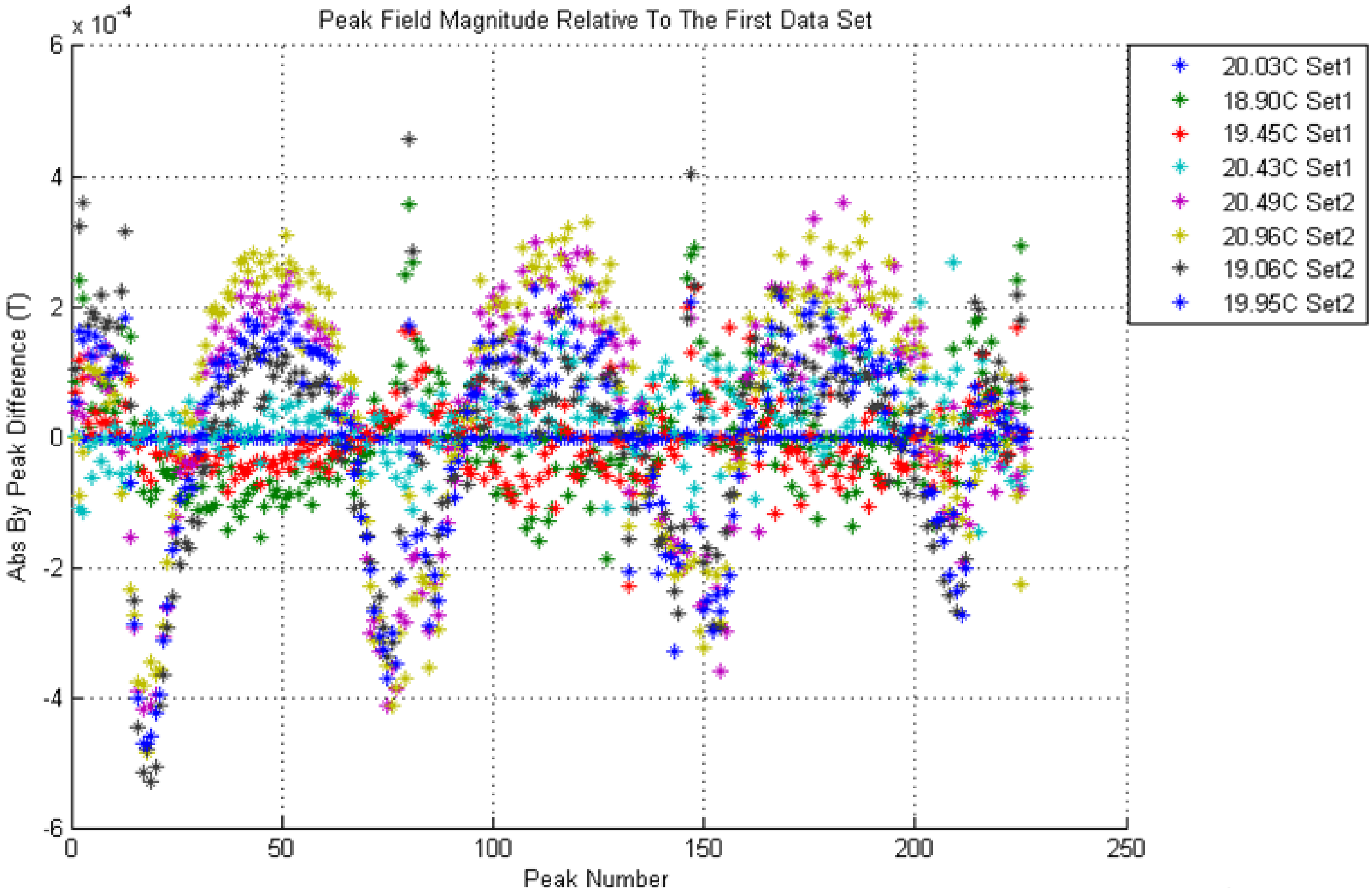
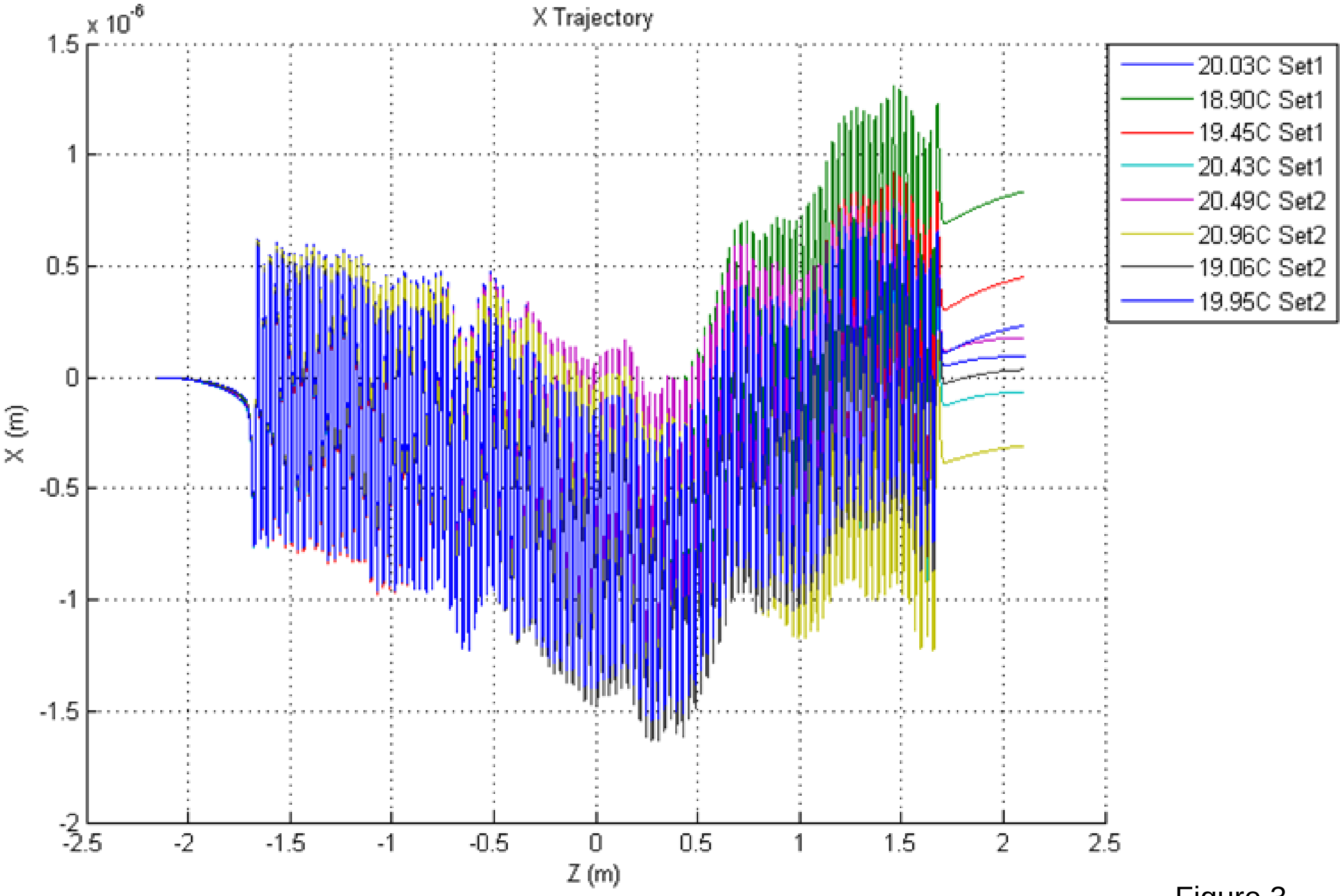


Figure 2



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