Improvement of a vibrating sample magnetometer

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Improvement of a Vibrating Sample Magnetometer

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Abstract

Measuring the components of the magnetic moment of a nanostructure is important to describe several of its physical properties. Doing this with fairly high speed and accuracy, the Vibrating Sample Magnetometer (VSM) is suitable for this task. The VSM uses the principle of a sample, vibrated by a transducer, which causes a changing flux in nearby coils, inducing a voltage, which can be measured. Smart positioning of these coils makes it possible to measure the components of the moments. The VSM used in the group Physics of Nanostructures was not accurate enough. Mostly caused by vibrations, but also from system components, the sensitivity was $10^{-8}$ Am$^2$ with a stability of 0.3%.

By installing a new coil-house and air cushions under the transducer table, the vibration signal is about ten times smaller. Additionally improvements are made to the set-up itself and the computer software, by which it has become more user friendly and more stable.

The realized improvements caused some difficulties in calibrating the system, so further optimisation still needs to be done. However, first measurements show an improvement in the sensitivity. Although a exact value is not measured the sensitivity is now better than $10^{-8}$ Am$^2$. 
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Preface

I could tell that I did my traineeship in the group Physics of Nanostructures because of the subject, but that is only part of the reason. Most important, I think, is to get acquainted with the scientific work as done in a research group. But that is not all. It should be a lot of fun to work with the people around. That gives a positive spirit, also knowing that they are prepared to help when needed. So let me just say thanks to those who did help or just made it a good time (helping in that way):

- Jef Noijen and Henk Swagten for their good and friendly support and help. Jef also for helping me around the electronics and some very nice measurements!
- Gerrie Baselmans and the people of the workshop for helping me with the design and engineering of some new parts.
- Floor de Nooij for her contribution to my report.
- Harm Wieldraaijer for his loudly presence.
- All of the group Physics of Nanostructures for the nice time and all the help they have given.
- Fred van Nijmweegen en Gerard Harkema for their support of the PhyDas system.
- Lourens Rijniers for his assistance with LabWindows.
1 Introduction

To measure the magnetic moment of a material they can be placed in an external field. Insight in how the external field influences the magnetic moment of a nanostructure tells something about several magnetic properties of the sample. Dependent on the orientation of the sample in the external field the measured moment can have different values, following the easy and hard axes of the magnetic material(s) used. Other parameters can be told from a so-called hystereses loop, from which e.g. the magnetic susceptibility or saturation magnetisation can be deducted.

From several ways to measure the magnetic moment of a sample, the Vibrating Sample Magnetometer (VSM) uses the induction method. A vibrating causes a changing magnetic flux in nearby coils thereby causing a induction voltage which can be measured. Because the nearby coils are placed in a specific way, it is possible to measure two, of three, directions of the magnetic moment of a sample.

The VSM turns out to be a rather fast way and accurate enough to, e.g., measure the moment of a couple of monolayers of ferromagnetic materials on a ten by ten millimetre substrate.

In the group Physics of Nanostructures a VSM has been build recently. Goal of the traineeship, of which the results are described in this report, is to improve this VSM. Not only the hardware but also the software are improved in some points.
2 VSM technique and theory

2.1 Experimental setup and theory

2.1.1 General
With a vibrating sample magnetometer the amplitude and direction of the magnetic moment of a sample are measured. The technique is based on flux- and induction voltage measurements. The VSM setup is shown in figure 1 and will be briefly described below. A more extended description can be found in [VAN00].

![Figure 1. VSM Setup. The sample is shown in 'zero'-position between the pick-up coils. [VAN00]](image)

When a sample is placed in an external magnetic field the material is magnetized. The magnetization, $M$, is determined by:

$$\vec{M} = \frac{\sum \vec{m}_{at}}{V}, \quad (1)$$

with $m_{at}$ the magnetization per atom and $V$ the volume. The sample may be represented by a single dipole if the sample is well shaped, for the purpose of this research and report 4 times 12 mm with a thickness of several angstroms, and the distance from the pick-up coil(s) to the sample is large compared to the sizes of the sample.

