Using the Sentron Angle Sensor, Linear 2-Axis Hall IC, 2SA-10G probe to check the alignment of a magnetic field

Felix Kress University of St Andrews

Introduction

The basic idea behind this is that we have a strong magnetic field in the z-direction, while a weak one in the $\boldsymbol{x}$- and $\boldsymbol{y}$-direction. We try to align the 2D Hall probe in such a way, that it only measures the $\boldsymbol{x}$- and $\boldsymbol{y}$-field components. The 2-Axis Sentron Hall Sensor seemed to be a logical choice as it already had been used in a similar setup by I.B. Vasserman et al[1]. The motivation in our case is that we want to know whether our uniform 1T field in the $\boldsymbol{z}$-direction is still aligned with the tracker for the Mu2e experiment and if it is not, how drastic the misalignment is.

Suitability of the Sentron Angle Sensor

When testing the suitability of the Sentron Angle Sensor we encountered several issues. First of all the Sensor contains a ferromagnetic disk in order to amplify the external magnetic field and concentrate it on the Hall elements. This ferromagnetic disk could potentially distort the 1T field. However, when looking at the dimensions of the disk, we see that we don't have to worry about this:

We can use a model found on the internet[2] to approximate the effects of the disk, when it is fully saturated in the 1T field. Its dimensions are: Diameter = 0.2 mm and thickness < 0.1mm. The disk has a cylindrical shape, while the model uses a rectangular one. In order to obtain approximately the same result we use the same thickness and area: Area of the top of the cylinder: $A = \pi r^2 \Longrightarrow$ Area of the top of the rectangle: $A = \pi\, 0.1^2$ mm^2$= a^2$, where $\boldsymbol{a}$ is the width of the rectangle $\Longrightarrow a \approx 0.178$ mm.

Having these parameters we can calculate the effects of the disk at a distance of 5mm:

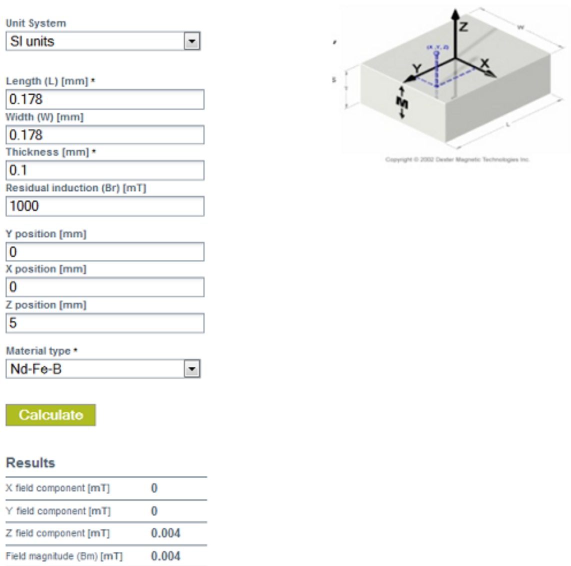

Figure 1: Calculation of the magnetic field produced by a rectangle using a model provided by dextermag.com

We can see that the effect is negligible mainly because the disk is so tiny.

However another factor we might consider is that the disk saturates in the 1T field and therefore our measurements become unreliable (i.e. the sensitivity drops). We tested this and it doesn't seem to be an issue. As well as this I. B. Vasserman et al didn't seem to have any issues concerning this.

The next worries we had concerning the probe was, how it would be affected by time and temperature. I left one of the Hall probes untouched for 14 hours and measured a change of 1.7G ((2.65545V-2.64731V)*212 V/G ≈ 1.7G; see calibration section). Hence we have no control over the drifts which can happen in the time span of 10 years. Another issue had to do with the temperature dependence of the probe. I.B. Vasserman et al provided me with the following graph, which illustrates that there can be a change of 1G, when the temperature changes by 1 C.