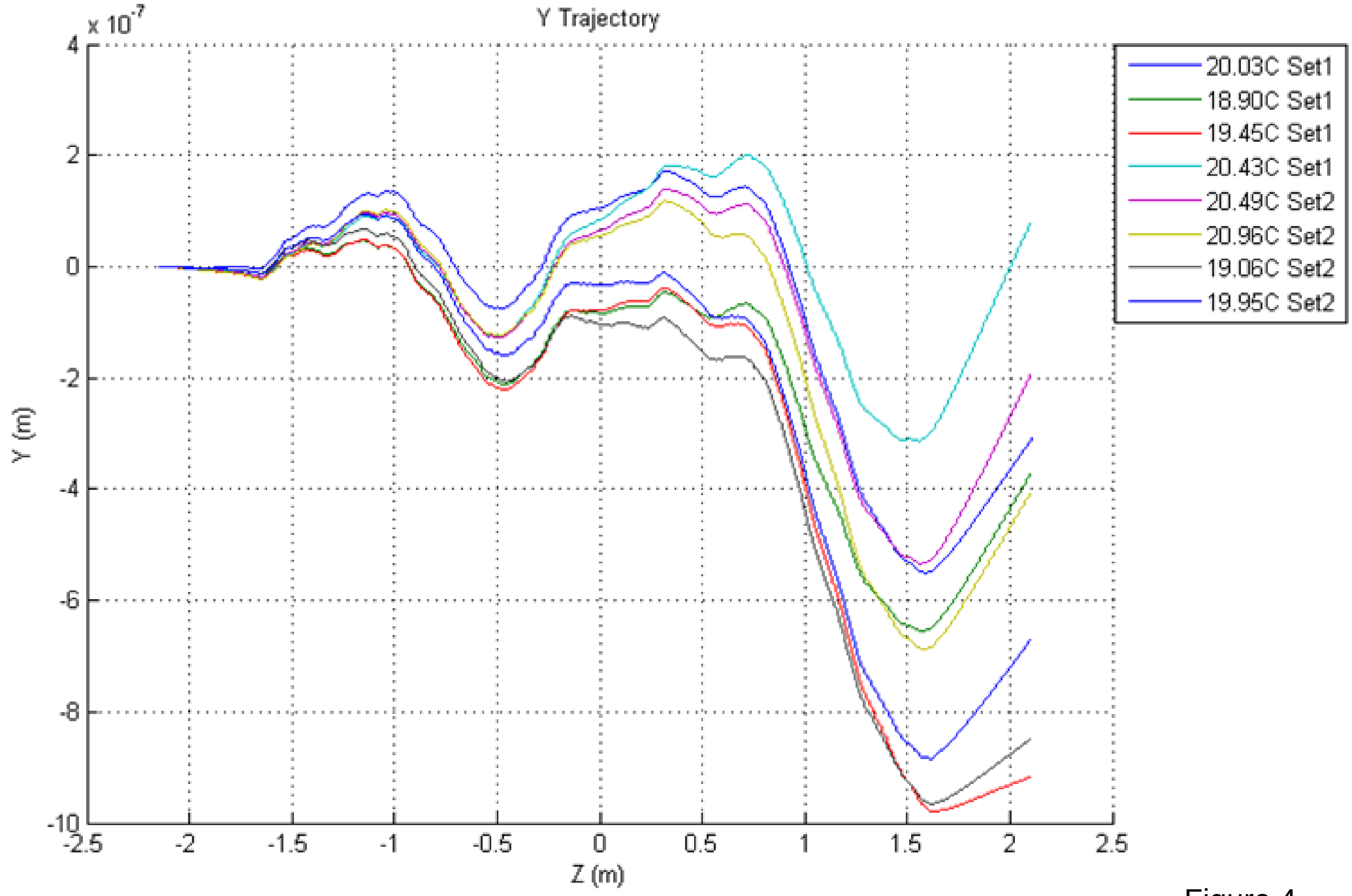
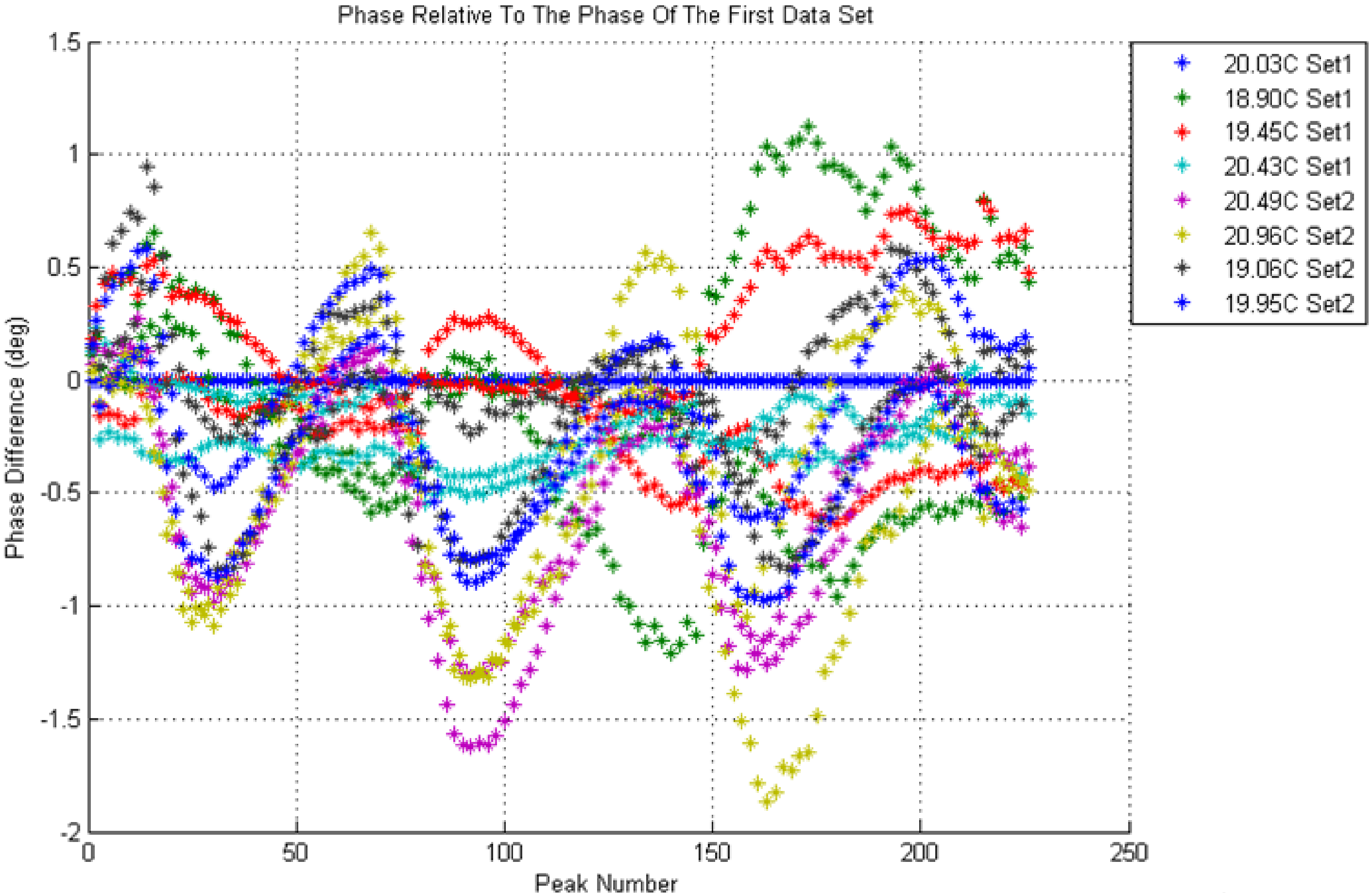


Figure 4