$$\vec{m} \approx \sum \vec{m}_{at} = M \cdot V \quad (2)$$

When this dipole is moved up and down along the z-axis by a transducer with a specific frequency, a time specific magnetic flux is generated. According to Faraday's law, this flux induces a voltage in nearby coils. That induced voltage is linear to the induction field created by the sample, which in turn is linear to the magnetic dipole moment.
Improvement of a Vibrating Sample Magnetometer

In the VSM present at FNA, the induction field is picked up by eight pick-up coils, which are located on two sides of the sample in groups of four. Between two large electromagnets a homogeneous field is created. The position of the coils is fixed to the homogeneous field and the pick-up coils are connected in such a way that possible fluctuations of the homogeneous field are compensated. The induction voltage generated in the pickup coils when the sample is vibrating is given by:

\[ U(t) = -\frac{d\phi}{dt} = - N\mu_0 \frac{d\vec{H}}{dt} \cdot \vec{m}, \]  

(3)

In this formula \( \phi \) is the by the sample generated flux, \( N \) is the number of coils, \( \mu_0 \) the magnetic permeability in vacuum and \( \vec{m} \) the magnetic moment of the sample.

The field vector \( \vec{h} \) is the vector at the sample location generated by a unity current through a pick-up coil. When split-up for each direction \( (x,y,z) \) and with the movement in the z-direction like \( z(t) = z_0 \sin(\omega t) \) the induced voltage in one coil is:

\[ U(t) = - N\mu_0 z_0 \omega \cos(\omega t) \left( \frac{\partial \vec{h}}{\partial x} m_x + \frac{\partial \vec{h}}{\partial y} m_y + \frac{\partial \vec{h}}{\partial z} m_z \right), \]  

(4)

This means that when the amplitude \( z_0 \) and the sample are relatively small the voltage is linear proportional to the amplitude and the frequency \( \omega \).

In the setup shown in figure 1 we use a eight coil system because with one coil it is not possible to determine the three directions of the samples magnetic moment.

In figure 2 a more detailed picture is given of the coil system.

---

Figure 2. Coil system shown from three directions. [VAN00]
Notice that $2x_0$ is roughly the distance between the poles of the homogeneous field coils. The position of the coils as given in table 1 is relative to the position of a sample.

<table>
<thead>
<tr>
<th>$x_1=x_2=x_3=x_4=-x_0$</th>
<th>$x_5=x_6=x_7=x_8=x_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y_1=y_3=y_5=y_7=y_0$</td>
<td>$y_2=y_4=y_6=y_8=-y_0$</td>
</tr>
<tr>
<td>$z_1=z_3=z_5=z_7=z_0$</td>
<td>$z_2=z_4=z_6=z_8=z_0$</td>
</tr>
</tbody>
</table>

**Table 1:** Relative positions of the pick-up coils

This gives, after some mathematics, the precise voltage components in each pick-up coil. If the voltages are added or subtracted from each other, the results are linear proportional to the $x$, $y$ and $z$ components of the magnetic moment of the sample. These combinations of pick-up coils are given in table 2:

<table>
<thead>
<tr>
<th>Coil</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>x-Det</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>y-Det</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>z-Det</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

**Table 2:** Coil combinations for measuring the components of the magnetic moment of the sample

More detailed information to understand these combinations can be found in [VAN00].

From a more detailed inspection of table 2 one can find an even smarter combination such that the computer system attached to the setup is dealing with two voltages only. These voltages are given by:

$$V_A = -V_1 + V_3 - V_6 + V_8$$
$$V_B = -V_2 + V_4 - V_5 + V_7$$

(5)

If these voltages are added or subtracted the formulas for $V_x$ and $V_y$ are found:

$$V_x = V_A + V_B$$
$$V_y = V_A - V_B$$

(6)

These are again linear proportional to the magnetization in $x$- or $y$-direction of the sample (see figure 1).

As shown, this method only measures two directions of the field at the same time. It is not possible to measure the $z$-component. To measure this third component the sample has to be repositioned.
2.1.2 Noise
Because measurements yield relatively small signals it is important to
consider the noise signal in some detail. A more thorough description is given
by [VAN00].

Thermal noise
The movement of the electrons in the signal amplifier causes thermal noise.
The noise power is the same for all frequencies and is given by:

\[
\frac{V_n^2(f) df}{df} = 4kTR df
\]  

(7)

In this formula \( k \) is the Boltzmann constant, \( T \) is the absolute temperature, \( R \)
is the gas constant and \( f \) is the frequency.
Thermal noise is not influenced by the position and/or orientation of the pick-
up coils and is non-correlated to the movement of the transducer.

