Modeling the Magnetic Field of a Rectangular Ceramic Magnet

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Outline

- Motivation
- Magnetic Field Measurements
- Magnetic Field Model of a Straight Wire
- Magnetic Field Model of a Rectangular Coil
- Magnetic Field Model of a Uniformly Magnetised Rectangular Block
- Magnetic Field Measurements of a Rectangular Coil
- Magnetic Field Measurements of a Magnetised Rectangular Ceramic Block
- Conclusion

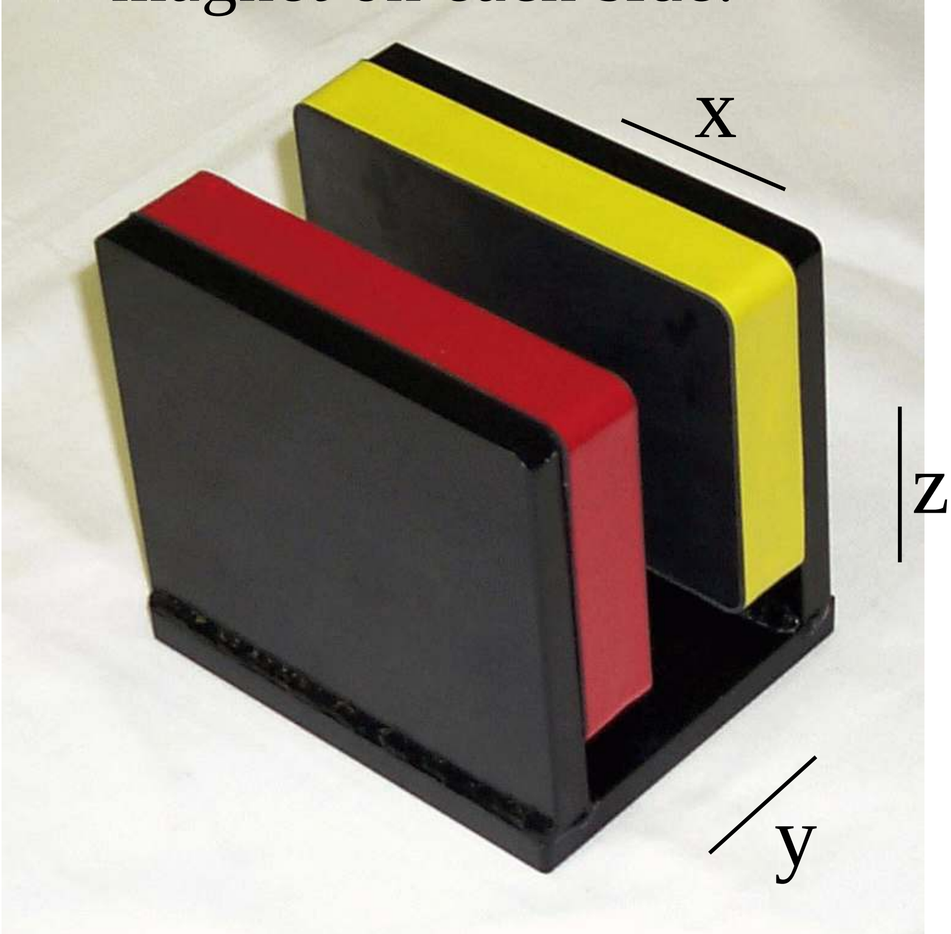
Motivation

A need for a laboratory magnet for the following experiments:

- Standing waves on a vibrating wire
- Force on a current as a defining measurement of magnetic field
- Motional EMF experiment (The Physics Teacher, March 2001)

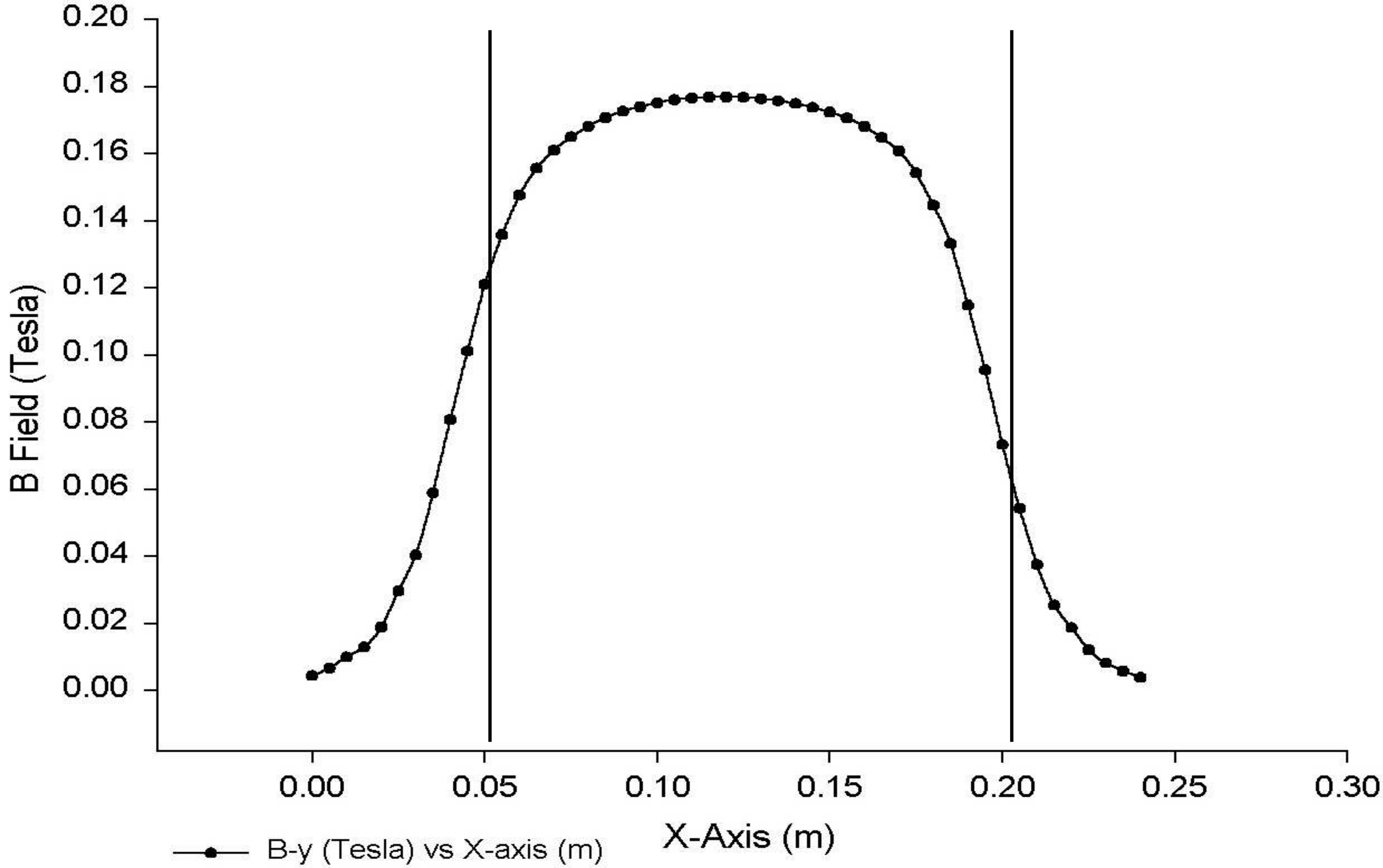
The new magnet

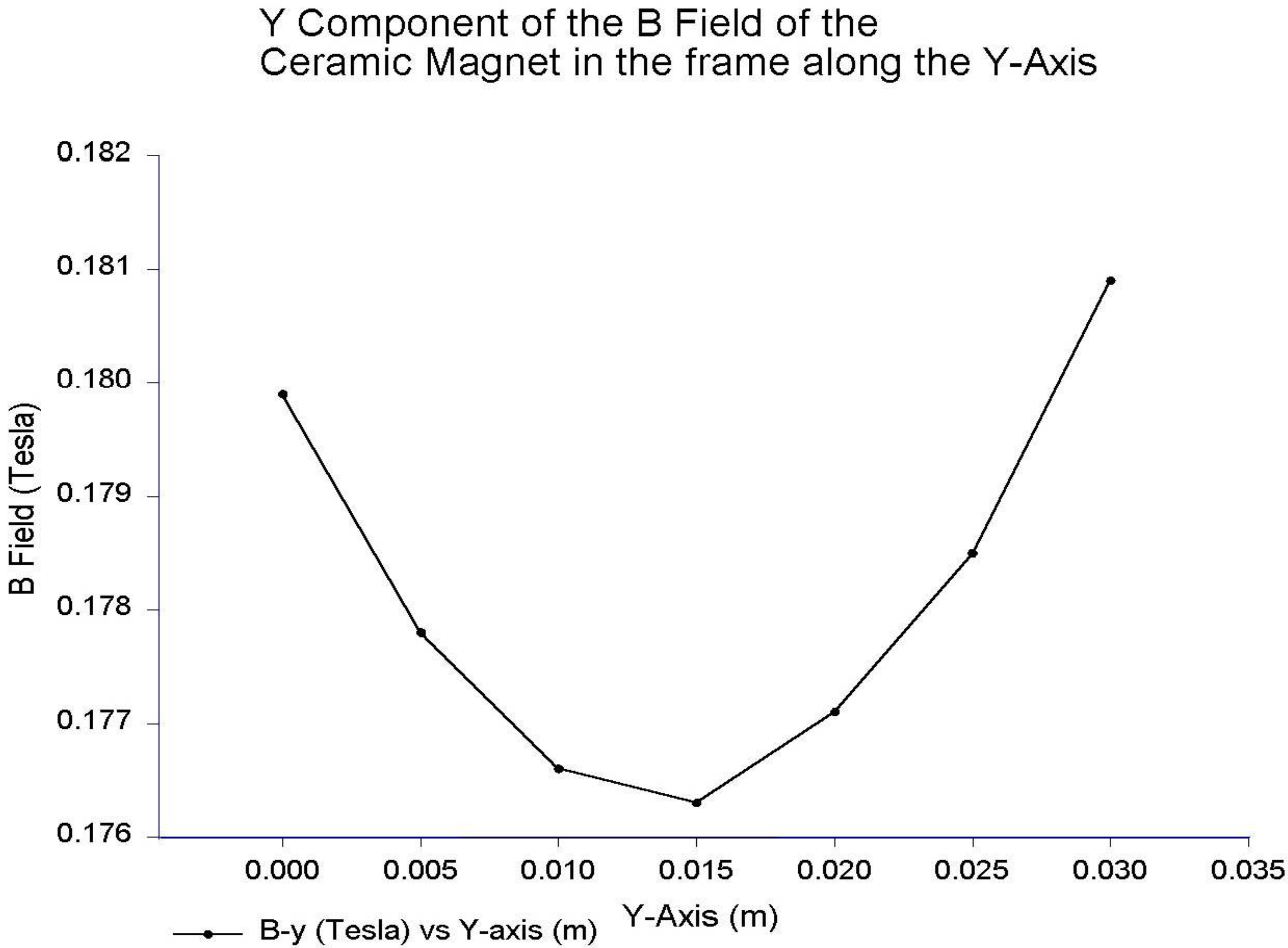
A U-shaped steel frame with a 4 inch x 6 inch x 1 inch ceramic magnet on each side.