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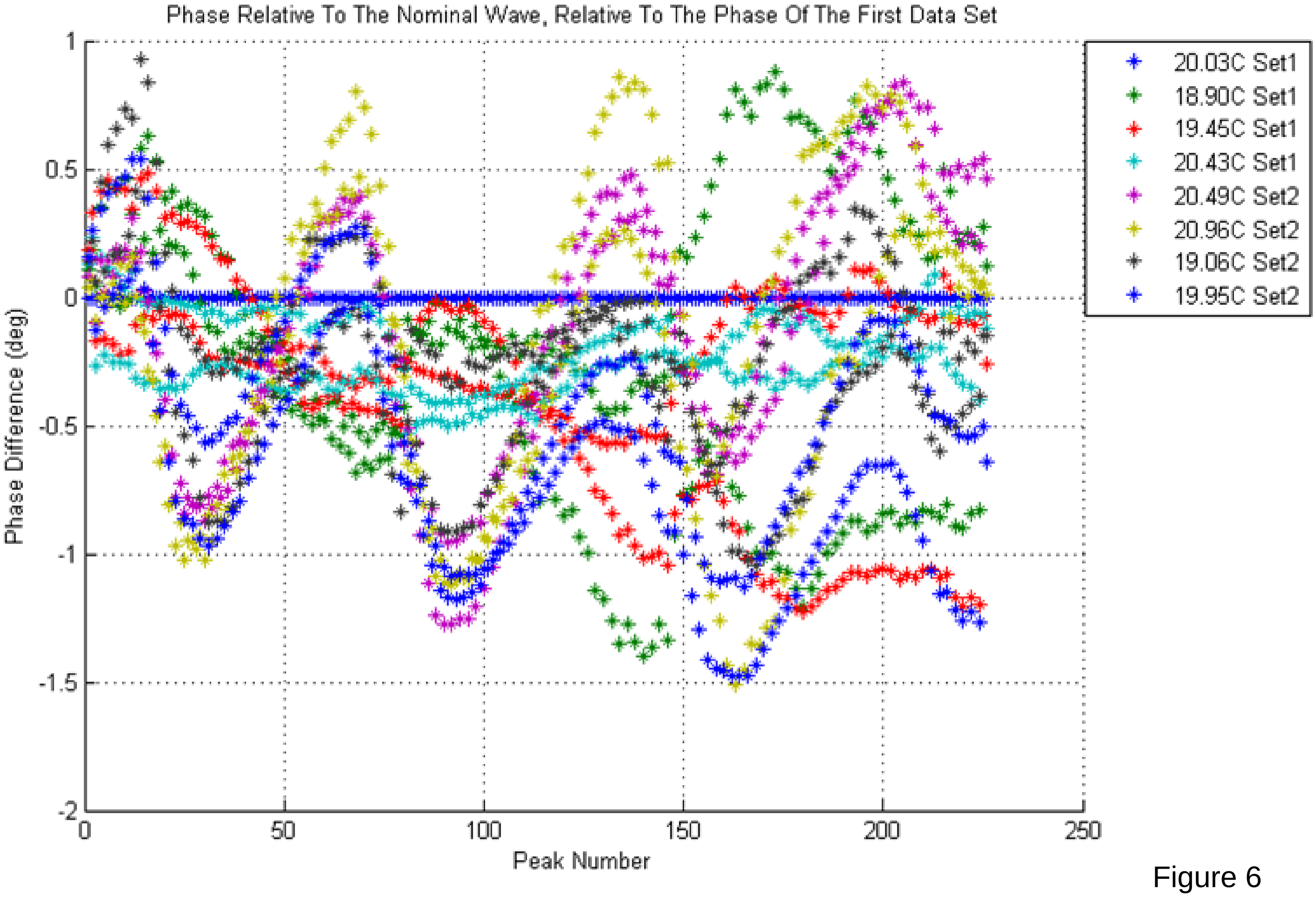

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