1/f Noise
1/f Noise is seen in thin metal films and in halfconductors. So it is seen in the
setup in several parts, which contain such materials. The noise has been
empirically correlated proportionally to the inverse frequency. Because the pre-
amplifiers have a constant “input voltage noise spectral density” above 60
Herz the influence of 1/f noise on the signal is much smaller than the thermal
noise and can therefore be neglected.

2.1.3 Field noise
There are two types of field noise. One is created by fluctuations in the
homogeneous field. These fluctuations can be caused by current fluctuations
in the coils. Because the flux \( \phi \) is given by:

\[
\phi = \oint_C \vec{B} \cdot \vec{n} da = \mid \vec{B} \mid A \cos(\alpha), \text{this gives } \frac{d\phi}{dt} = \frac{dB}{dt} A \cos(\alpha)
\]  

(8)

The coils in the given setup (figure 1 and 2) are less sensitive for these
fluctuations because the coils are perpendicular to the x-axis. More
specifically, if there is a fluctuation, coils on both sides of the sample are
picking it up. Because the coils are connected as given in table 1 and
equation (5) they cancel out the effect.
Movement of the pick-up coils caused by the mechanical vibrations and sound originating from the transducer, create the other type of field noise. As described above the effect of the homogeneous field is cancelled out but vibrations caused by the transducer directly influence the measured flux created by the vibrating sample. These vibrations can only be cancelled out if the pick-up coils are tightly fixed to their position. When they rotate over a small angle the flux is change:

$$\phi = \int \int \int B \cdot \vec{n} \, da = B A \cos(\alpha)$$

$$\Rightarrow \frac{d\phi}{dt} = -B A \frac{d \cos(\alpha)}{dt} = -B A \sin(\alpha) \dot{\alpha}$$

$$\Rightarrow \phi = B A \sin(\alpha)$$

(9)

![Figure 3](image)

**Figure 3** Pick-up coil positioned in a field H. [VAN00]

The time derivative of $\phi$ shows clearly that a coil with its axis parallel to the applied field is less sensitive than a coil with its axis perpendicular to the applied field. (Think of a sine plot, its derivative is higher near zero than at $\pi/2$)

A full calculation can be found in [VAN00].
2.2 Software and Data processing

A PhyDas system connected to a PC running the VSM software does the setup control and the data acquisition and processing. The computer software is specially written for the VSM using LabWindows.

![PhyBus System Diagram](image)

**Figure 4.** Structure of the PhyDas system. The PhyDas system has a modular structure so parts can be easily repaired, changed or added. [VAN00]

As shown in figure 4 the PhyDas system has a modular approach using several interfaces for setup control and data acquisition. Each module, with its own interface, has a dedicated task. Most interfaces function independently and are only connected to the PhyBus communication line. Nonetheless, most time dependent interfaces in this setup use the same clock signal from the MSI PCK clock-out. As shown the DDS-clock (Direct Digital Synthesizer) and the ASR (Analog Signal Recorder) are connected so the period of the transducer (and therefore the sample) is synchronized with the sampling rate of the ASR. The data recorded by the ASR is returned to the PC software, which calculates the magnetic moments and displays them on screen and writes them to a file on disk. The software also has a modular structure.
The main program is just there to start the user interface and the command parser. The parser actually sends commands from the interface to the different VSM hardware libraries. These libraries contain all the software routines to control the PhyDas interfaces and the data acquisition and processing. They in turn send their commands to the PCI hardware libraries, which are responsible for the low level communication through the PCI connector with the different PhyDas interfaces, or back to the user interface to update the shown information.

By using such structure the user interface is more or less separated from the rest of the software and new commands are added easily. When a new device is connected, only a new module and command in the parser have to be added. This makes it also easier to make changes or improvements. More on the structure and function of the software can be found in [VAN00]. In the paragraph 2.3 the mentioned modules of the PhyDas system and software will be described more thoroughly.
2.3 Review of some possible improvements to the FNA-VSM

2.3.1 In the setup
There are several problems in the setup that has to be solved. The most important is to reduce the vibrations of the pick-up coils. Although they have their axis parallel to the magnetic field and to the flux generated by the sample, the movement of the coils is still an important noise factor. It might even be possible to improve the sensitivity by a factor 10 if the pick-up coils are more fixed. This can be done by another coil-house between the poles of the external field coils.

