

DESY SUMMER STUDENT PROJECT



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Development of Automated Magnetic Hysteresis Generator for In-Situ Experimentation and Analysis of Magnetic Properties of Amorphous Ribbon

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Abstract

The main objective of this project was to develop a magnetic hysteresis generator that automated the process of graphing the magnetic response of materials and could be used within an x-ray beamline. The process should be able to provide variable frequency and amplitude magnetic fields to the material. Loops for $\text{Fe}_{75}\text{P}_9\text{Si}_{8.5}\text{B}_{7.5}$ ribbon under varying amplitude fields are developed and the results have been analyzed.



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1 Introduction

Magnetic hysteresis loops give a metric for the magnetic susceptibility of materials and information about their time varying magnetic properties. [1] They are a plot of a samples magnetic response (magnetic or B field) versus the H field of its environment. Important properties of a hysteresis loop include the width between horizontal axis intersections, or coercivity, and the levels at which the B field of the sample saturates. [1] From this information we can learn more about magnetic properties of materials and utilize them in engineering projects as well as enrich the understanding of magnetism in solids in general.

When combined with high energy x-ray beamlines, observations can be made of the stress and strain of the sample as function of the magnetic field of its environment. The Debye-Scherrer rings are analyzed to determine the lattice spacing and hence deformation of the structure in the field. [2]

2 Goals of the research project

The main objective of this project was to develop a hysteresis loop generator capable of producing a tunable magnetic field for a sample ribbon. The device needed to have an opening for an x-ray beam to hit the sample and continue on to a detector as well as being able to run multiple measurement and power devices.

3 Design and Setup

3.1 Overview of Setup

The setup we used for the device consists of a waveform generator, data acquisition card (DAQ), isolation amplifier, and helmholtz coils. Within the coils are two smaller coils that measure the induced field of the sample. We used a Hameg 2550 waveform generator connected to an isolation amplifier, and an Agilent u2531a data acquisition card to sample voltage values. The waveform generator feeds voltage to the larger helmholtz coils, and the DAQ reads the induced field voltage from the smaller coils and feeds this value to a computer program.

The inner pair of coils were connecting in opposite polarity so that by themselves, they would cancel eachother's voltage. They are also in series so as to reduce their overall resistance and limit the heat produced, thus keeping a more constant resistance across them.



Figure 1: View of the entire setup.

4 Hardware

4.1 Preparing the Induction Coils

We used a stepper motor to spin the coils paired with a control box to step through each turn. We were able to spin the coils in increments as small as $\frac{1}{360}$ th of a turn. The wire is moved slowly down the length of the coil and windings are laid down layer by layer. Both coils were created with the same geometry and number of turns in order to equally negate one another.

Finding the induced field from the voltage across the sample coil is simple. Invoking Faraday's law, we see that

$$U_{induced} = -N \frac{d\phi_B}{dt} \quad (1)$$

Rearranging the equation and noting that the area of the sample is constant, we have

$$-\frac{U_{induced}}{NA_{sample}} = \frac{dB}{dt} \quad (2)$$

Integrating both sides, we arrive at an equation for the magnetic field of the sample based on the induced voltage:

$$-\int \frac{U_{induced}}{NA_{sample}} = B \quad (3)$$

All that is left is for the DAQ to deliver $U_{induced}$ to the computer in order to analyze the results.



Figure 2: Coil Winding Setup.

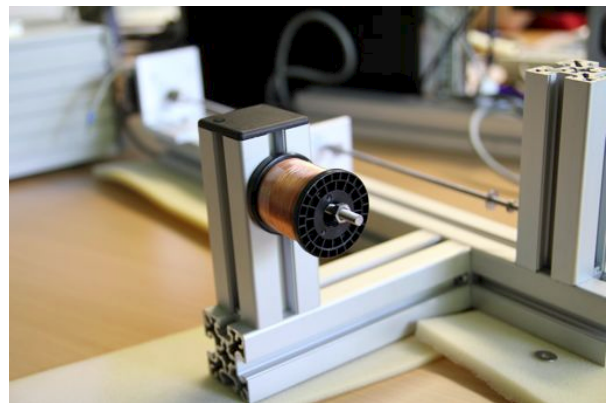


Figure 3: Spool.