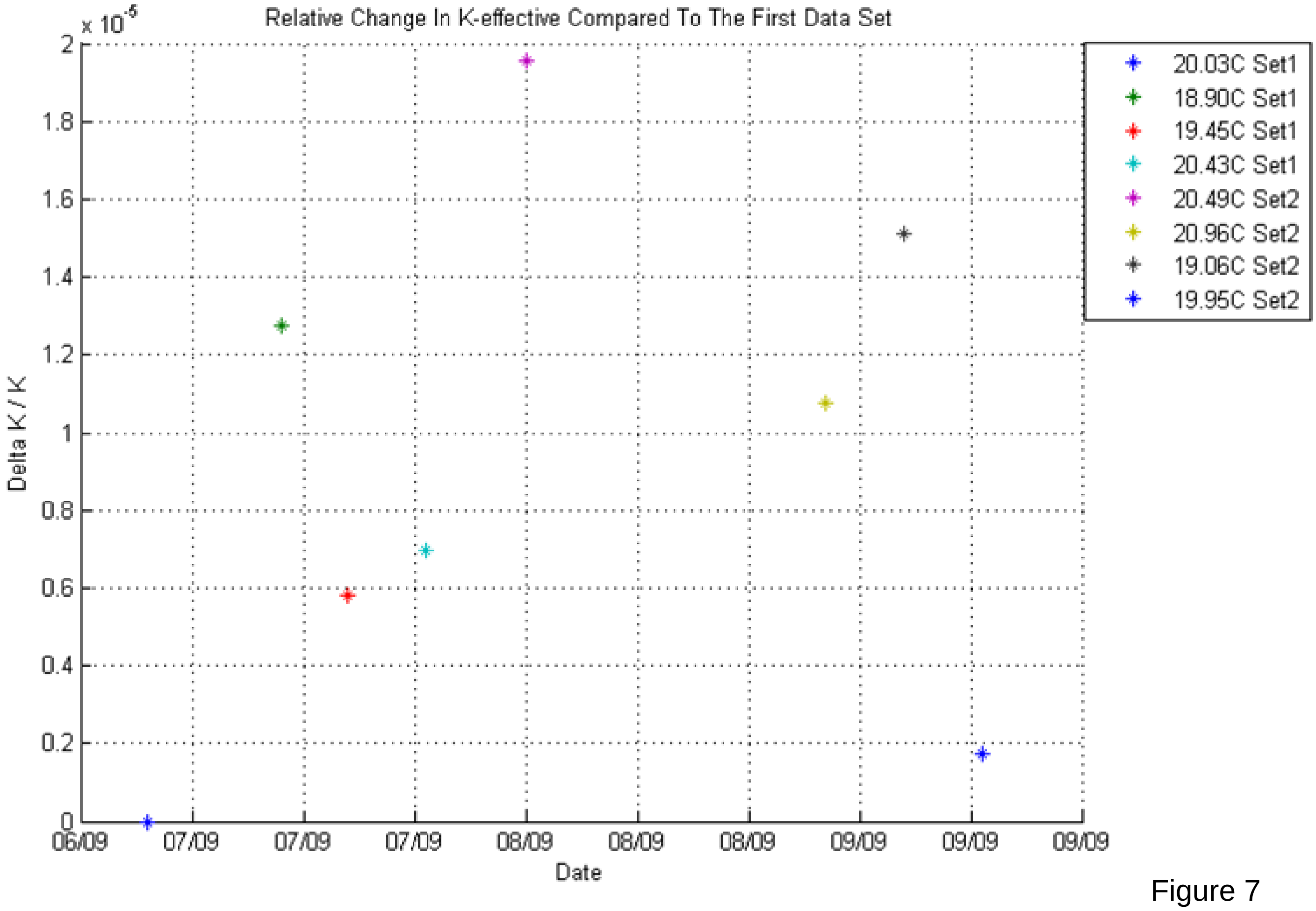

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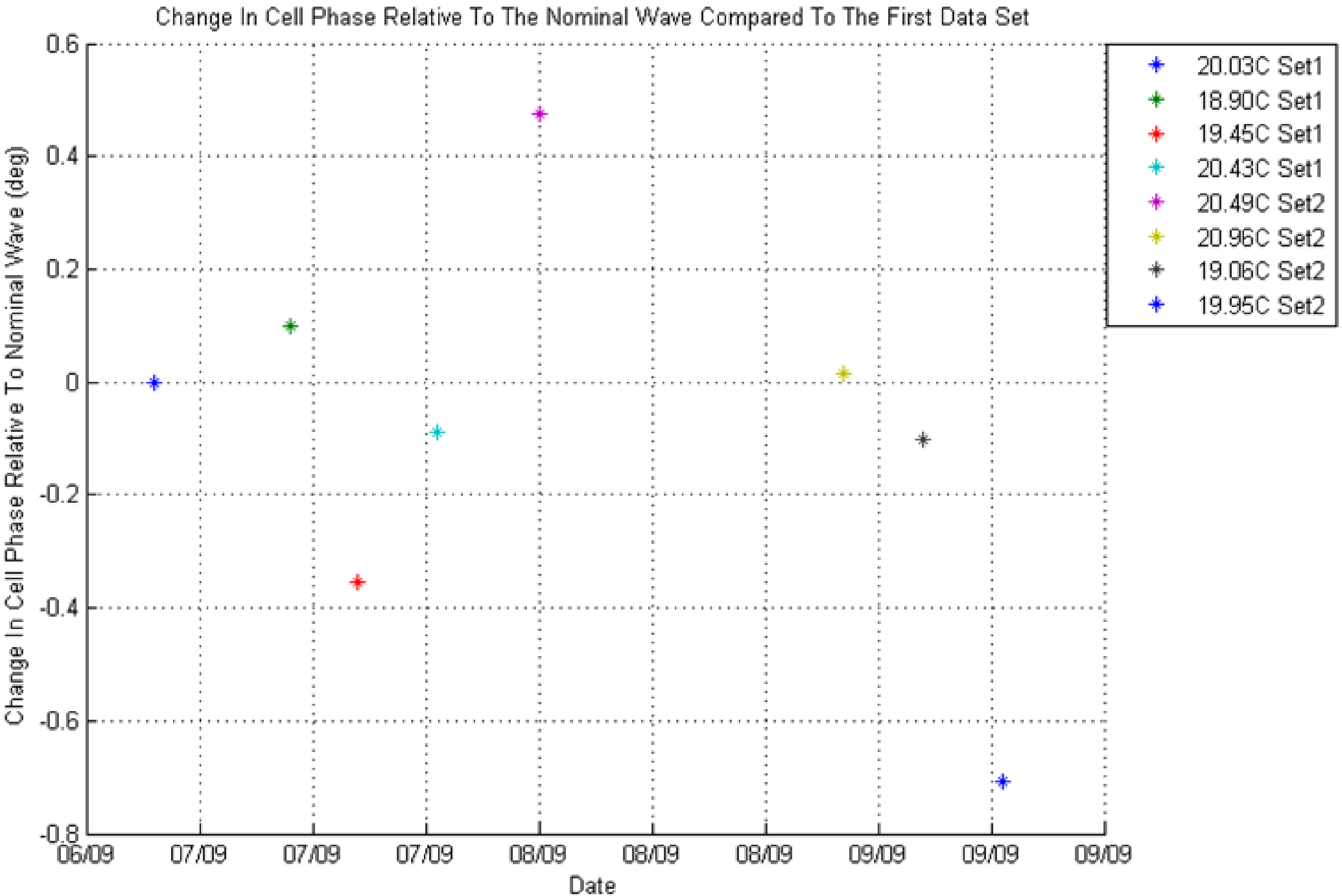