Another problem is the position and orientation of the sample. The sample is brought in to the measuring area with a probe, which hangs on the transducer. The probe has no orientation neither has the sample hanging at the probe, so orientation is done by hand, which of course is not very accurate. Doing some measurements while rotating the probe around its axis and then doing the final measurement with the optimized orientation optimizes the orientation.

The other problem is that of positioning the sample in the middle between the pick-up coils. At this time a Perspex probe is used, which is not symmetrical and not straight. This gives an extra possibility for sample misalignment. A better fixation of the sample position would improve the possibility to compare several samples.

To decrease the vibrations further, air cushions could be used under the table holding the transducer instead of rubber plates currently used.

The problem of the vibrating pick-up coils and the positioning of the sample is be solved if a more rigid coil-house and coil fixation is used. If the probe is made of a more rigid material, like Kel-F, a type of plastic, this would prevent undesirable swinging of the probe and would made it more straight. But also the magnetic moment of the probe should be small. This means using a less rigid material.

A better orientation is done by making a probe with an oriented headpiece, which fits in to the transducer in only one manner.

Another possible change to the system is not so much an improvement but more a simplification. It involves combining two power sources into one so they both fit into the system-crate.

The PhyDas system...
The modular structure of the PhyDas system makes it easier to improve its performance. Most of the different interfaces function normally. There are two problems found. Many interfaces use a “floating” zero/ground in their electrical circuits. This was done to prevent one device influencing the other. At the same time this also gives the problem that a signal between two devices is not defined in a unique way. Also, electronics like the pre-amplifiers work with very low voltages (nV) and are therefore very sensitive. If they are not shielded by a metal box attached to a ground they are influenced by signals
and fields from outside the amplifiers-boxes. So some sort of earthing is desirable.

A second improvement is to upgrade the DDS. The DDS should be able to reset itself when it starts or ends. This would reset the off-set of the generated sine-function to zero. The current software routine is not able to do this because the DDS interface is not recognizing the command.
2.3.2 *In the software*
Several modules in the software were requiring an improvement. Especially the way the homogeneous field is set for values near zero can be improved. At this time there is a module called “Field.c”, which contains all the software commands to control the field. This module gives low-level commands to the hardware libraries, which set the PhyDas interfaces through the PCI connection.

The coils that create the homogeneous field are connected to a power voltage supply. This supply is controlled by the output of the DAC interface from the PhyDas system. The needed DAC value is calculated by comparing the current field, measured with a Hall-probe, with the required field. The required step size in the DAC value is calculated, so the DAC cannot make too large steps. When steps are larger then the maximum step size have to be made, the software makes the maximum step size until the Hall-probe measures the required field. This method works fine for fields far from zero. In this far field region (from 50 to 657 kAlm) the needed accuracy is not very high. For samples the most interesting field range is around –20 to 20 kA/m because most samples will show a switch in their magnetic moment when the homogeneous field switches. Precisely in this range of small fields the method described above shows its mishap. When setting the field around zero, all kinds of inaccuracies are important. The sensitivity of the Hall-probe, which is used to measure the current field, the sensitivity of the coils of the homogeneous field and the remanence of the electromagnets are the most important ones. If the software gets information from the Hall-probe that the required field is not yet set, the software tries to correct this by resetting the coils. When working with very small field-step-sizes (many small steps around zero field) this gives the problem that the field will jump up and down, thereby lowering the accuracy as shown in figure 6.
Figure 6. Measurement of a sample in a small field range around zero field. Clearly shown is the error in field setting and in the calibration of the VSM. Measurement done with a SiO$_2$/Co(500 Å) sample from -8 to 6 kA/m.

This problem can be cancelled by the following procedure. Instead of comparing the current field and the required field and then calculating how many steps in what size the DAC has to be increased or decreased, the use of a table would be better. This table provides the software a list containing the exact DAC value for each field in a smaller DAC values range. (The DAC can operate in several ranges.) For larger fields this cannot be done because it harms the electromagnets to go from a low field to a high field in just one step. Therefore the DAC-table method should be limited to be used only in the range between -20 kA/m to +20 kA/m.