4.2 Measurements of the Helmholtz Coils

Theory states that helmholtz coils should produce a near uniform field between the two coils. [3] A derivation for the field of a helmholtz coil is shown in appendix B. To accurately determine the radius of the coils, we measured the induced B field with a magnetometer while concurrently measuring the current supplied to the coils. Below is a graph of the relation between the H field provided by the helmholtz coils and the current flowing through them.

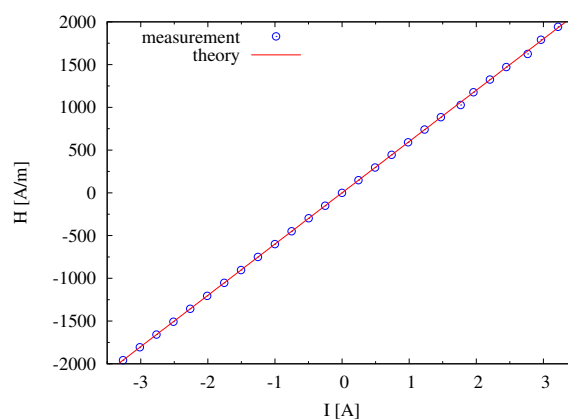


Figure 4: Empirical vs. Theoretical H Field for Helmholtz Coils.

Plugging in values of current and the B field based on the graph into the equation in appendix B, we are left with a measure of 0.148 meters for the radius coils.

5 Software

For installation instructions, please see appendix A. Everything for the device was programmed within labview. Using device drivers, the waveform generator can be con-

trolled and the DAQ delivers data to the labview program. The basic setup of the program goes as follows: voltage waveforms are set manually or within the labview program and outputted to the coils, the DAQ fetches a buffer of induced voltage values of the sample, and finally the buffer is analyzed within labview and written to an output file. The Labview file is shown below. The graphs depicted in the program are of the input voltage, the induced voltage, the integrated induced voltage, and an unscaled hysteresis loop of the input voltage versus the integrated induced voltage.

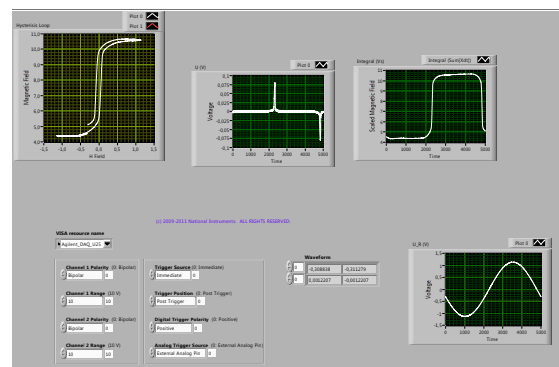


Figure 5: Labview Program.

The graphs display only the amount of data given in the buffer. The buffer is updated based on the sampling frequency, and by tuning these values we can display the number of periods we would like on our graphs.

Corrections were made outside of labview to account for possible problems in the integrating process. A constant bias in the voltage reading forced our measurement of the voltage to rise linearly. Thus, we subtract out the linear offset by getting values from the start and end of one period, finding the slope between them, and subtracting the noise from each indexed value within the buffer of measured voltage values.

Additionally, we needed to account for background noise within the induction coils. To do this, each measurement is accompanied by a background measurement made before it. We then match the phase of the background noise with the measured sample voltage, and deduct it from the measured value to get the pure sample response. A graph of the background noise is shown. It is sinusoidal since it is driven by a sinusoidal input voltage.