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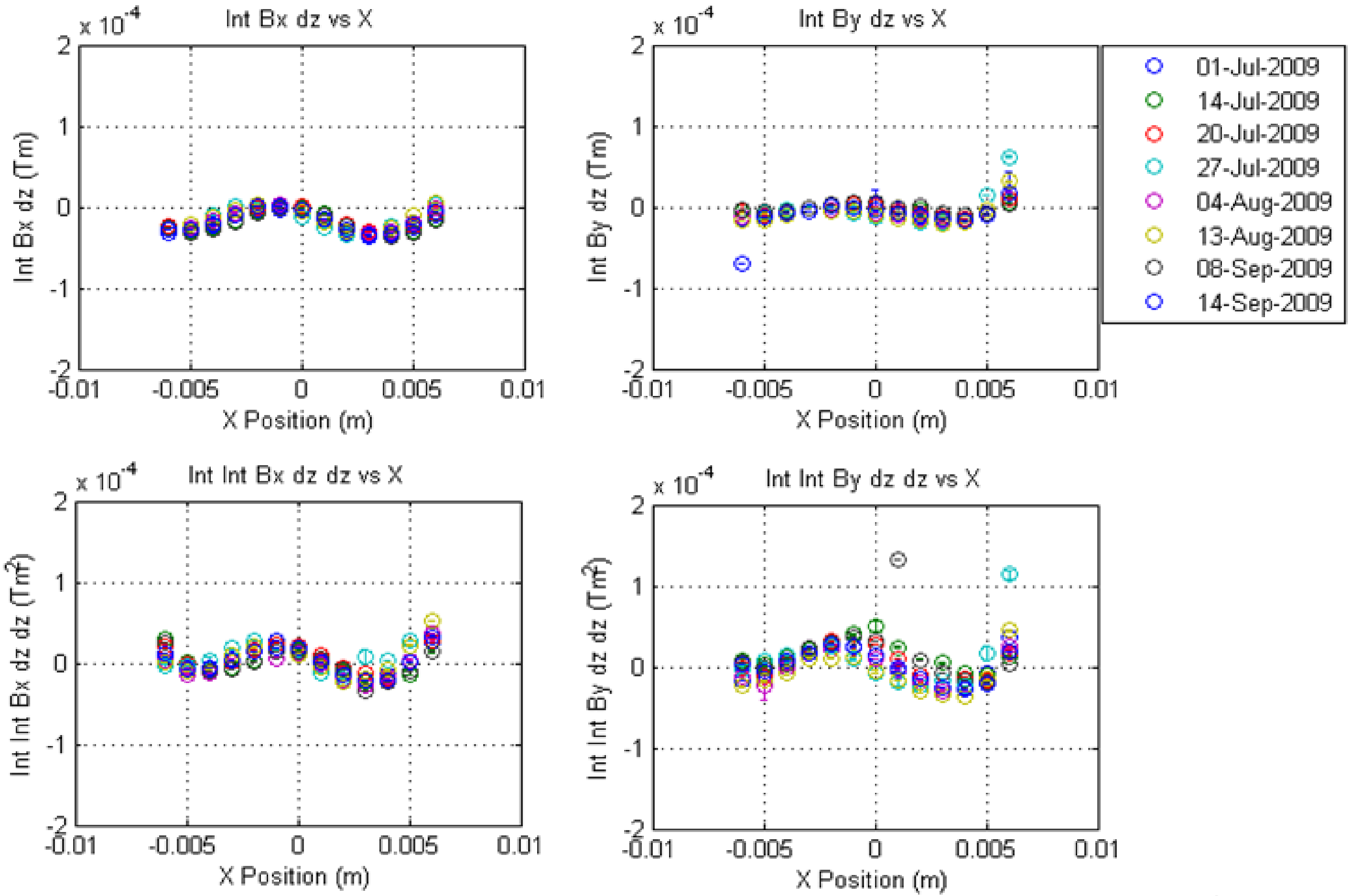

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