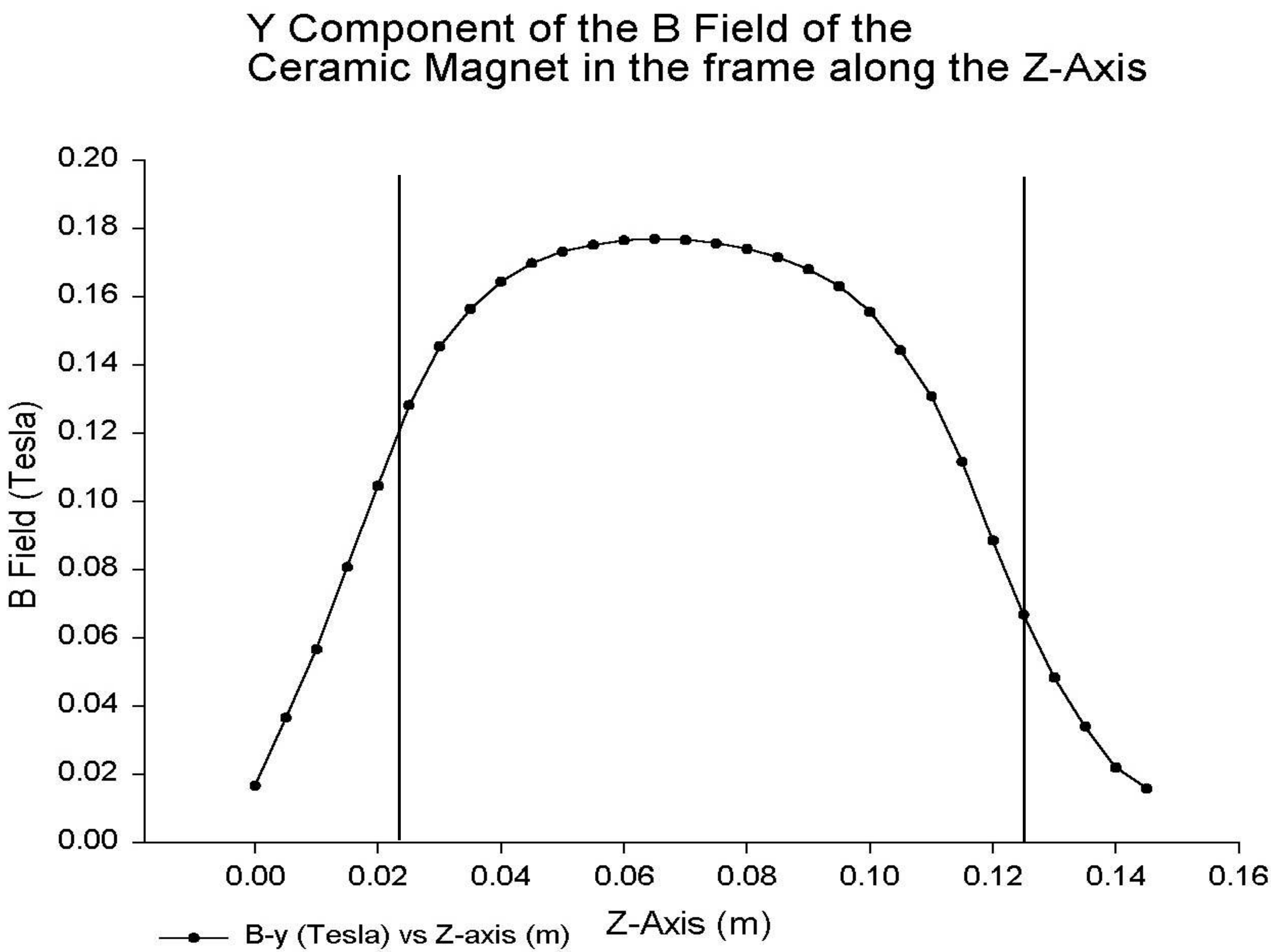


A magnetic field of about 1750 gauss in an air gap of 1.5 inches.

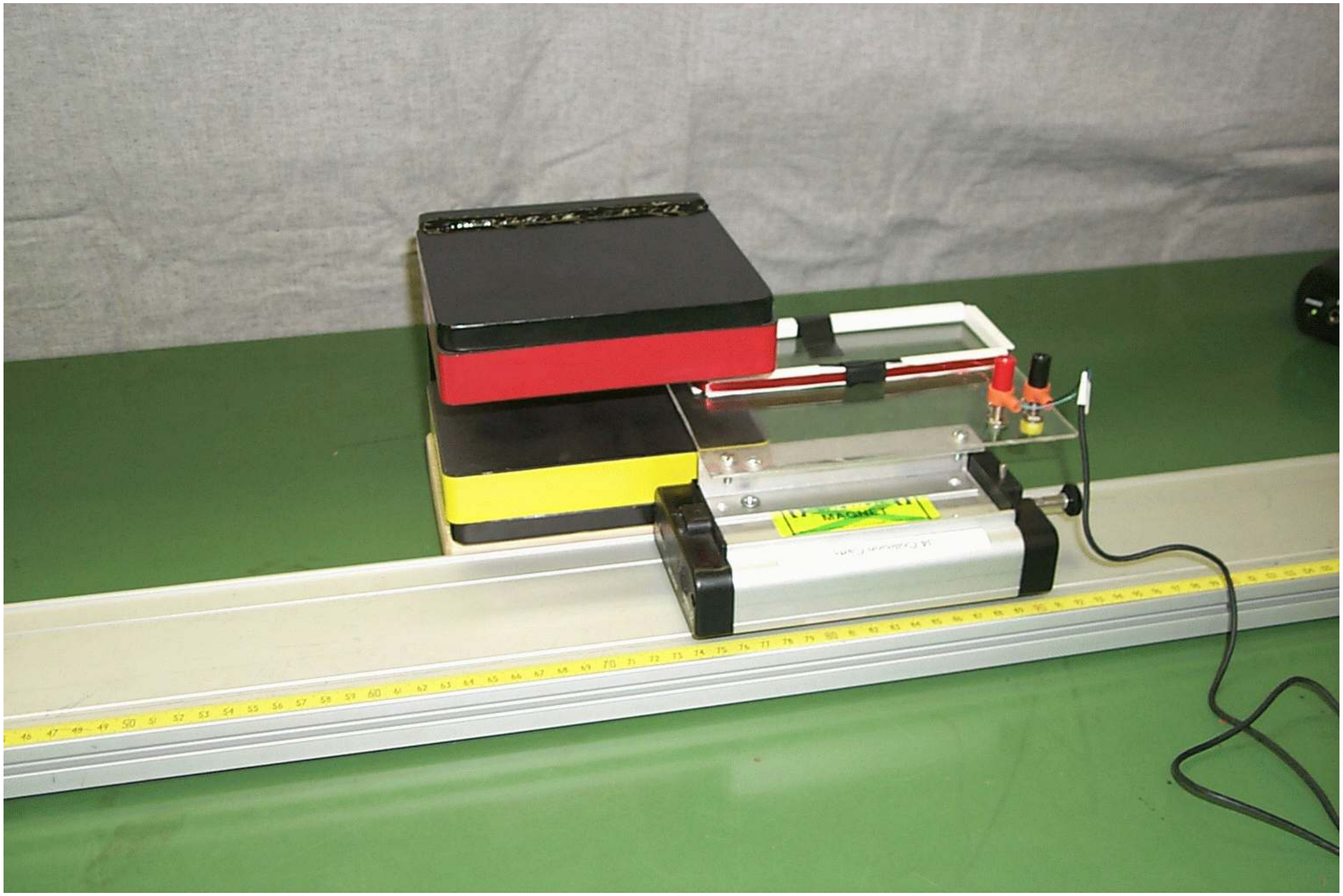
Y Component of the B Field of the
Ceramic Magnets in the frame along the X-Axis