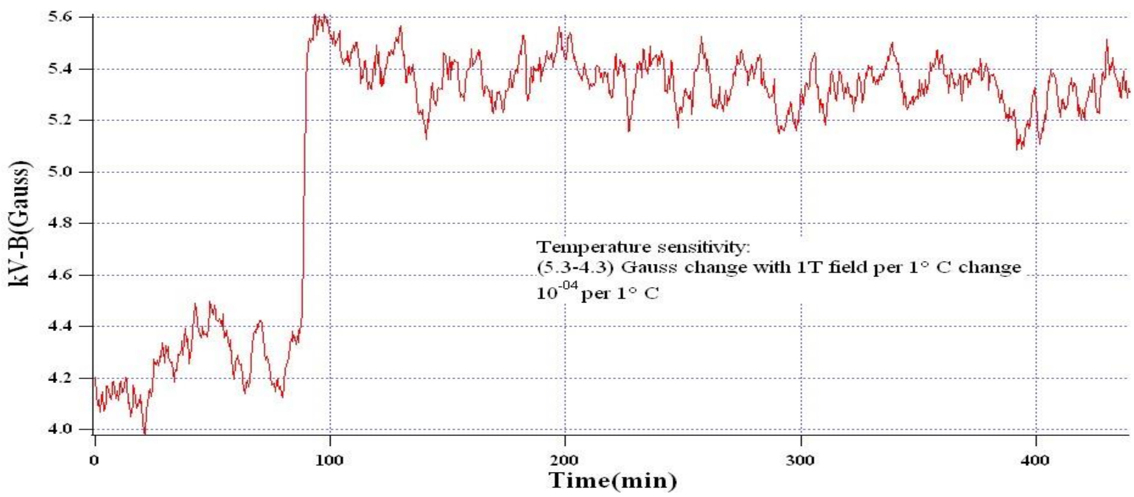

Figure 2: Sentron Hall Probe Time Dependence, temperature control on, first part T = 22.5 C, second part T = 23.5 C. Temperature sensitivity ≈ $1*10^{-4}$, Figure taken from a presentation by I.B. Vasserman et al

We also didn't know how the calibration of the probe would change with time.

Our conclusion was that we won't be able to use the Hall probe as a measure of misalignment. This however did not mean we couldn't use them at all. We came up with the following simple model:

The Hall probes will be aligned in such a way, that they show an effect of approximately 0 magnetic fields in the x- and y-direction. Now if there happens to be any misalignment we would know because the readings of the Hall probe would change. In order to estimate the amount of misalignment we use simple solenoids, which produce magnetic fields in the x- and y-direction. We apply a field through the solenoids in order to return the reading of the Hall probe to 0. Then this provides us with a measure of misalignment. This should work as the solenoids are not as sensible to changes in temperature and time.

To test whether this model worked I did the following:

Note: The following results were obtained by using the "2nd Hall probe"

Calibration

The analog Hall probes used, first had to be put into an appropriate circuit. The read out would be provided by a voltage. If the magnetic field changed, this voltage would change. Therefore I first had to calibrate the probe to see what voltage change would correspond to what magnetic field change. I did this by using existing high accuracy Hall probes and a variable magnetic field showing in z-direction.

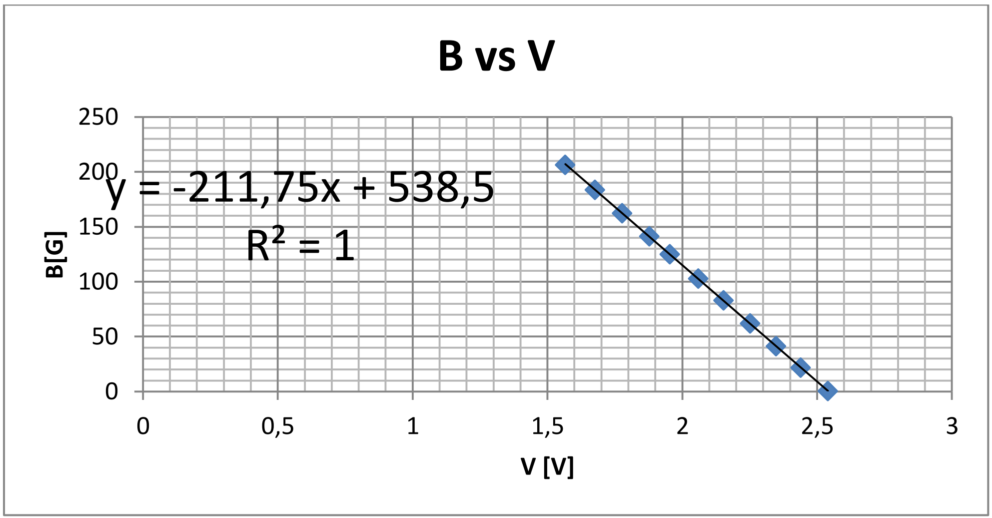

Figure 3: Calibration of the Hall probe: B vs V

It can be seen that the magnetic field changes by approximately 212G, when the voltage changes by 1V. It can also be seen that the Hall probe is rising linearly, especially considering the R^2 -value of 1. However we also need to treat this calibration with caution, as I wasn't able to perfectly align the Hall probe with the magnetic field. Therefore this calibration should be done again once we figured out a way how to align the Hall probe with the field accurately enough.