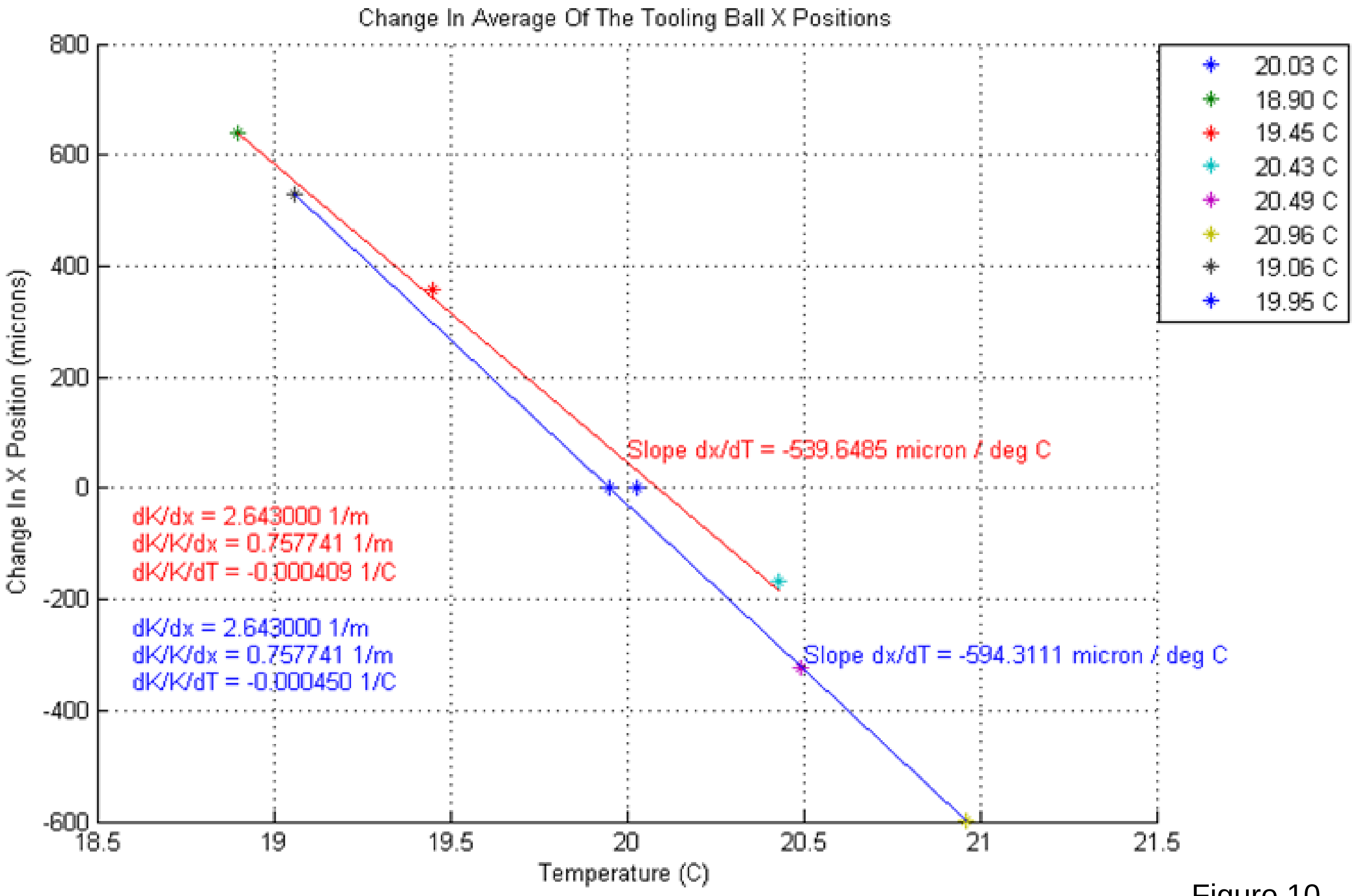

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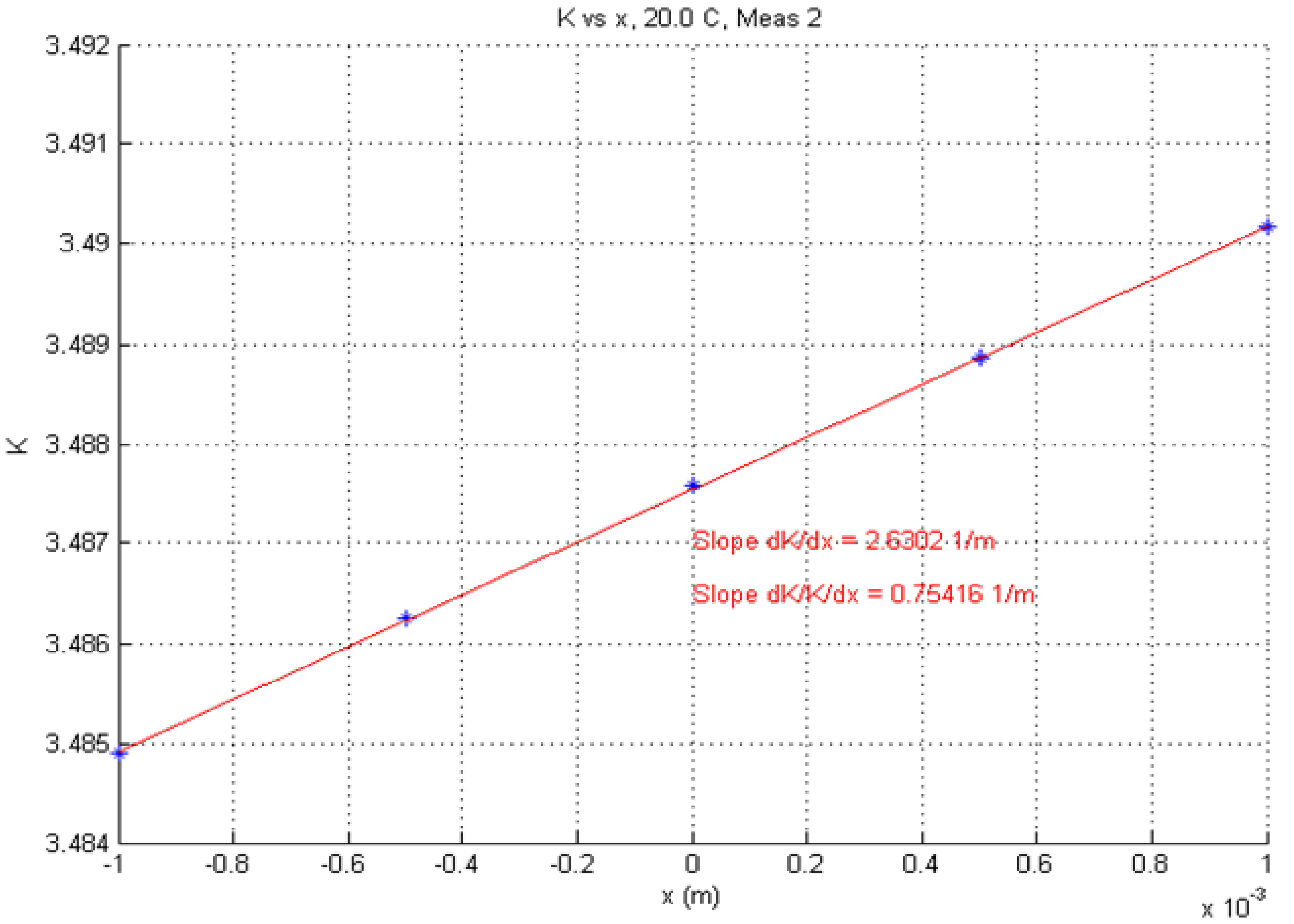