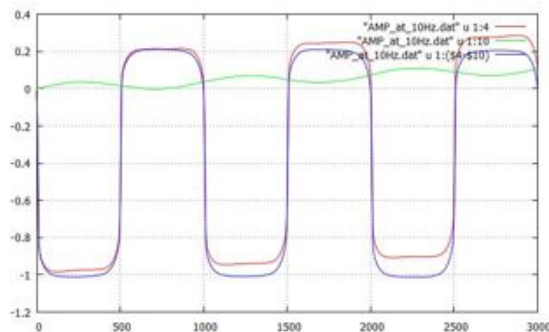


Figure 6: The background noise is shown in green. The original signal is red and the corrected signal (original - background) is displayed in blue.

6 Measurements

Using $\text{Fe}_{75}\text{P}_9\text{Si}_{8.5}\text{B}_{7.5}$ amorphous ribbon, we have created hysteresis loops for the sample under varying amplitude. The graph below depicts the response of the ribbon to a 10 Hz input voltage.

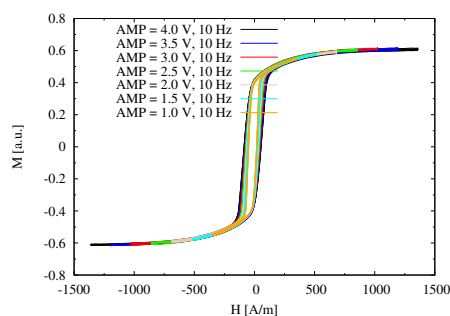


Figure 7: Varying Coercivity with Amplitude.

Important parameters of the loop include its coercivity and saturation values. We can see that the coercivity increases as the sample comes closer to saturation.

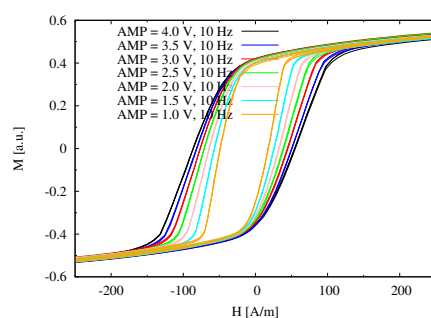


Figure 8: Zoomed view of coercivity changes.

The spins align in the sample in the presence of an external field, and the stronger the field the more they align and the more resistant they are to changes in the opposing direction. As the coercivity is the spacing between when the sample's magnetic field switches from negative to positive and vice versa, stronger spin alignments would increase the external field required to change the sample and thus increase the samples coercivity. The coercivity was fitted using gnuplot and exhibits nonlinear characteristics

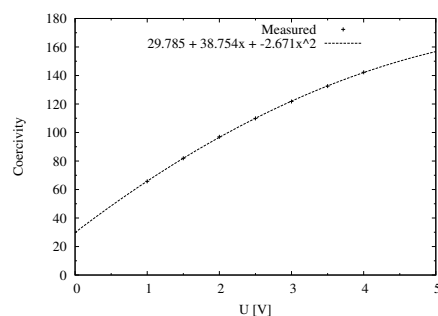


Figure 9: Coercivity versus Amplitude.

versus the applied H field. The function it matched to was $29.785 + 38.754x - 2.671x^2$.

7 Conclusions

The labview setup enables us to create magnetic hysteresis loops for small ribbon samples placed within the helmholtz coils. Using external data analysis software, in our case gnuplot, we are able to make scaled graphs and eliminate sources of noise. In the case of $\text{Fe}_{75}\text{P}_9\text{Si}_{8.5}\text{B}_{7.5}$, the coercivity increases as the external field increases as expected.

Future improvements for the device could be an all in one production of scaled and noise free hysteresis loops as opposed to using an external program to account for noise and create the final loops. This could come from using only labview and would allow for an easier system to use for beamline measurements.

Acknowledgements

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References

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- [3] S.R. Trout. Use of helmholtz coils for magnetic measurements. *Magnetics, IEEE Transactions on*, 24(4):2108 –2111, jul 1988.

8 Appendix

8.1 Installation Instructions

Labview: Install the full version of Labview 2011 using the install disk that comes with the product.

Waveform Generator: From the Hameg site, install the labview driver and the usb interface driver. For the usb driver, follow section 3.2 in the manual within the same directory as the downloaded driver.