A second software improvement should be made in the DDS library, if the DDS is adjusted in the way described before. The DDS would then need a reset command every time it starts and a reset/phase reset command every time it stops. At this time the software gives a reset command, which is not compatible with the hardware implementation in the DDS.
3 VSM Results

3.1 Implementation of improvements

Because of the timeframe of the traineeship a selection had to be made of possible improvements. First choice was the coil house, because it was expected this would give the greatest signal improvement. Therefore a quick survey has been done to the magnetic properties of some materials that could be used.

3.1.1 Materials

When measuring the magnetic moment of a sample it is important the background signal is as low as possible. Therefore the material for the coil house and probe should have magnetic properties much smaller than most samples. On the other hand the materials should be rigid enough to minimize vibrations of the coils or the vibration of the probe.

Three materials that can be used are: Kel-F, Ertallite and Perspex. Kel-F is very rigid, Ertallite and Perspex have good magnetic properties. All these materials are diamagnetic.

In figure 7 the magnetic moments against fields from −1000 to 1000 kA/m are shown.

![Graph showing magnetic moments against fields for Kel-F, Ertallite, and Perspex materials.](image)

Figure 7. Measurements of the magnetic moments of Kel-F, Ertallite and Perspex. All measurements are done with SQUID. The samples had the same size and volume.

From figure 7 table 3 can be derived.

Table 3. Magnetic moments measured in SQUID. The right column shows the field derivative of the magnetic moment.

<table>
<thead>
<tr>
<th>Material</th>
<th>Magnetic moment/field (mAm²/kA/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perspex</td>
<td>((-6.03 \pm 0.01) \times 10^{-8})</td>
</tr>
<tr>
<td>Ertallite</td>
<td>((-7.53 \pm 0.02) \times 10^{-9})</td>
</tr>
<tr>
<td>Kel-F</td>
<td>((-1.53 \pm 0.01) \times 10^{-7})</td>
</tr>
</tbody>
</table>
Improvement of a Vibrating Sample Magnetometer

These results show that Perspex has the smallest magnetic moment at each field in the given range.

3.1.2 Coil house
During the building of the VSM the coil locations were already optimized, the new coil house will be designed with the present locations of the pick-up coils as specific design parameters. To prevent the coils from vibrating caused by the transducer the coils completely fit in to the coil house. To dampen the vibrations from the surroundings the material the house is made of, should not be fully rigid. After some measurements, Perspex shows to have the best magnetic properties for this purpose. Perspex has a diamagnetic moment over the field of \((-6.03 \pm 0.01) \times 10^{-8}\) See table 7. Figure 8 shows the new design.

![Figure 8. New coil house.](image)

A technical drawing of the new coil house can be found in appendix A. The new house will tightly fit around the core of the coils that create the homogeneous field for extra stability. Unlike the old coil house the new will have a probe guide. An unexpected problem had to be solved because the old probe had some anomalies such that it did not fit into this guide. A new Perspex probe has been made, its diameter was too large. It did fit into the probe guide in the coil house but the friction appeared to be too large for the
transducer thereby reducing the amplitude. To solve this problem a new probe of Perspex was made with only a straw on at the tip holding the sample. This also further reduced the magnetic contribution of the probe to the measurements. The specific use of the probe guide was lost. To reduce the noise from vibrating cables they are attached to the coil house and shielded.

A second improvement has been made later on. Instead of rubber plates, air cushions are placed under the table that holds the transducer in its place.

Another improvement made is a new voltage power supply for the PGA (Programmable Gain Amplifier) and the pre-amplifiers. In the old setup both had separate power supplies, which did not fit in to the setup crate. This was done to prevent interference. In the new design there are still two power supplies but now in one box which fits in the setup crate. A print layer layout of the electrical circuits can be found in appendix B.

Modifications are made to the DDS. It has been redesigned to reset itself at startup and shutdown. Hereby the offset will always be zero. However these modifications created another problem. The interface between the PhyDas system and the attached computer stopped functioning. This probably was related to the PCI-interface on the motherboard of the PC. Installing another PC solved the problem.
3.2 Implementation of software improvements

Several modifications have been made to the software. Some were only for debugging or controlling constants and parameters. Others involve how the modules work. Only the larger changes are described here. Smaller changes are documented within the software itself and only concern debugging.