After having calibrated the Hall probe I made the solenoids by simply wrapping wire around the Hall probe in such a way, that I would have a solenoid producing a field in the x-direction ,coil 1 and one producing a field in the y-direction ,coil 2:

Figure 4: The 2nd Hall probe set up with the 2 solenoids

First I tested the effect of applying a voltage to coil 1 and therefore producing a current, which would then result in a magnetic field, in the x-direction:

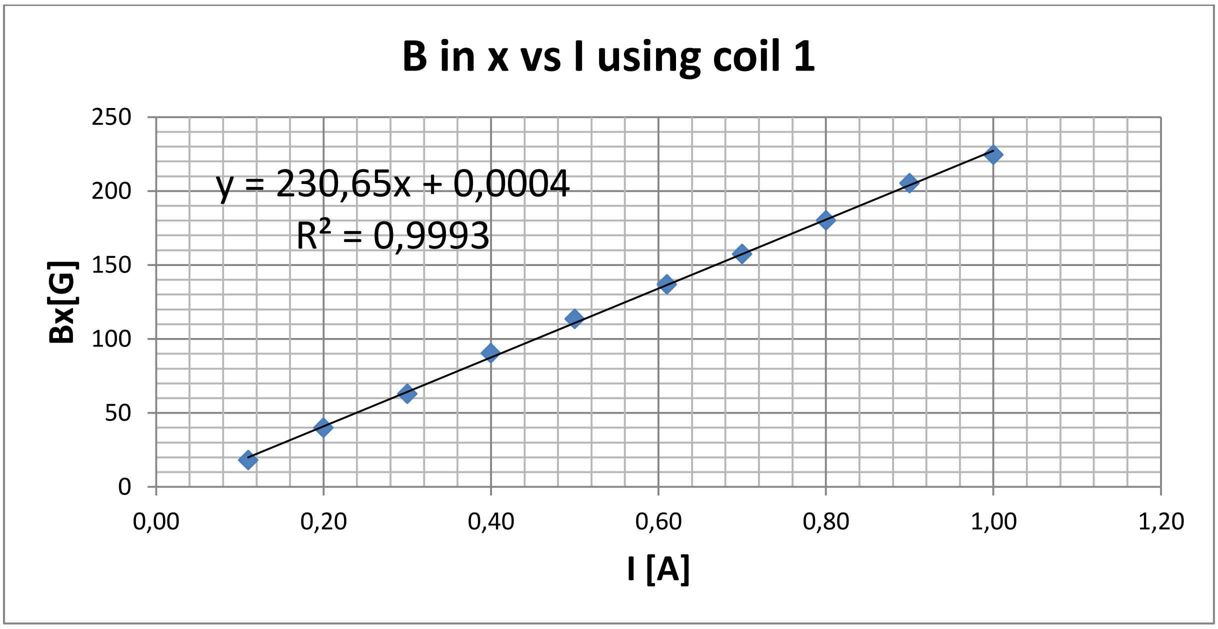

Figure 5: B in x vs I using coil 1

It can be seen that when using a current of 1A, we produce a field of approximately 231G in the x-direction. Therefore we know what the magnetic field will be when using a certain current. However we again need to take into account that our solenoid was not perfectly aligned, hence it will probably also produce a field in the y-direction. The following graph looks at the dependence of the field in y-direction, when changing the current through coil 1.