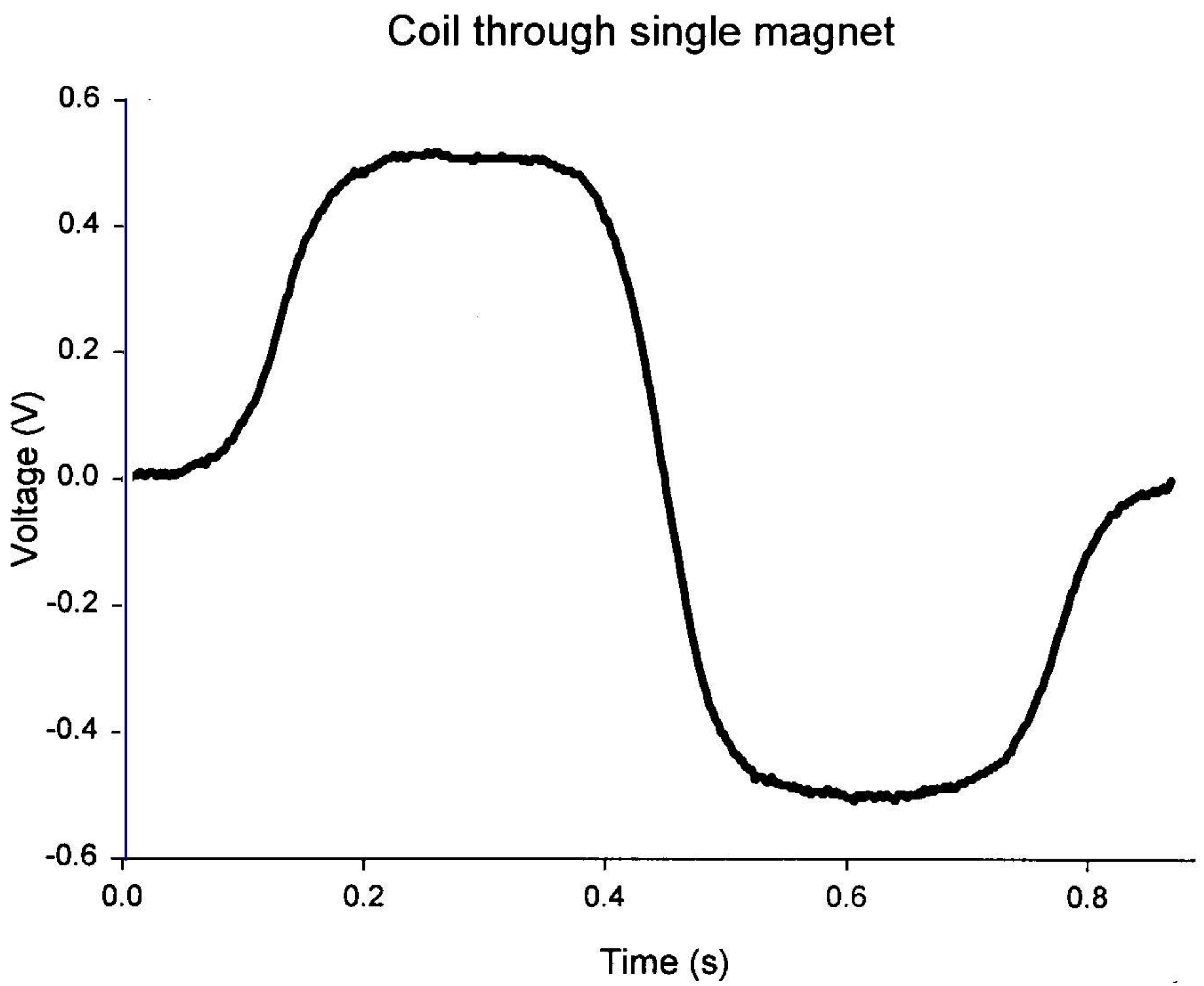



Y Component of the B Field of the
Ceramic Magnet in the frame along the Y-Axis
0.182
0.181
0.180
0.179
0.178
0.177
0.176
B Field (Tesla)
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
Y-Axis (m)
B-y (Tesla) vs Y-axis (m)

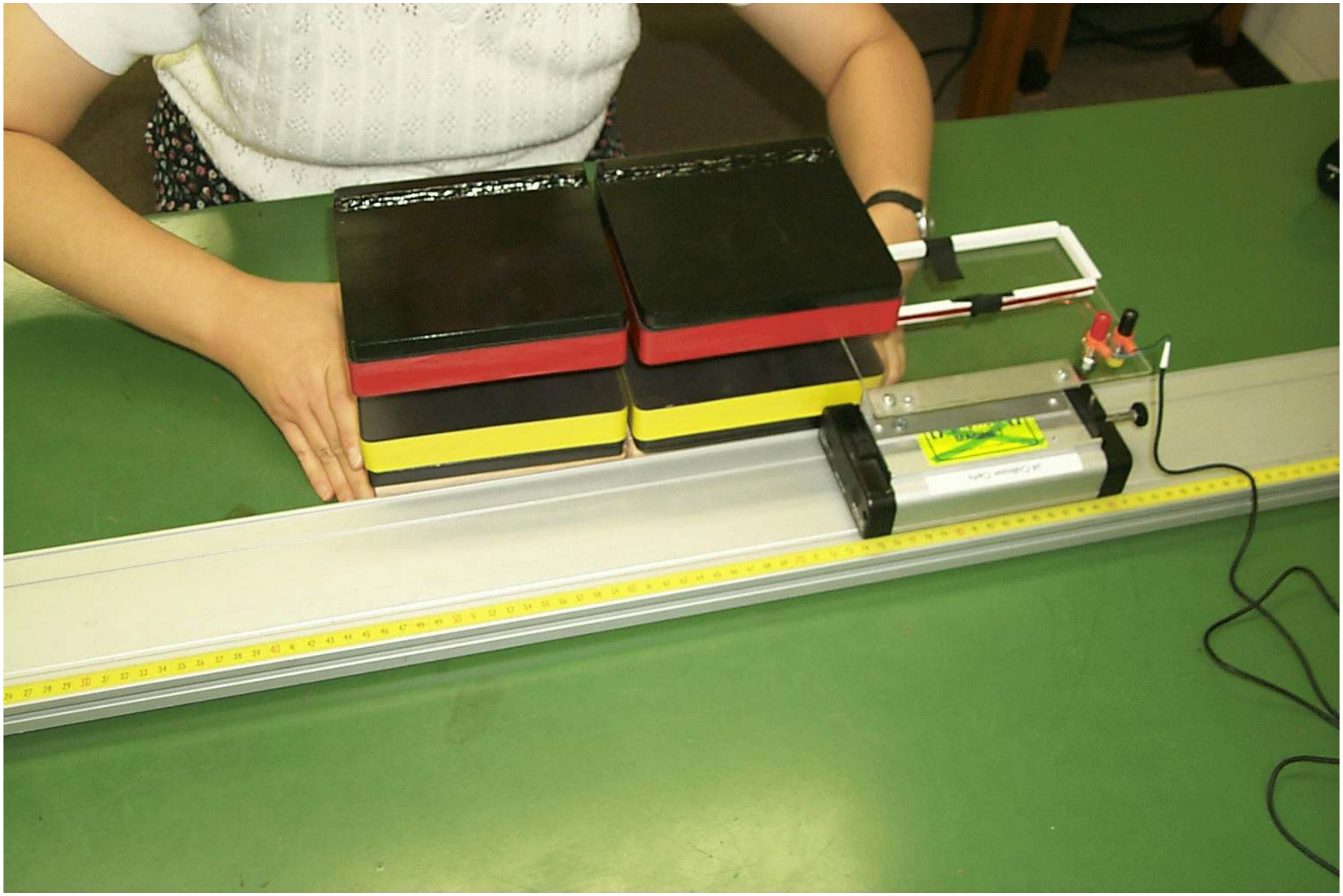

Y Component of the B Field of the
Ceramic Magnet in the frame along the Z-Axis
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
B Field (Tesla)
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
Z-Axis (m)
B-y (Tesla) vs Z-axis (m)

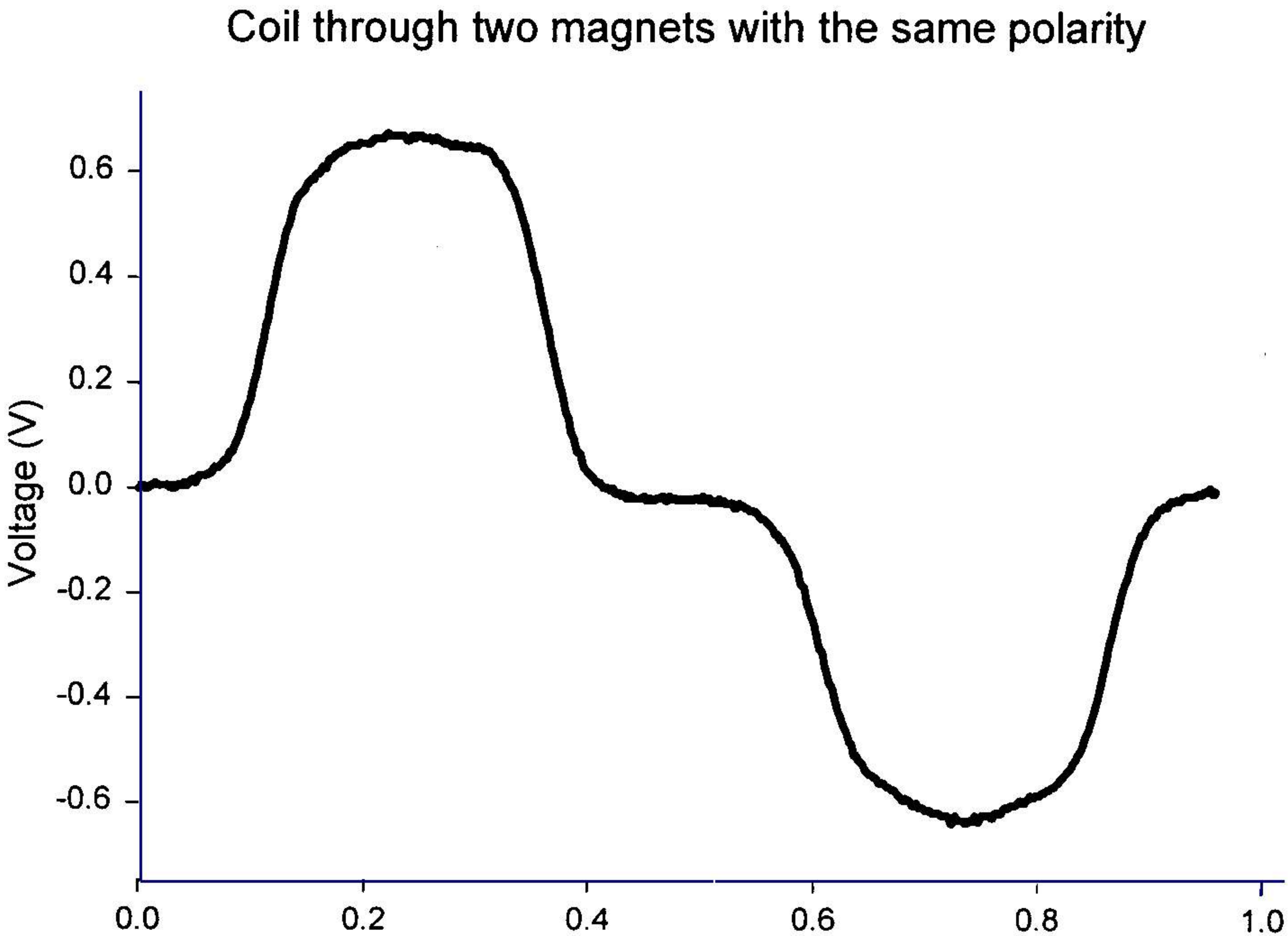
Coil sweeping through the magnet
in the motional emf experiment.