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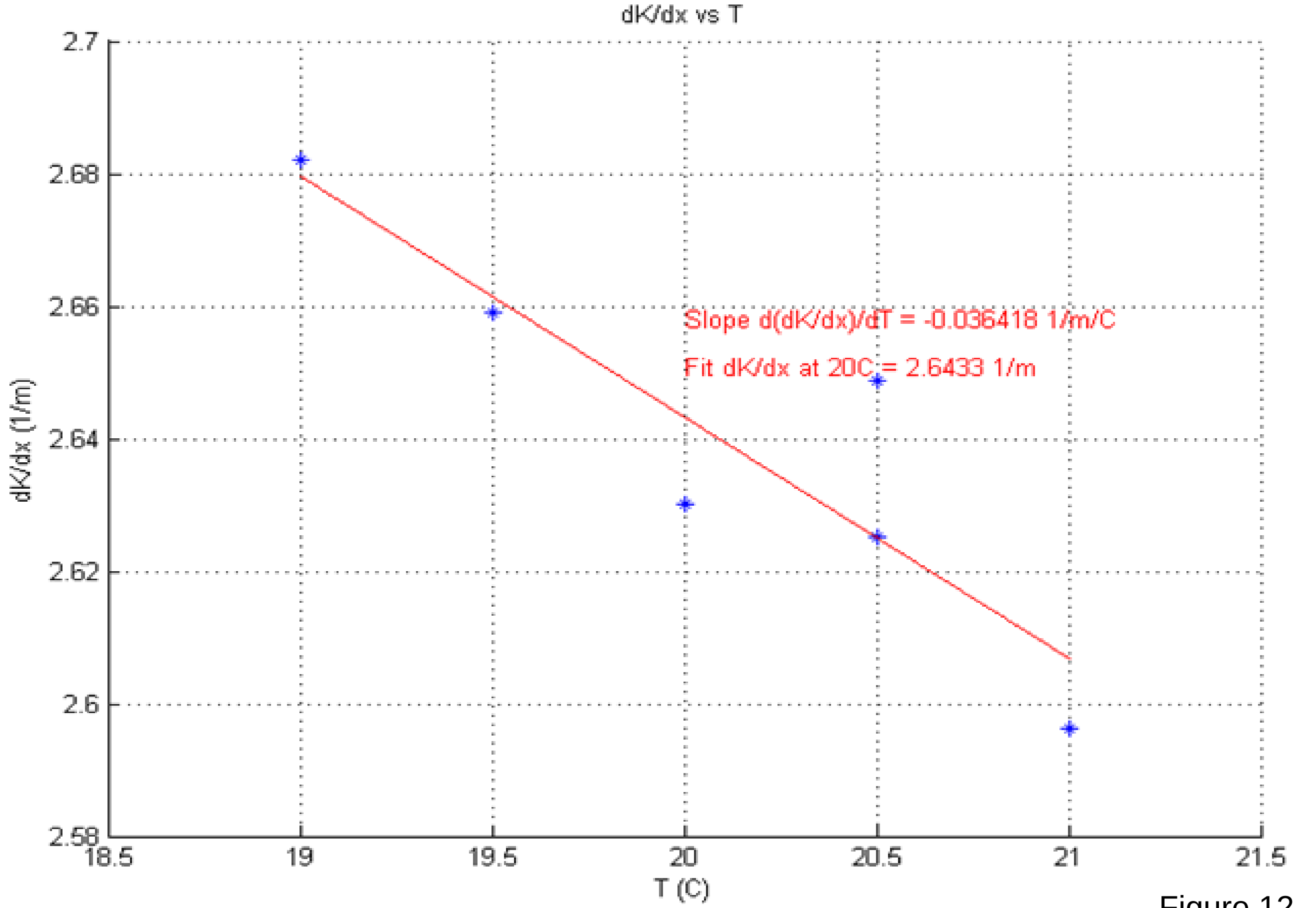