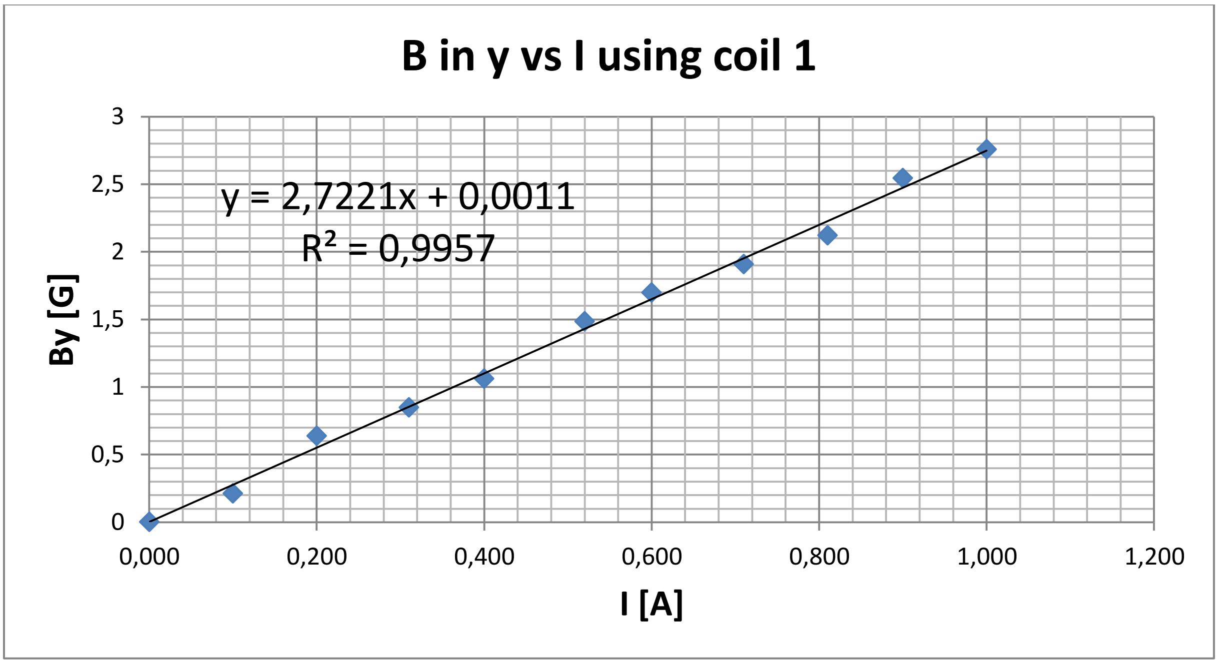

Figure 6: B in y vs I using coil 1

Hence we have a change of 2.7G, when applying a current of 1A. This is quite small in comparison to 231G (1.2%) but needs to be taken into account.

Now I did exactly the same with coil 2 and got the following graphs:

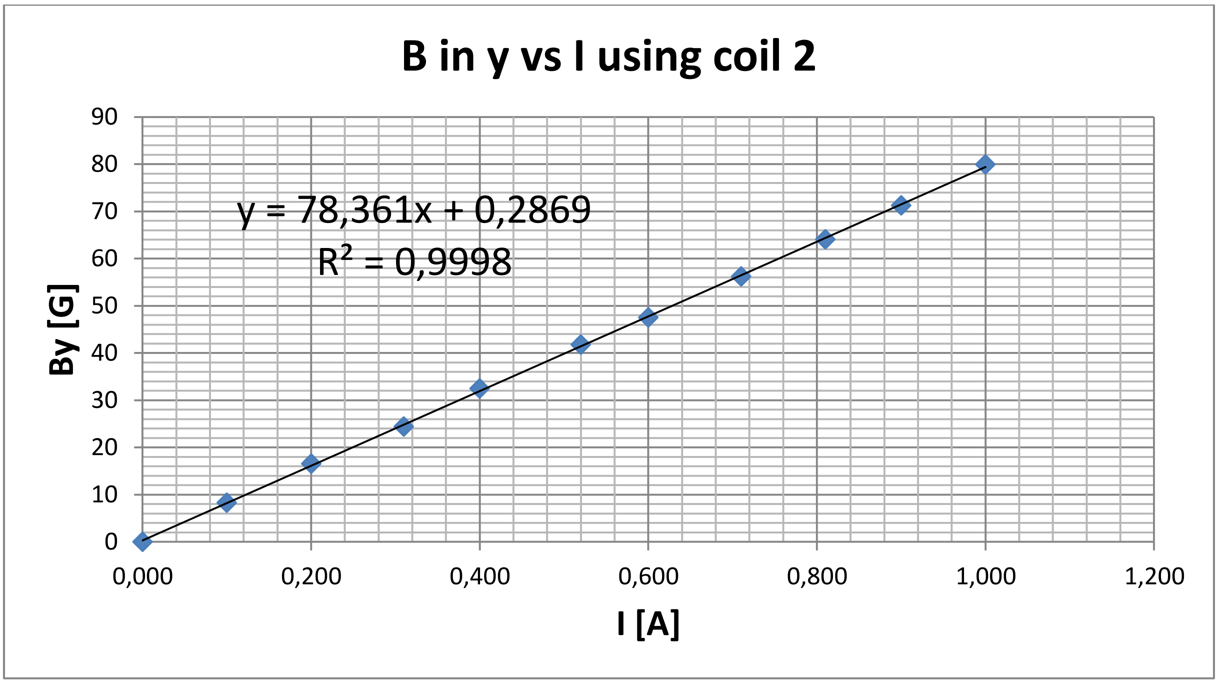

Figure 7: B in y vs I using coil 2

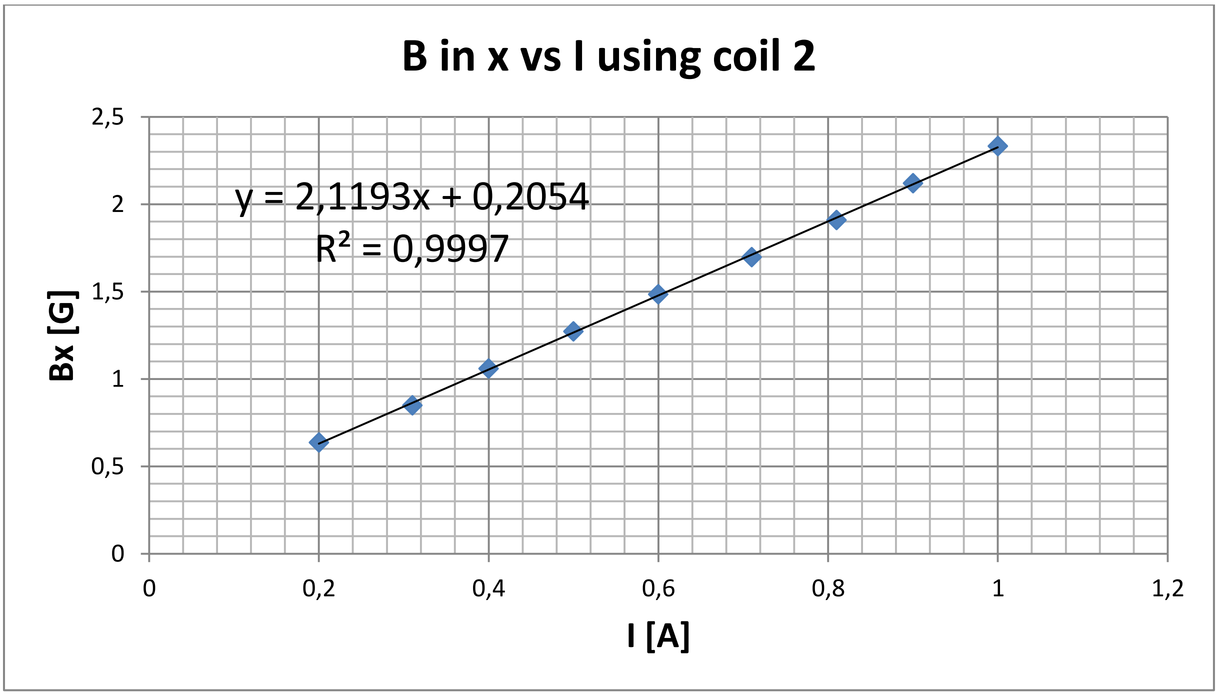

Figure 8: B in x vs I using coil 2

It can be noticed that the alignment of the field in $\boldsymbol{y}$ is still quite good ($\frac{\mathbf{2.1}}{\mathbf{78.4}} \approx \mathbf{2.7}\%$), but that the field produced in $\boldsymbol{y}$ due to coil 2 is less than the field produced in $\boldsymbol{x}$ due to coil 1 (78.4G in comparison to 230.7G). This makes sense when having a look at the formula which describes the magnetic field produced at the center of the solenoid:

$$B = \frac{\mu_0 I N}{\sqrt{l^2 + 4r^2}}$$

Here B is the magnetic field in T, μ_0 is the permeability constant ($4\pi\times10^{-7}$ V·s / (A·m)), I is the current in A, N is the total number of turns of wire in the solenoid, l is the length of the solenoid in meters and r is the radius of the solenoid in meters (Source: http://www.netdenizen.com/emagnet/solenoids/thinsolenoid.htm[3]).