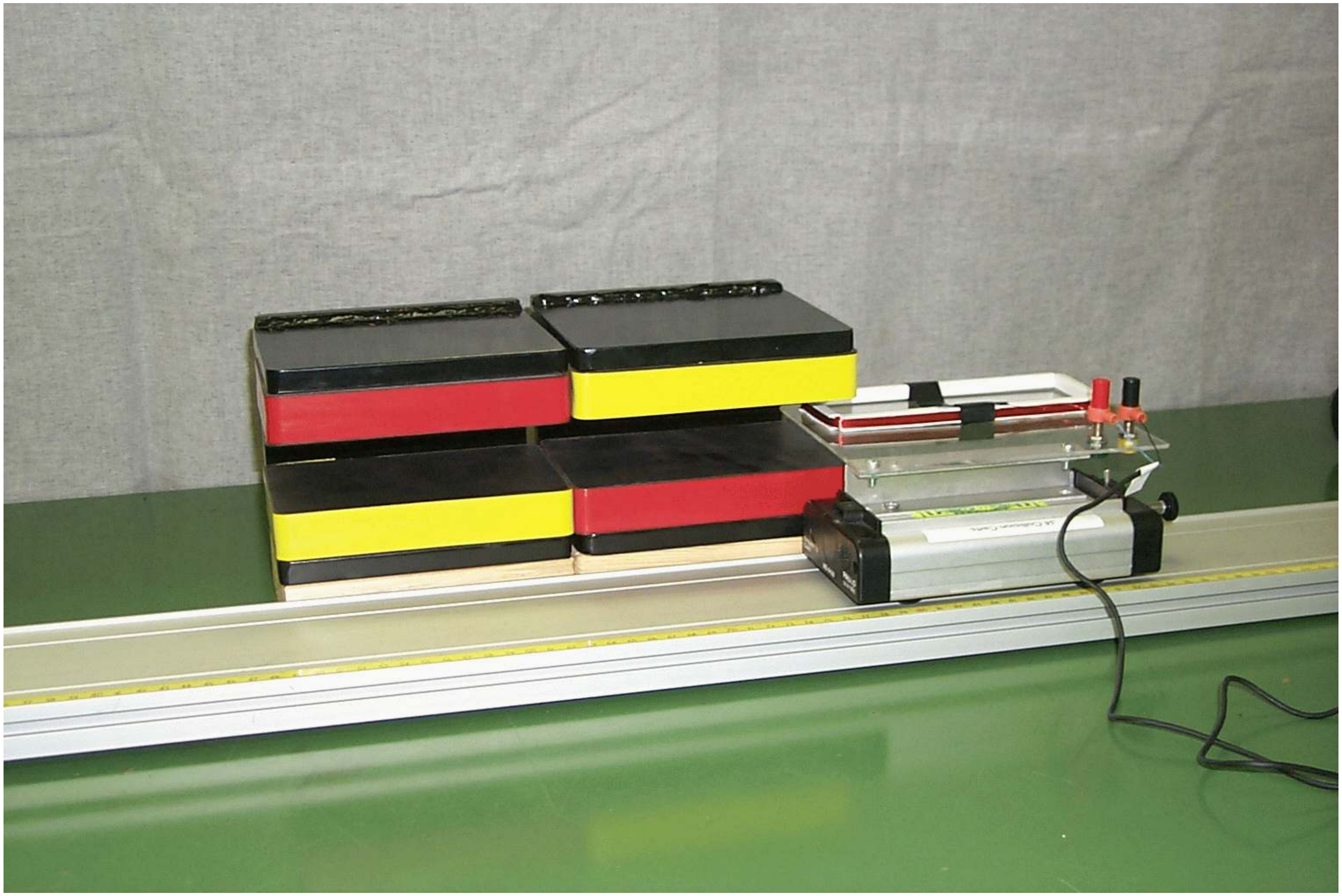

Coil through single magnet
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
Voltage (V)
0.0
0.2
0.4
0.6
0.8
Time (s)

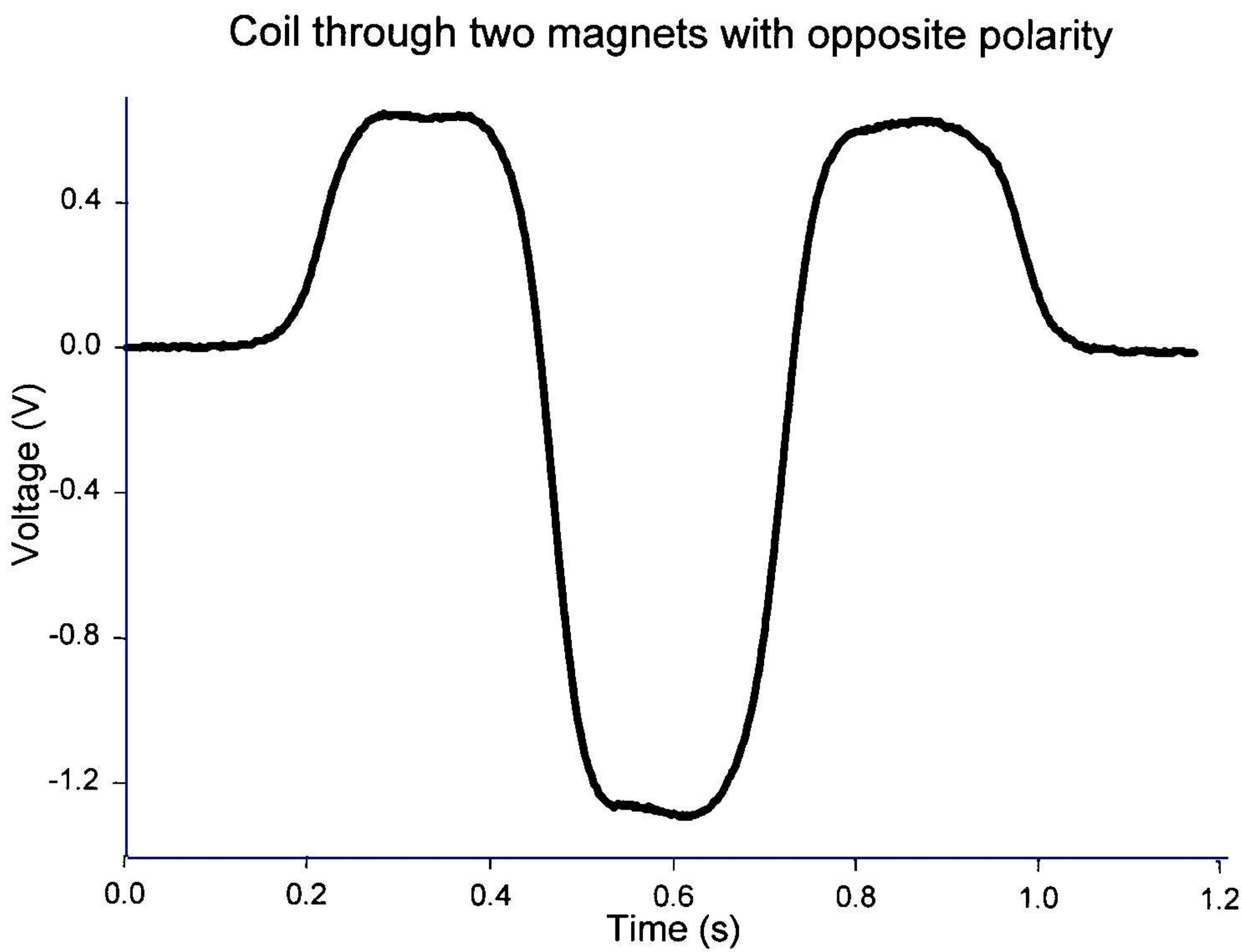
Coil sweeping through two magnets with the same polarity in the motional emf experiment



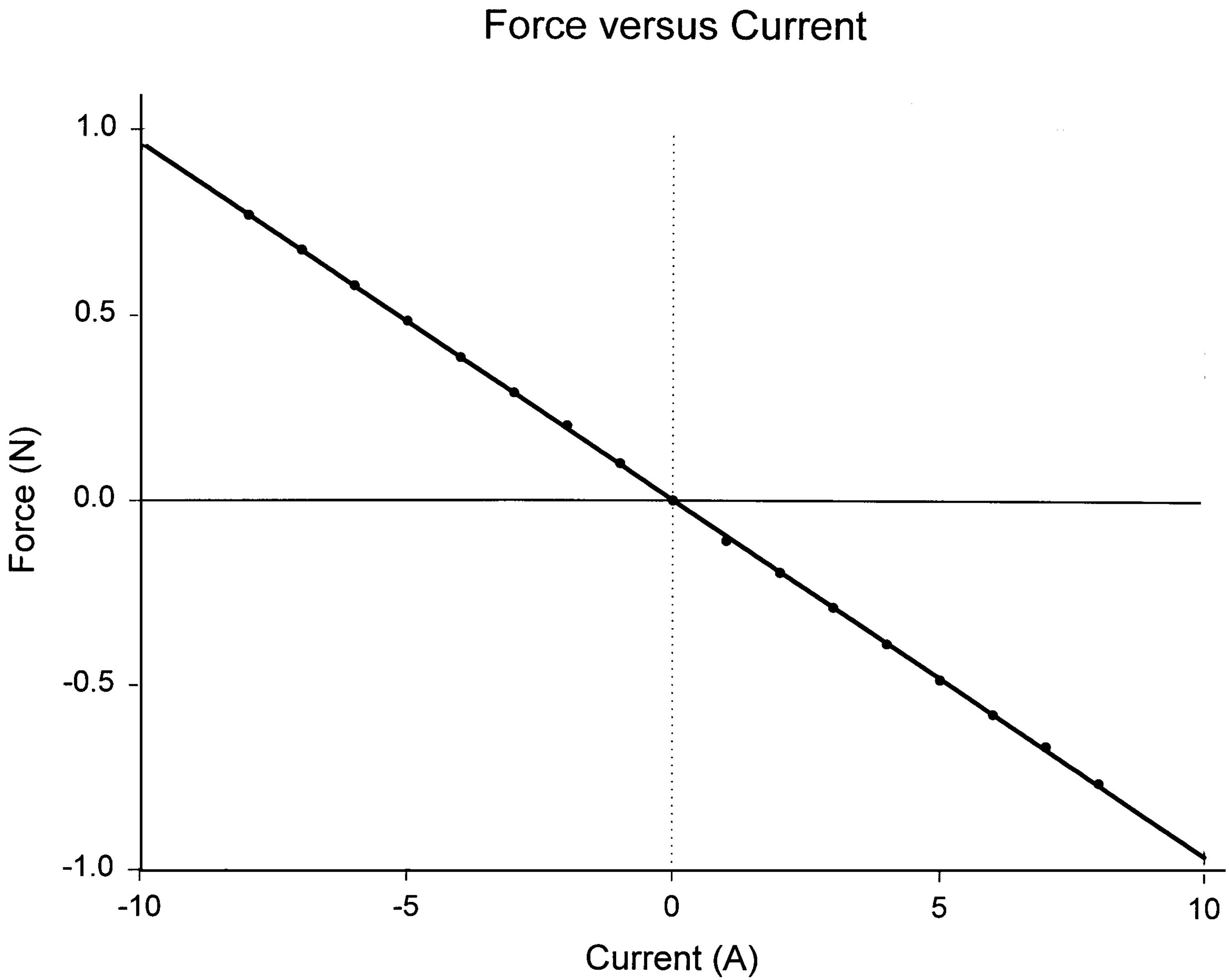

Coil through two magnets with the same polarity
Voltage (V)
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
0.0
0.2
0.4
0.6
0.8
1.0

Coil sweeping through two magnets with reversed polarity in the motional emf experiment