The largest change is made in how the software controls the PhyDas system around zero field. For this region, from \(-20\) kAm to \(+20\) kAm, a different sequence has been written in the field.c module. This new sequence does not calculate the next DAC value from the current field and DAC value but uses a table with DAC values to set the field. By doing so errors in the measurement and setting of the field are not added to each other. Results of this new sequence are shown later.

To use the new DDS features a few lines of programming were added to the software to use the new reset / phase reset function. The used commands are given in the DDS-manual [DDS].
3.3 Results of implemented improvements

3.3.1 Stability
The stability of the VSM is determined by the stability of its parts like the PGA (Programmable Gain Amplifier) and signal enhancers. To determine the stability long time measurements were done. Normally such measurements would take up to 16 hours but due to technical and software problems no measurements of this period were done.

To neglect the noise contribution from background noise from e.g. the diamagnetic probe a sample with a large moment was used, in this case a fully saturated nickel sample, with a magnetic moment of $1.47 \cdot 10^{-1}$ mAm$^2$. The measurements were done directly after enabling the hardware.

Figure 9. Measurements over a period of approximately an hour. These measurements were done at a constant magnetic field of 241 kA/m and one measurement per minute with 11s integration time was done.

Heating of the electrical equipment and stabilizing of the transducer frequency and amplitude probably causes the observed drift. Because the small time frame the measurements are taken in it is not possible to get a good impression of the overall stability of the VSM. The stability in figure 9 at about 60 minutes is less than 0.3%. In the old situation this endured for over 150 minutes.

3.3.2 Background signal
Important are the improvements in the background signal. Most of the sensitivity problems with the VSM are due to vibrations of the pick-up coils made by the transducer. Another problem is the background signal produced by the magnetic moment of the probe and dirt on it, mostly the remainings of samples. As told, to minimize the vibrations of the pick-up coils a new coil house has been made. Also air cushions are placed under the table holding the transducer so vibrations through the ground are limited.

To measure the background signal two measurements are done. The first one is done with the probe in upward position attached to the transducer. This will
keep the weight on the transducer the same without the probe hanging in the sample area. This cancels the risk of any contribution to the measured magnetic moment. The result is shown in figure 10.

![Figure 10](image)

**Figure 10.** Measurement of the background signal without the probe in the sample area. The measured moment is the result of the vibrating coil house and vibration of the pick-up coils. Only the x-component is shown.

Compared with [VAN00] this result shows a ten times improvement. The same measurement is done with the probe hanging in the measurement area. The result is shown in figure 11.

![Figure 11](image)

**Figure 11.** Background signal measurement with the probe in its normal position. Only the x-component is shown.

This result seems the same as in figure 10. By [VAN00] it is shown that when the probe contribution still existed it would be opposite to the vibration noise. Figure 11 shows roughly the same as figure 10. This concludes that the probe contribution is much smaller compared to the vibration noise, which of course is an improvement. On the other hand the vibration noise itself is about 10 times smaller compared to the original set-up. The old value at 300 kA/m
equals $1.25 \cdot 10^{-3}$ mAm$^2$ while the new value at 300 kA/m equals $1.5 \cdot 10^{-4}$ mAm$^2$.

3.3.3 Sensitivity & first results
Because of time no thorough stability measurements are done yet. Still a first measurement has been done. The result is shown in figure 12.

In this figure the improvements made to the field setting are shown. The field is no longer jumping around zero but is steadily increasing or decreasing. On the other hand it is also shown that the calibration of the field setting and measured moments is not perfect yet. The theoretical value of the $x$-component of the magnetic moment of the sample is $1.33 \cdot 10^{-3}$ mAm$^2$. Measured from the distance between the highest and the lowest value the experiment above shows a magnetic moment of $1.72 \pm 0.08 \cdot 10^{-3}$ mAm$^2$. A full calculation of this moment is given in appendix D. Most likely the difference is caused by a calibration error in the field setting and the value for $m_x$ and measurements of the size of the sample.

Figure 12. Measurements to a Si$_2$O/Co(500Å) sample. The blocks mark the result going from positive to negative field. The triangles show the result from negative to positive field.
To see if these improvements result in a greater sensitivity measurements are done to a Si$_2$O/Co(10Å) sample. The result is shown in figure 13.