In our case the main effect in the change of magnetic field was due to r. Its value got larger because the 2nd solenoid had to be put on top of the 1st one. However this effect shouldn't be able to reduce the field by such a great amount, especially considering that l is larger than r and that we only have a square root contribution. Therefore there might be other factors. One of them is probably that it wasn't too easy to wind the second solenoid and therefore the individual windings are not exactly parallel to each other (figure 4). This will cause a reduction in the field contribution in the y-direction. Another reason could be, that the Hall probe measuring the y-direction contribution is calibrated in a different way. These two potential causes are definitely worth investigating.

Temperature effects on the probes due to solenoids

When passing a current of 1A through the solenoids they start to heat up. This creates two problems. One of them is that the solenoids might get damaged by the heat; the second one is that the Hall probes are sensitive to temperature changes. Considering the second issue I tested what happens to the Hall probe reading when passing a current of 1A through the first coil (i.e. heating up the coil and the Hall probe positioned within it):

y-direction:

V_1 = 2.664

V_2 (after 2 minutes) = 2.664 (the coil was very hot)

x-direction:

V_1 = 2.130

V_2 (after 2 minutes) = 2.137 (the coil was very hot)

However, we don't know whether the scale of the Hall probe is being changed, or whether the 0 – offset. Hence we tried to control the temperature through another method and now no field was being applied. We used a heating pad to heat up the probe and a temperature sensor (AD 592) to monitor the heating.

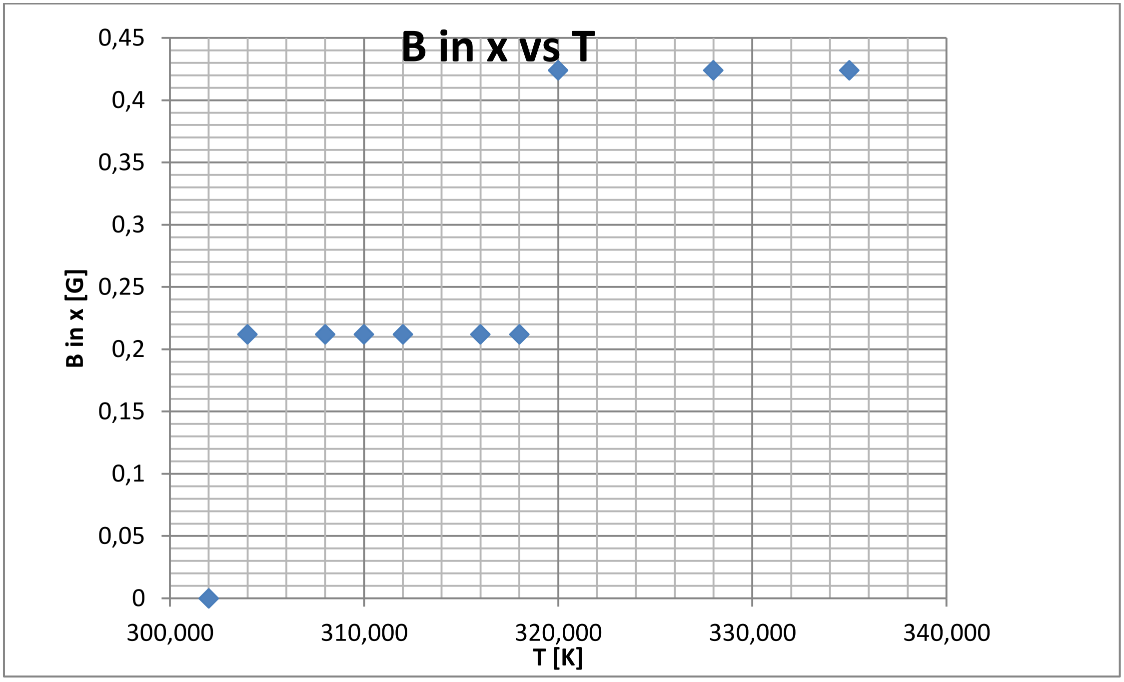

Figure 9: B in x vs T

From the graph we can see that when the Hall probe only has the effect of the earth's magnetic field, which effects I have neglected, then a change of approximately 20K will provoke a change of approximately 0.5G.