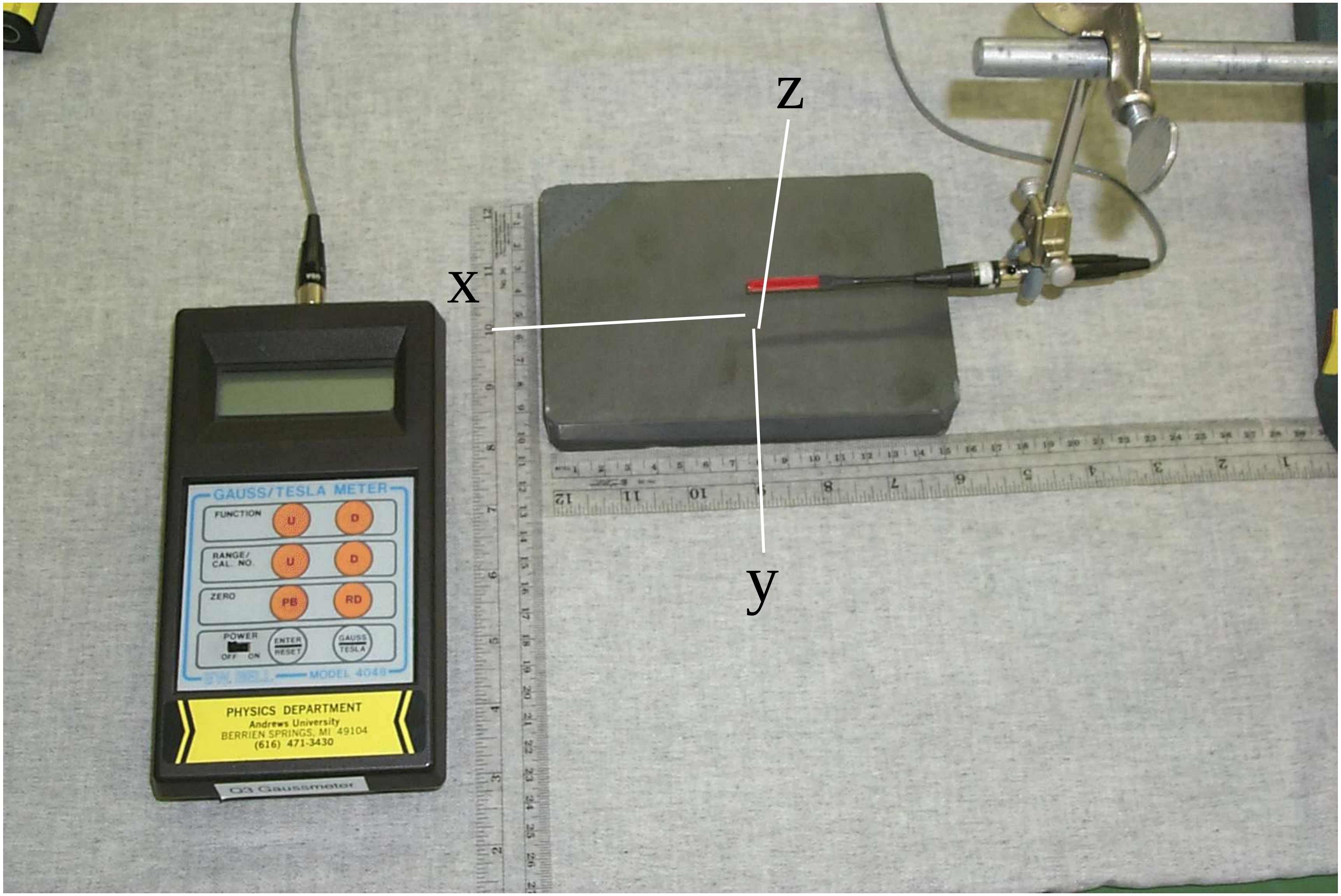



Coil through two magnets with opposite polarity
Voltage (V)
0.4
0.0
-0.4
-0.8
-1.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Time (s)

Force on a current experiment with a 10-turn coil


Force versus Current
1.0
0.5
0.0
-0.5
-1.0
Force (N)
-10
-5
0
5
10
Current (A)