The communication port then needs to be setup. This can be done by following section 4 within the guide. Note which COM port the generator is assigned to. When selecting the generator within a new labview project, the VISA resource name requires the selection of the COM port that is used for the generator.

When using the waveform generator with the computer, make sure the USB setting is enabled (indicator will be the USB label in the top right of the waveform's lcd screen). If not, select the usb setting by going to Menu, interface, and picking usb. For the labview driver, drag the hmf2500 directory to your labview instr.lib directory (for default Windows 7 install, this is in Program Files (x86)/National Instruments/LabVIEW2011/instr.lib)

The generator is now ready for use. You can use labview example programs to run the generator - these are found in the downloaded labview driver folder within the instr.lib directory that was previously copied to the labview directory. The included examples are very helpful and vital to implementing the generator within a labview project.

Data Acquisition Card: Follow the instructions on the CD to setup the DAQ card. Accept the option of installing labview files. Similarly to the waveform generator, this will provide example code that is invaluable for setting up the software within labview. For windows 7, additional drivers will need to be installed and can be found on the agilent website. They are the hardware driver and the labview driver. The labview driver supplies a instr.lib that needs to be dragged to the same directory within Labview 2011.

8.2 Derivation for Magnetic Field in Helmholtz Coil

We start with the Biot-Savart Law:

$$\mathbf{B}(\mathbf{r}, I) = \frac{\mu_0 I}{4\pi} \int_C \frac{d\mathbf{l} \times \mathbf{r}}{|\mathbf{r}|^3} \quad (4)$$

where \mathbf{r} is the vector from the source point to the field point and I is the current running through the wire.

We are looking for the magnetic field along the axis of the coil, since this is where our sample will be placed. By symmetry, the vertical component of the field is zero along the axis. We can then find the horizontal field:

$$\mathbf{B}(\mathbf{r}, I) = \frac{\mu_0 I}{4\pi} \int_C \frac{d\mathbf{l} \times \mathbf{r} \sin \theta}{|\mathbf{r}|^3} \quad (5)$$

where θ is the angle between \mathbf{l} and the vector from the axis to the field point. We can rewrite θ as $\frac{R_{loop}}{r} = \frac{R_{loop}}{\sqrt{R_{loop}^2 + z^2}}$ where z is the distance along the axis from the loop to the field point. Then,

$$\mathbf{B}(\mathbf{r}, I) = \frac{\mu_0 I}{4\pi} \int_C \frac{d\mathbf{l} \times R_{loop}}{(R_{loop}^2 + z^2)^{\frac{3}{2}}} \quad (6)$$

Along the curve neither R_{loop} nor z vary, so the integral becomes

$$\mathbf{B}(\mathbf{r}, I) = \frac{\mu_0 I}{4\pi} \int_C \frac{2\pi R_{loop}^2}{(R_{loop}^2 + z^2)^{\frac{3}{2}}} \quad (7)$$

We then have

$$\mathbf{B}(\mathbf{r}, I) = \frac{\mu_0 I}{2} \frac{R_{loop}^2}{(R_{loop}^2 + z^2)^{\frac{3}{2}}} \quad (8)$$

The trick for a Helmholtz coil is two-fold. First, the current is the number of loops (N) times the current through each loop (I_{loop}). The second part is based on the configuration of the loops. We are measuring in between two coils (which doubles the field), and the spacing is R_{loop} between them. So we multiply the total magnetic field by 2 and can use $z = \frac{R}{2}$.

Thus, we have

$$\mathbf{B}(\mathbf{r}, I) = \frac{\mu_0 I}{2} \frac{R_{loop}^2}{(R_{loop}^2 + \left(\frac{R_{loop}}{2}\right)^2)^{\frac{3}{2}}} \quad (9)$$

and simplified to our final equation:

$$\mathbf{B}(\mathbf{r}, I) = \left(\frac{4}{5}\right)^{\frac{3}{2}} \frac{\mu_0 I}{R_{loop}} \quad (10)$$