To see whether this has anything to do with the specific direction the Hall probe is orientated at (whether it has anything to do with the Earth's magnetic field), I did the same measurement with the y – direction sensor:

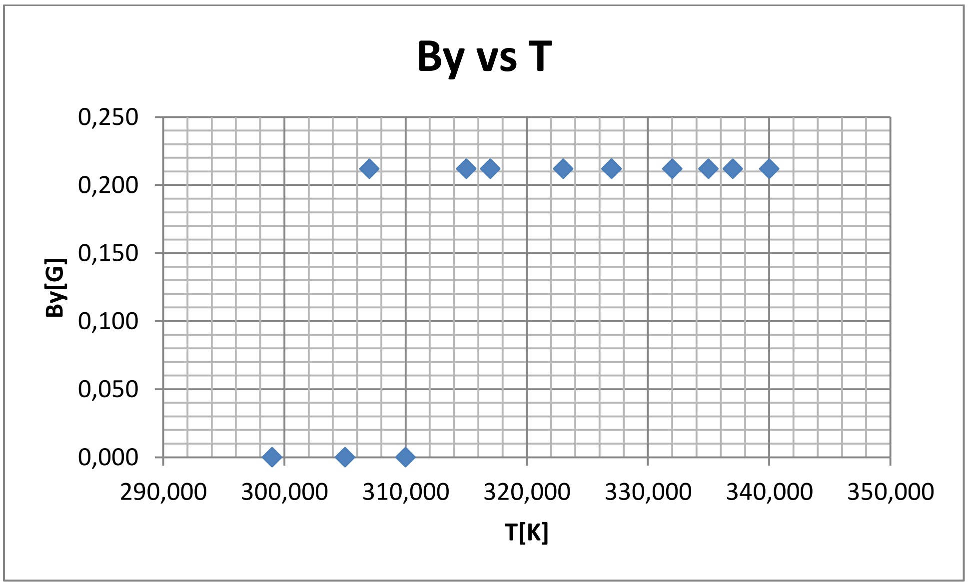

Figure 10: B in y vs T

We could conclude that orientation does make a difference because the change in the reading is less for the same amount of heating up. However I found out that this is probably not the case because when rotating the whole set up by 90˚, I got the following graph:

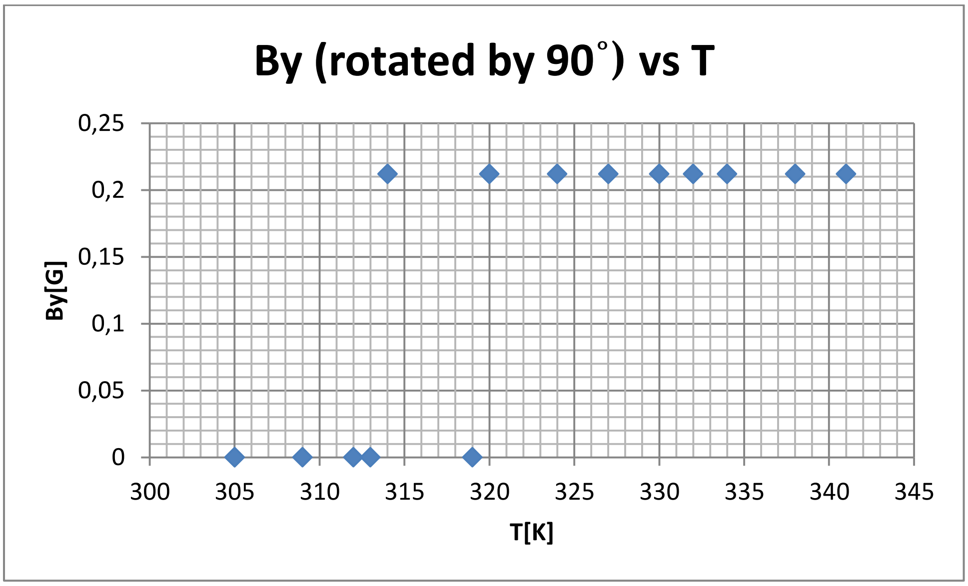

Figure 11: B in y (set up rotated by 90˚) vs T

This looks very similar to Figure 10 and therefore I concluded that the sensor in the y – direction is just not as sensitive to temperature changes as the one in the x – direction and that the Earth's magnetic field doesn't play a big role.

Problems with the measurements:

The temperature sensor is not directly measuring the temperature at the Hall probe.

The accuracy of the Hall probe is not good enough to get points in-between.

It is difficult to heat up the whole set up and especially to cool it down.

Note: The following results were obtained by using the "1st Hall probe"

Alfred Johnson figured out a better way how to be able to measure the temperature of the Hall probe. We basically put the 1st Hall probe (without the solenoids) and the temperature sensor onto a metal sheet which we could then place onto the heating pad.