Ceramic Magnet: 1" x 4" x 6"　　　I = 6300 A

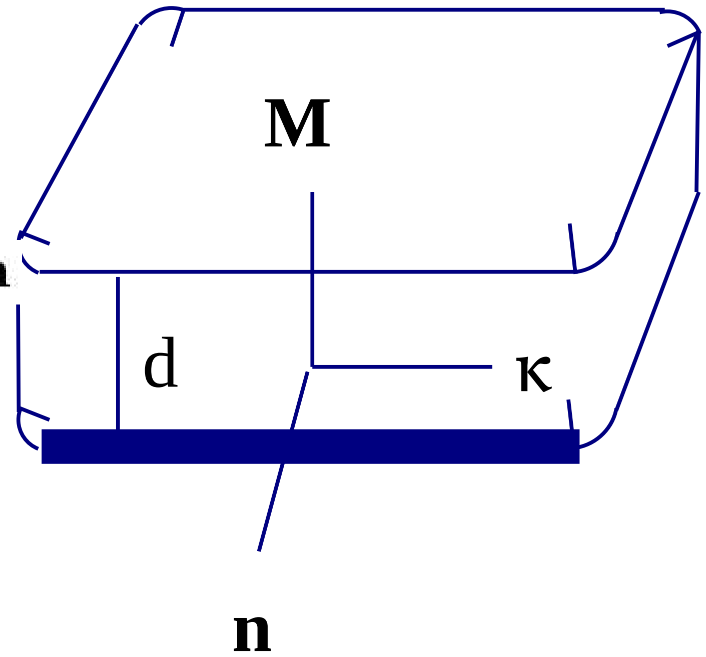


Magnetization surface currents of the ceramic magnet

Magnetic moment $\mu = I\ A$

Magnetization field M is
the magnetic moment per
unit volume

$\kappa = \mathbf{M} \times \mathbf{n}$

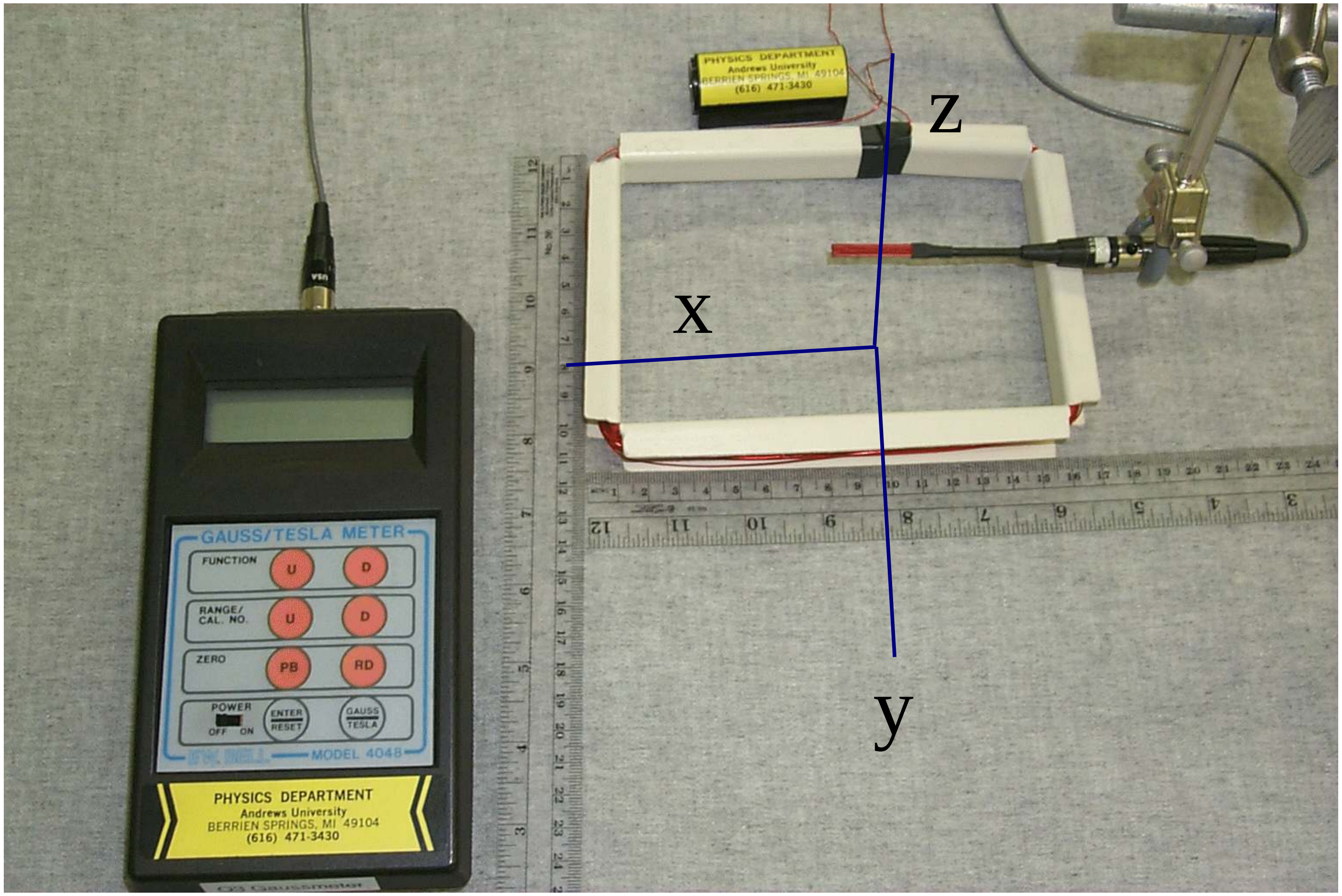


Surface current

Current $I = M\ d$

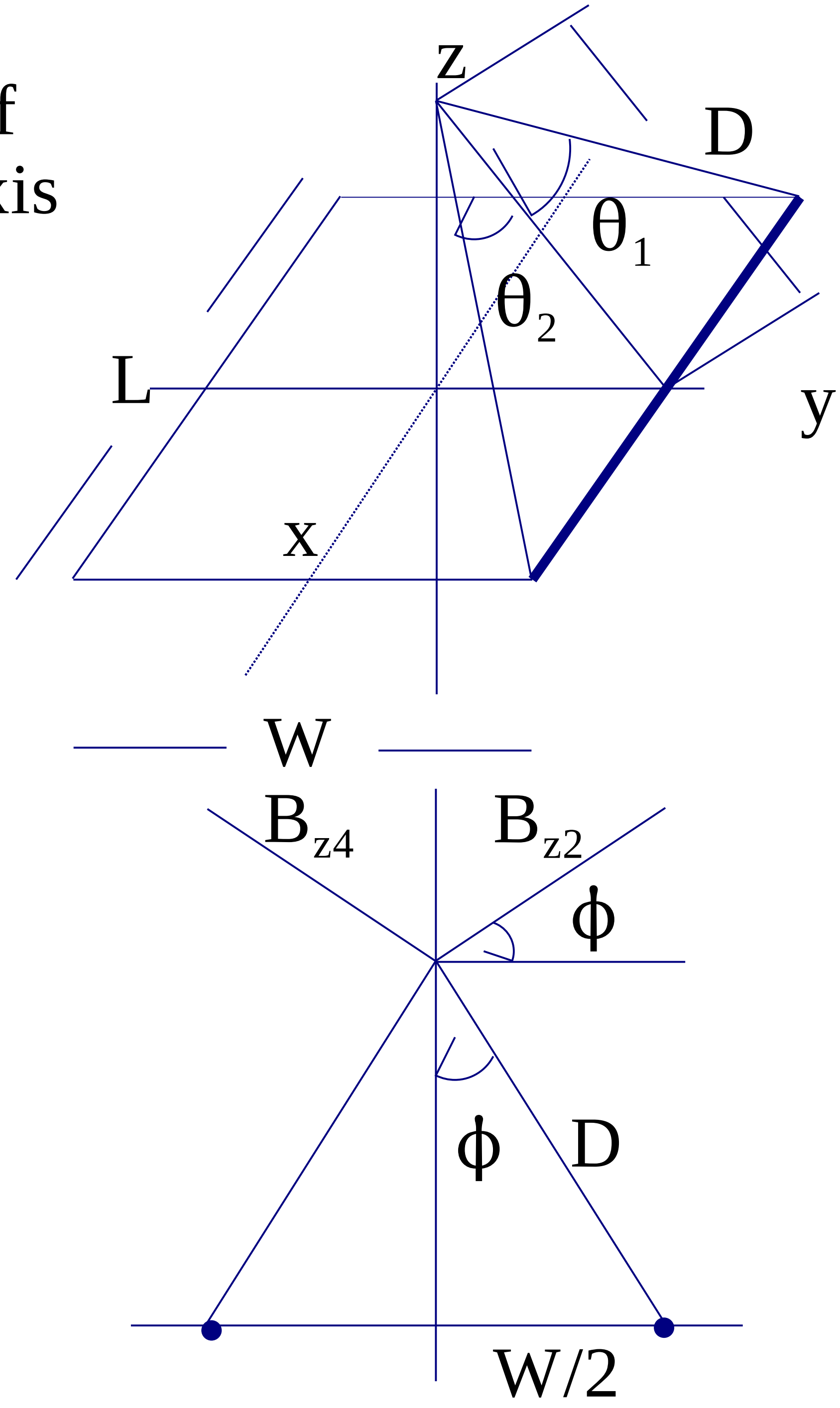
The ceramic magnet behaves like a rectangular current loop at distances large compared to the thickness d.

Magnetic field measurements for the rectangular coil



Rectangular coil 4 inch x 6 inch with 500 turns carrying a current of 1.03 amps

Calculation of the z component of the coil magnetic field on the z axis



The z component of the magnetic field from sides 2 and 4 on the z axis

$$B_z(z) = B_{z2} + B_{z4} + B_{z1} + B_{z3} = \frac{KWLI}{\sqrt{\frac{L^2}{4} + \frac{W^2}{4} + z^2}} \left(\frac{1}{\frac{W^2}{4} + z^2} + \frac{1}{\frac{L^2}{4} + z^2} \right)$$

The z component of the coil magnetic field on the z axis

$$B_{z2} + B_{z4} = \frac{KWLI}{\left(\frac{W^2}{4} + z^2\right)\sqrt{\frac{L^2}{4} + \frac{W^2}{4} + z^2}}$$

$$B_{z2} + B_{z4} = \frac{2KI}{D} \frac{L}{\sqrt{\frac{L^2}{4} + D^2}} \frac{\frac{W}{2}}{D}$$

The z component of the coil magnetic field on the x axis

$$B_z(x) = \frac{4KI}{W}\left[\frac{x+\frac{L}{2}}{\sqrt{\left(x+\frac{L}{2}\right)^2+\frac{W^2}{4}}} - \frac{x-\frac{L}{2}}{\sqrt{\left(x-\frac{L}{2}\right)^2+\frac{W^2}{4}}}\right] +$$

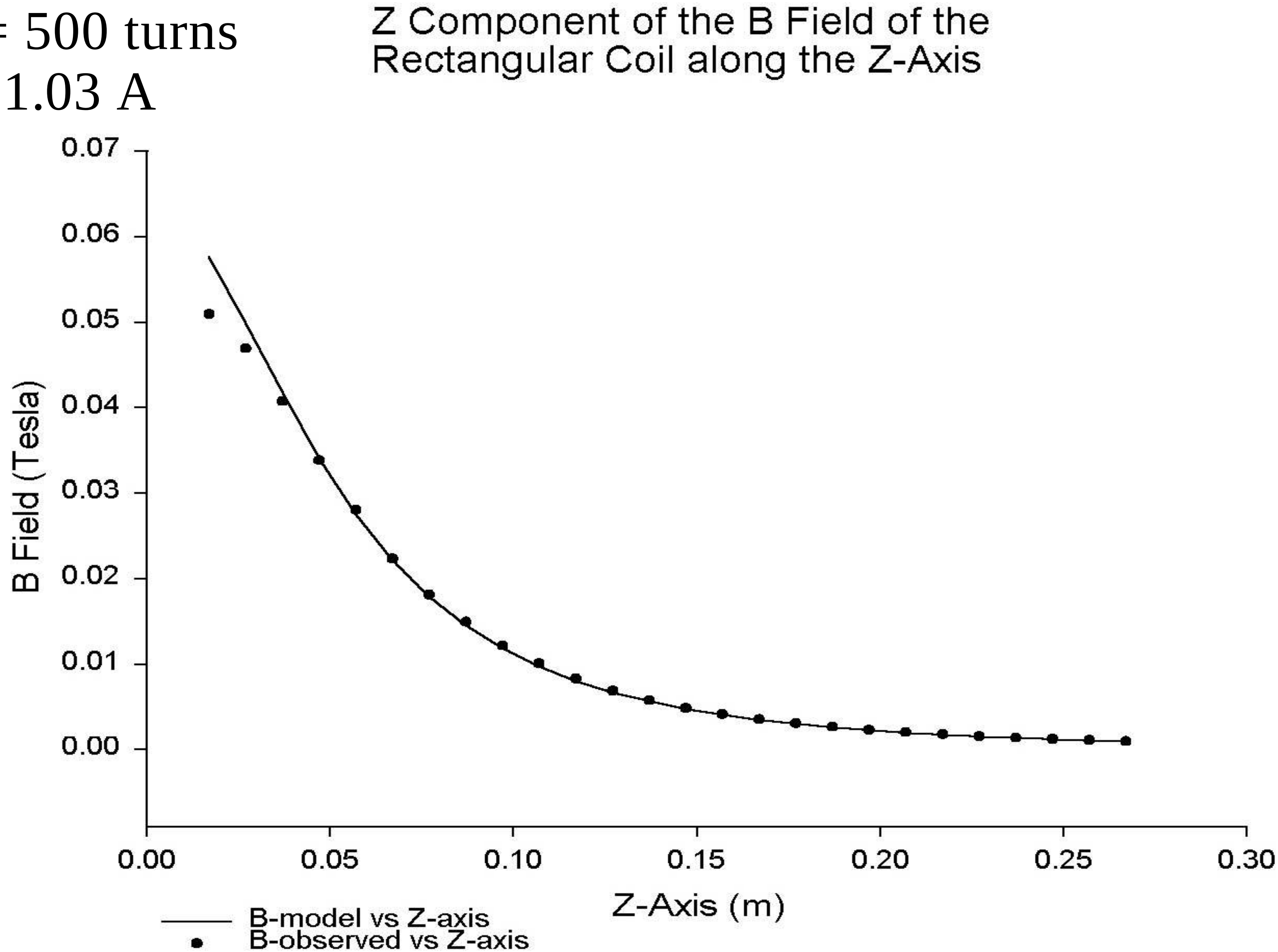
$$KIW\left[\frac{1}{\left(x+\frac{L}{2}\right)\sqrt{\left(x+\frac{L}{2}\right)^2+\frac{W^2}{4}}} - \frac{1}{\left(x-\frac{L}{2}\right)\sqrt{\left(x-\frac{L}{2}\right)^2+\frac{W^2}{4}}}\right]$$

The z component of the coil magnetic field on the y axis

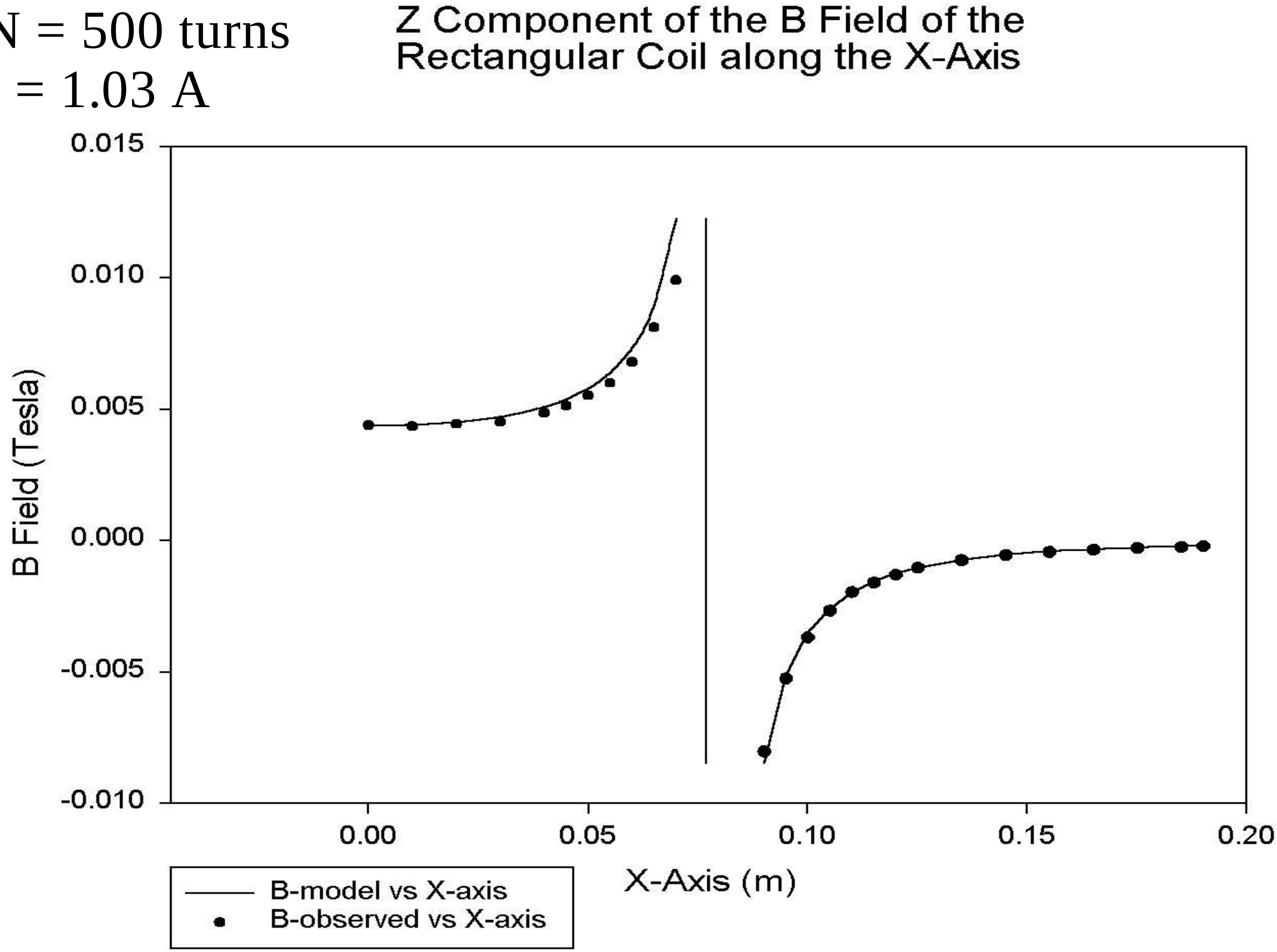
$$B_z(y)=\frac{4KI}{L}\left[\frac{y+\frac{W}{2}}{\sqrt{\left(y+\frac{W}{2}\right)^2+\frac{L^2}{4}}}-\frac{y-\frac{W}{2}}{\sqrt{\left(y-\frac{W}{2}\right)^2+\frac{L^2}{4}}}\right]+$$