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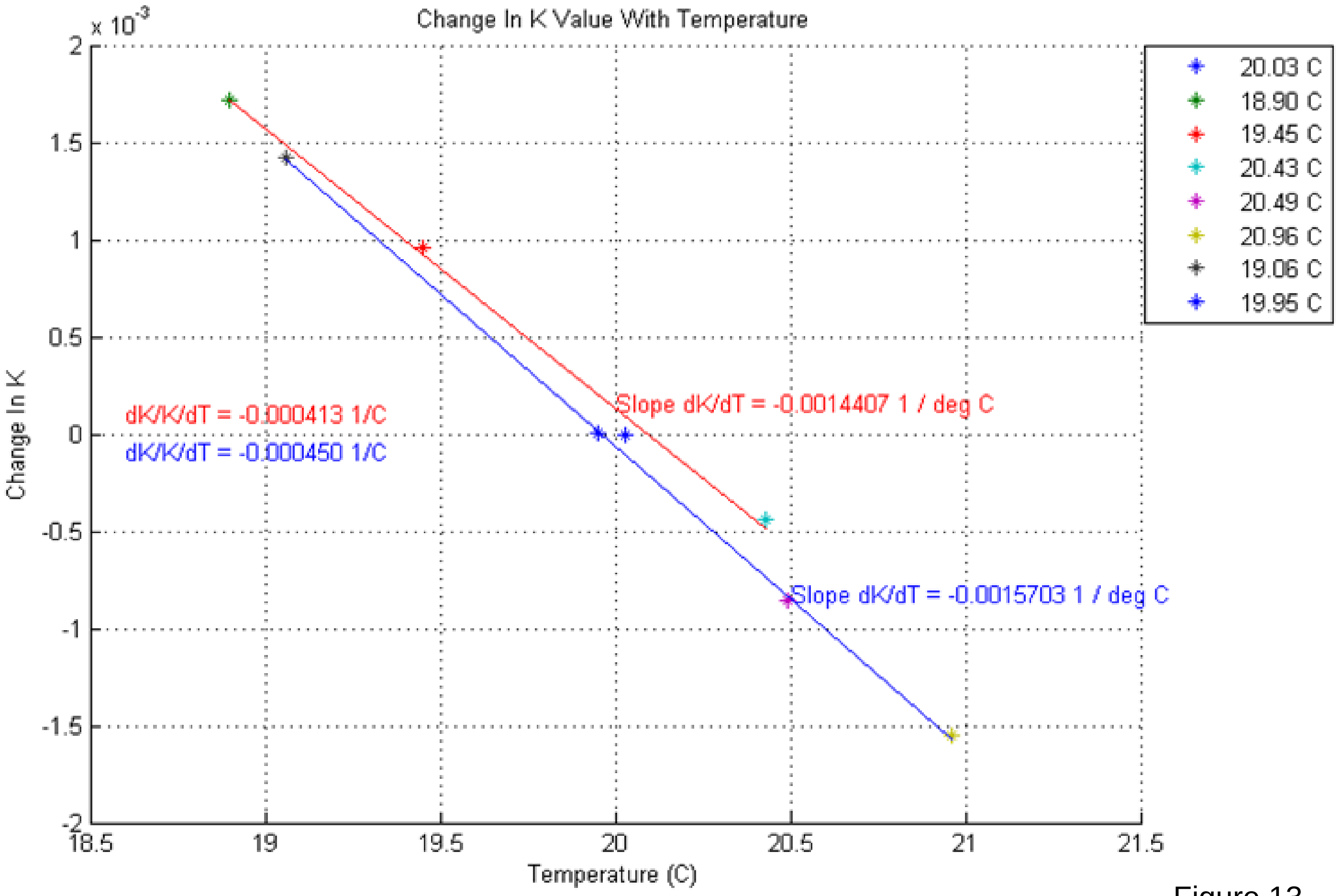

Figure 13

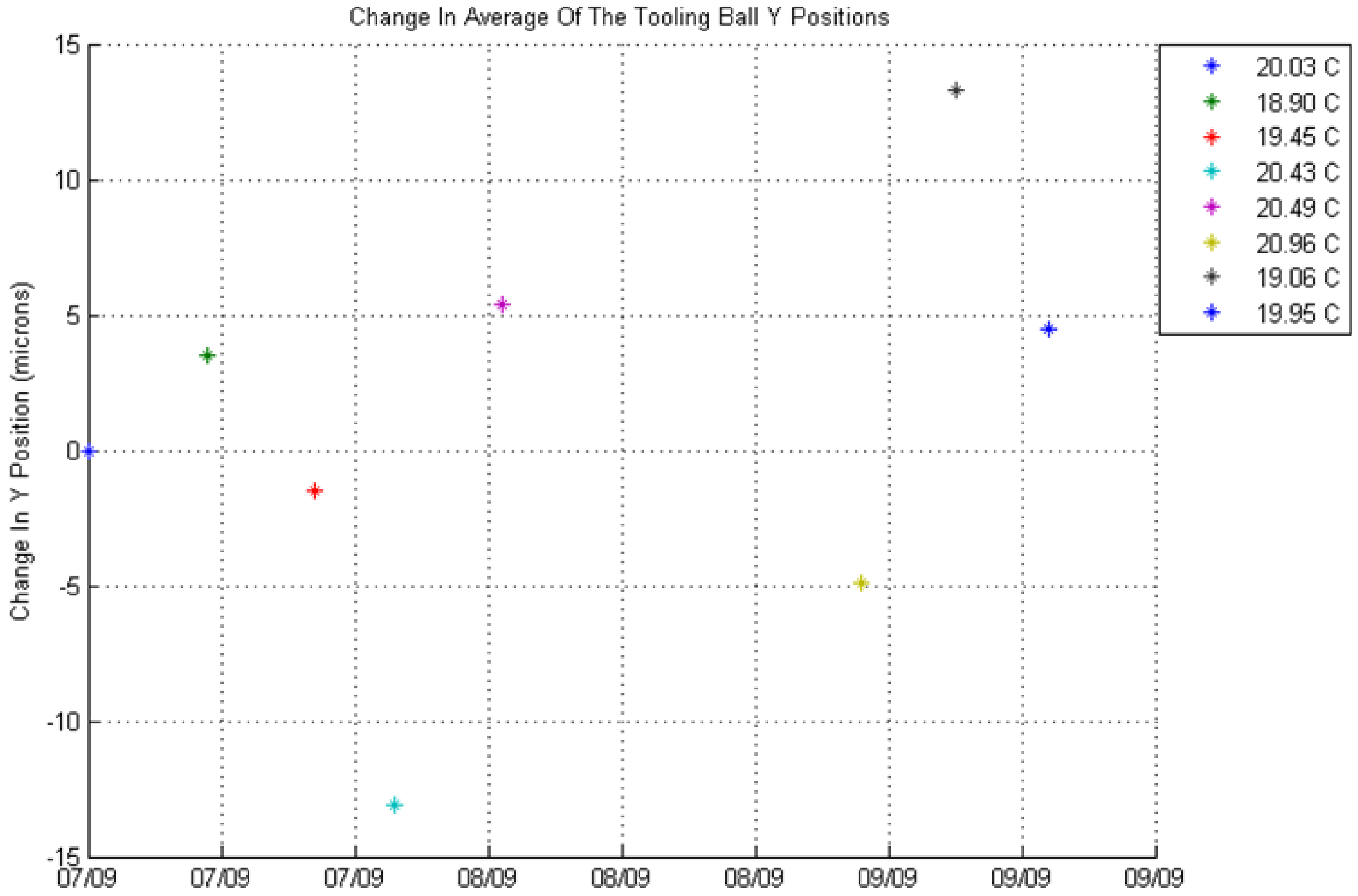

Figure 14