The following graph was the result:

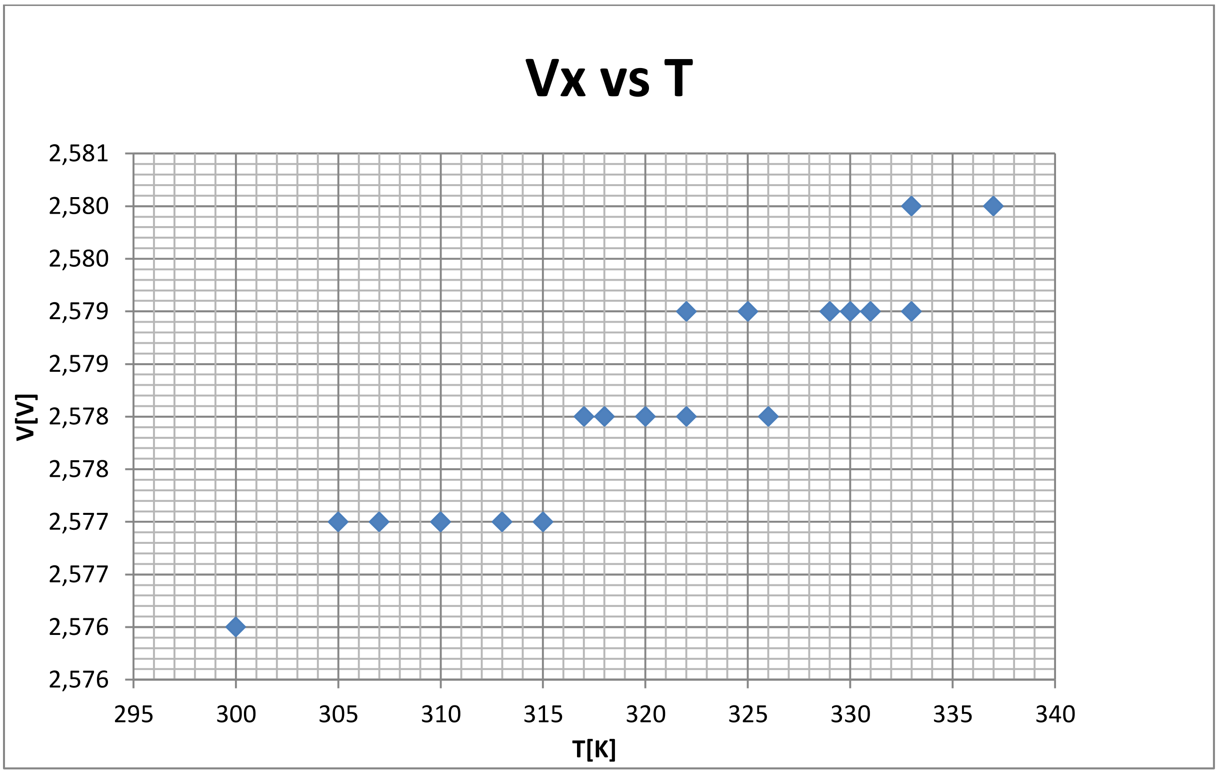

Figure 12: Vx vs T

We observe that the voltage measurement really does change when the temperature is being increased, even if there is no field (apart from the earth's magnetic field).

Next steps + Potential problems and solutions: Make new board (first coil around long side), Long term calibration check, Checking whether the Hall probes can detect small enough changes in angle (should be able to detect changes in 0.2G), Aligning the Hall probes!!! , How will radiation influence the sensor? , Use single axis hall probe to make set up smaller

Accuracy of the Hall probe: +- 1mV (fluctuation in the 0.1 mV range)

Temperature effects on the probes through solenoids (Can we cool them down, can we make measurements fast enough?)

Magnetic field distortions

Magnetic field distortions should not affect the Hall probe, as long as we place it in between two transducer pairs (i.e. at 30˚, when transducer pairs are placed at 15˚ and 45˚). Maximum distortion due to the transducer I found was 0.005G, which is much lower than the accuracy of the Hall probes themselves

References

[1] I.B. Vasserman et al, „Magnetic Measurements and Tuning of Undulators for the aps fel project", published in the proceedings of the 1990 particle accelerator conference, New York, 1999

[2]http://www.dextermag.com/resource-center/magnetic-field-calculators/field-calculations-for-rectangle

[3]http://www.netdenizen.com/emagnet/solenoids/thinsolenoid.htm

Temperature sensor 592