$$KIL\left[\frac{1}{\left(y+\frac{W}{2}\right)\sqrt{\left(y+\frac{W}{2}\right)^2+\frac{L^2}{4}}}-\frac{1}{\left(x-\frac{W}{2}\right)\sqrt{\left(x-\frac{W}{2}\right)^2+\frac{L^2}{4}}}\right]$$

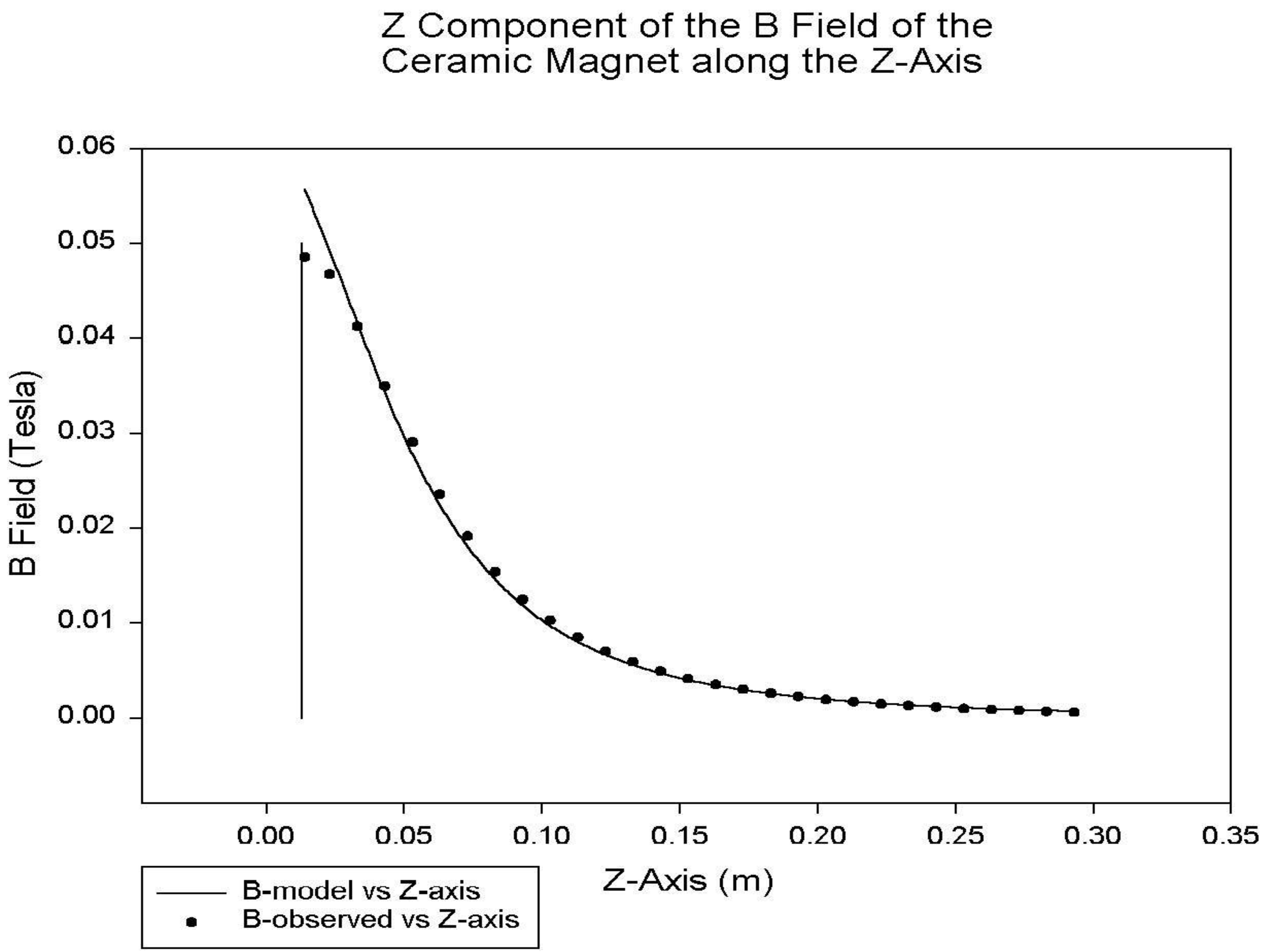
N = 500 turns
I = 1.03 A



N = 500 turns
I = 1.03 A