![Figure 13. Measurement of a Si$_2$O/Co(10Å) sample. Again the blocks mark the result going from positive to negative field. The drift shown at positive field could be caused by a calibration error.](image)

Just for qualitative comparison to [VAN00], one could derive from figure 13 that the sensitivity may be smaller than $10^{-5}$ mAm$^2$ because smaller steps in measuring the magnetic moment are shown.
4 Conclusions and Recommendations

4.1 Conclusions

Several improvements to the VSM are made in the mechanical and electrical set-up as well as in the software. First measurements show the sensitivity has most likely improved and may be smaller now than $10^{-5} \text{ mAm}^2$ ($10^{-5} \text{ emu}$). It is shown that the background signal caused by the probe is cancelled out and vibration noise is about ten times smaller. As a result the background signal around zero field has increased because contributions from vibrations and the probe no longer cancel each other out.

The choice to use Perspex has been made upon results that show that Perspex has a smaller diamagnetic moment than Kel-F, which is more rigid though.

With the new probe and coil house not only the background signal has been reduced, also the positioning of the sample is more consistent. The orientation is still a problem and can only be optimised manually.

Although exact measurements were not completed because of a software bug, causing the system to stop after about one hour, the system seems to stabilise in a shorter time compared to the old set-up.

The step size of the power system to the electromagnets is not small enough yet but the improvements to the software and DDS show a more stable and steadily increasing or decreasing field, even around zero.

Because a good calibration could not be done, first other problems had to be solved, at the moment the results are not optimised yet but overall the system seems to be improved.

4.2 Recommendations

First recommendation is to do a good calibration. This is a problem for which the precise actions in the software should be analysed to see how the software handles the input in the calibration module. The description in [VAN00] is insufficient because after doing one calibration, a second does not give a zero result.

After calibration, measurements to the sensitivity can be done. Count measurements at one field setting and determining the spread in the results could then be done.

To determine why the system stops functioning after about one hour most likely a good analyses of the involved software modules would help. If corrected, a good long lasting stability experiment, about 16 hours, is needed to tell the exact stability.

Furthermore, there are also some improvements to the set-up that could be applied. The orientation of the probe still has to be done manually. It would be easier to fix the orientation of the probe and the attachment of the sample to the probe in some way. The easiest is to fix the orientation of the head of the probe to the transducer.
Around zero the field setting still is not accurate enough. Besides the software improvement, which makes it possible to make smaller steps also the power supply to the electromagnets should be modified to make smaller steps more accurate. Perhaps a separate power supply for small fields solves this problem.
5 Literature

[VAN00] B. Vandevelde "Ontwerp en realisatie van een Vibrating Sample Magnetometer"
Maart 2000

[VAN] B. Vandevelde VSM Software descriptions

[DDS] User manual PhyBUS
85 MHz Direct Digital Synthesizer, Hardware revision 1
BLN 95-06 UM

[ASR] User manual PhyBUS
Analog Signal Recorder, Hardware revision C
BLN 93-21 UM

[LAB] Samual P. Harbison, Guy L. Steele Jr.
1995, Tartan Inc.
Doorsnede A-A

Teloreantie: ± 0.2 mm
Materiaal: Perspex
Getekend: Jelle de Jong
Telefoon: 4273
Appendix B

Schematics of the new power source
Appendix C

*Connection scheme of the PhyDas system*
Appendix D

Calculating the theoretical value of the magnetic moment of Co-500

Given a Co-500 sample with the dimensions in table 1.

Table 1. Dimensions of the Co-500 sample

<table>
<thead>
<tr>
<th>X (mm)</th>
<th>4.03</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y (mm)</td>
<td>5.50</td>
</tr>
<tr>
<td>Z (Å)</td>
<td>430</td>
</tr>
</tbody>
</table>

The volume is then: $9.52 \times 10^{-13} \text{ m}^3$

For Co: the magnetic saturation factor is: $1.76 \text{T} = 1.4 \times 10^3 \text{kA/m}$

$1.40 \times 10^6 \times 9.52 \times 10^{-13} = 1.33 \times 10^{-6} \text{ Am}^2 = 1.33 \times 10^{-3} \text{ mAm}^2$