Ceramic Magnet: 1" x 4" x 6" I = 6300 A



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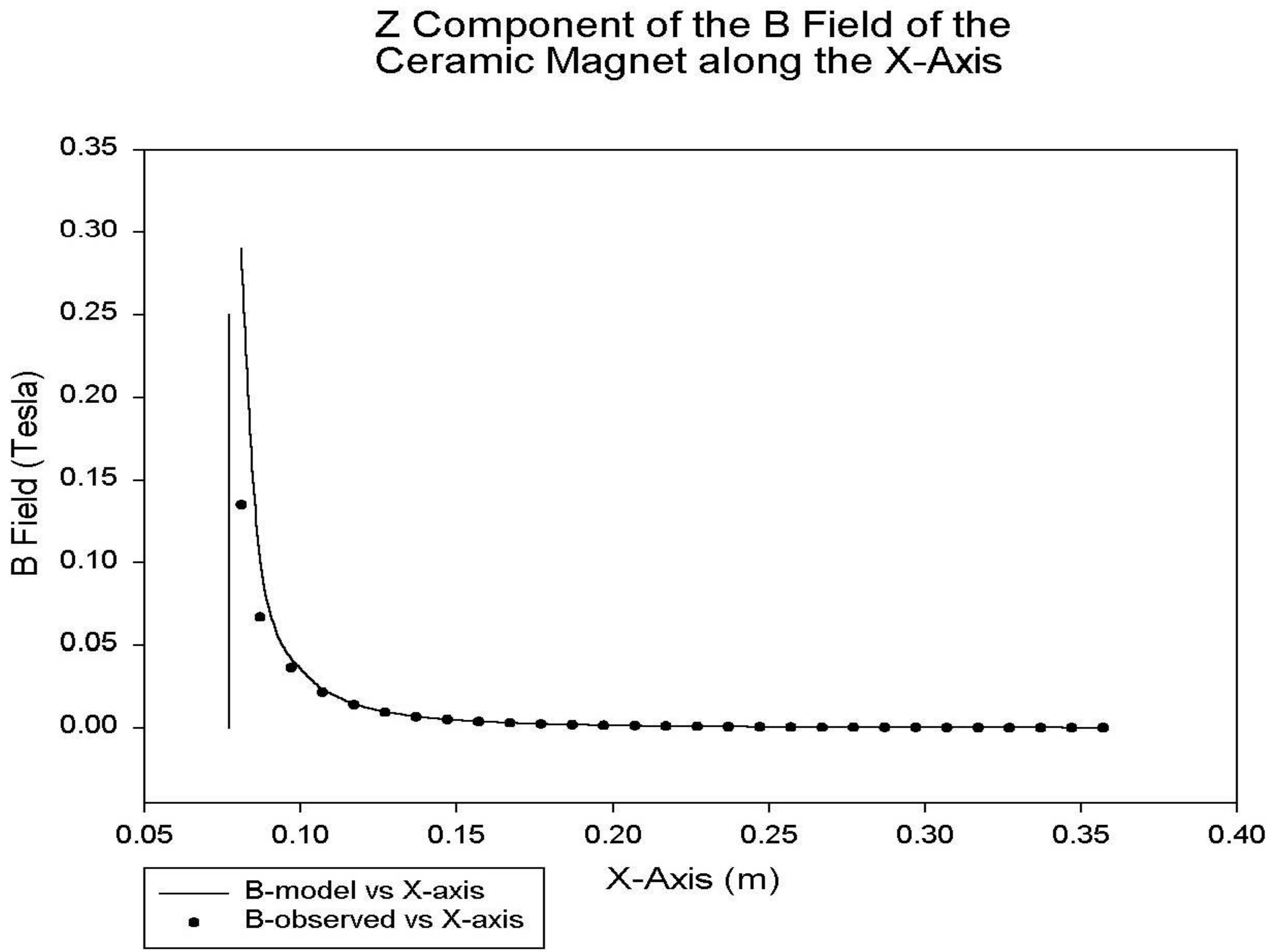
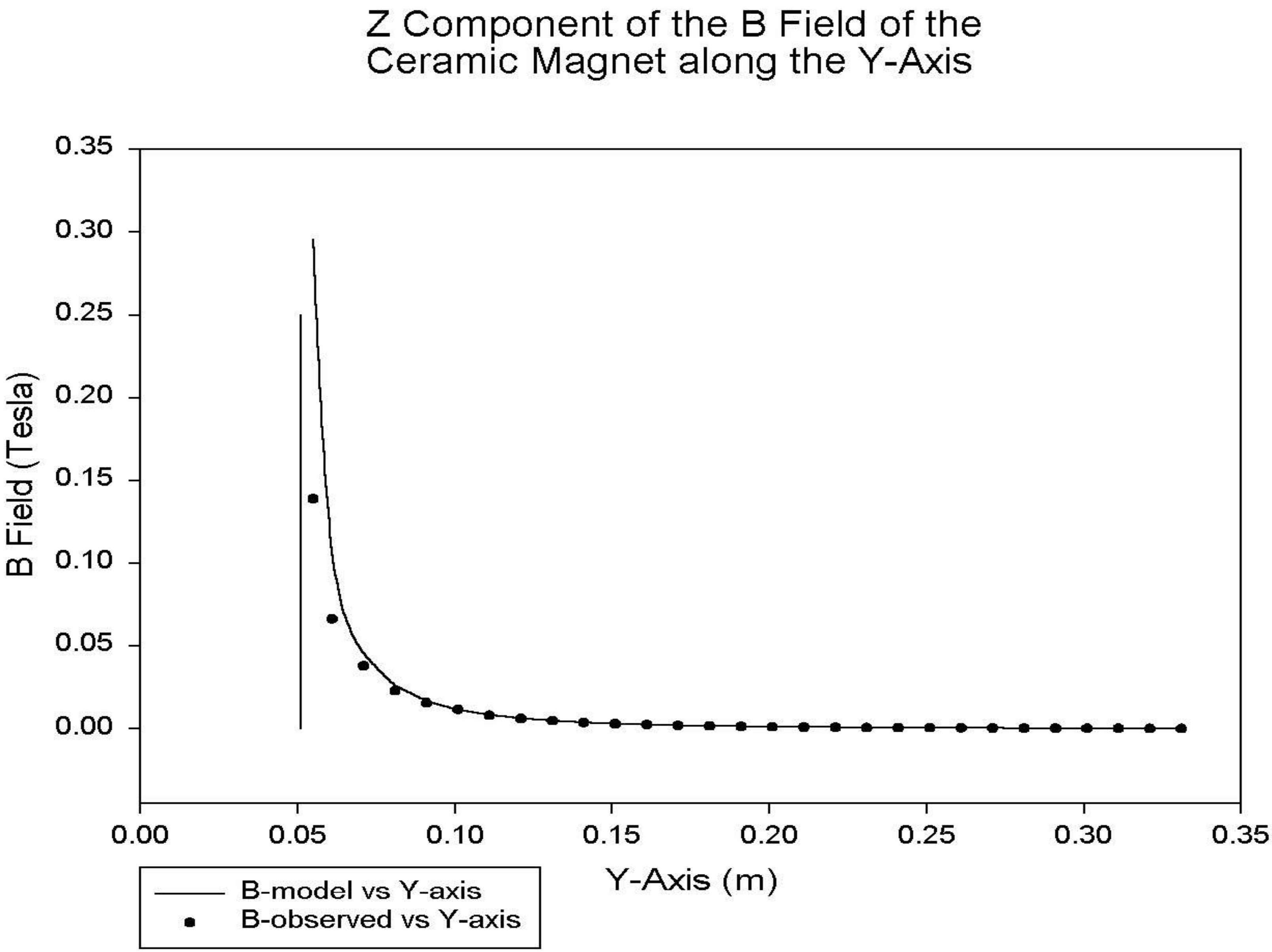
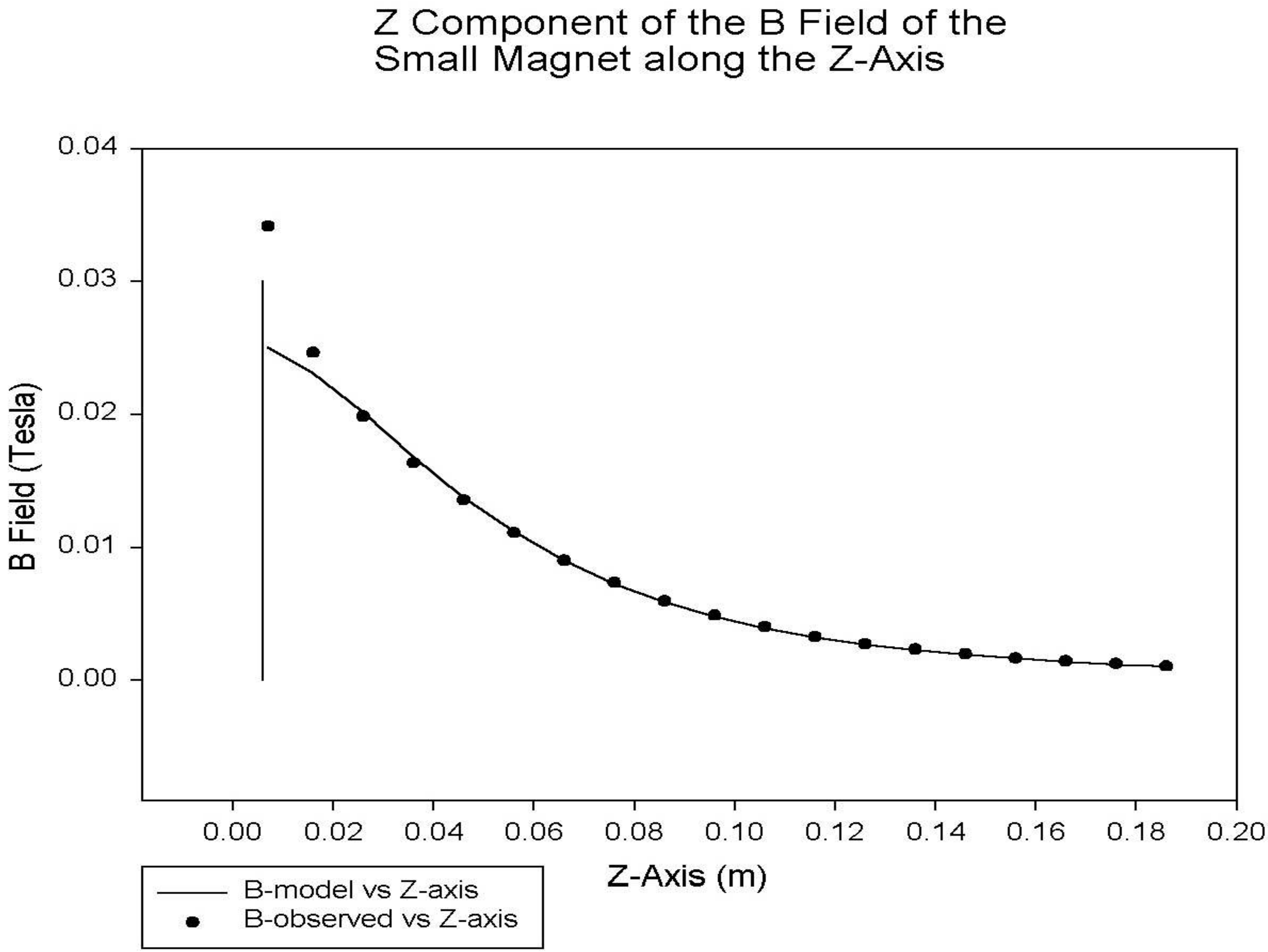


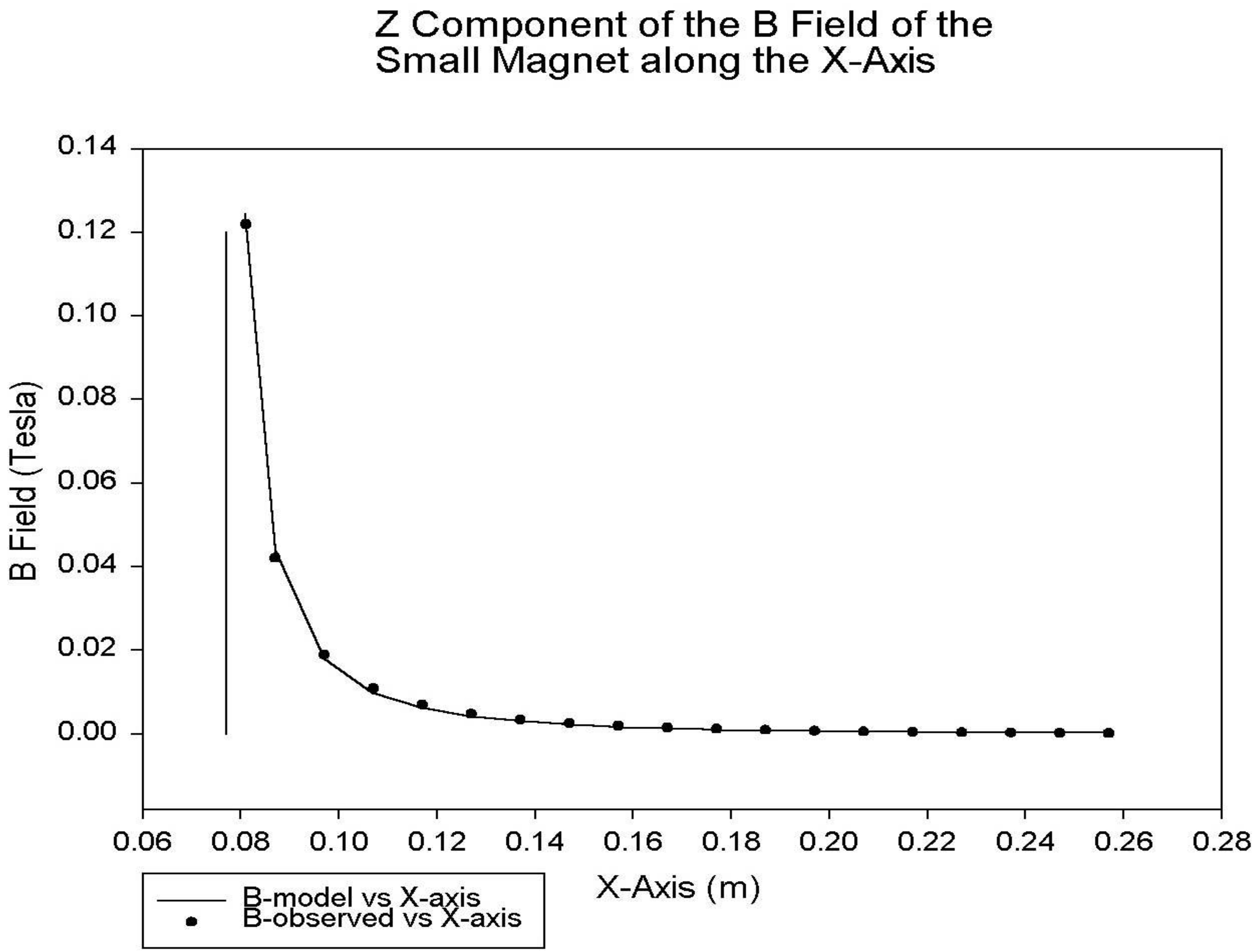
Ceramic Magnet: 1" x 4" x 6"   I = 6300 A



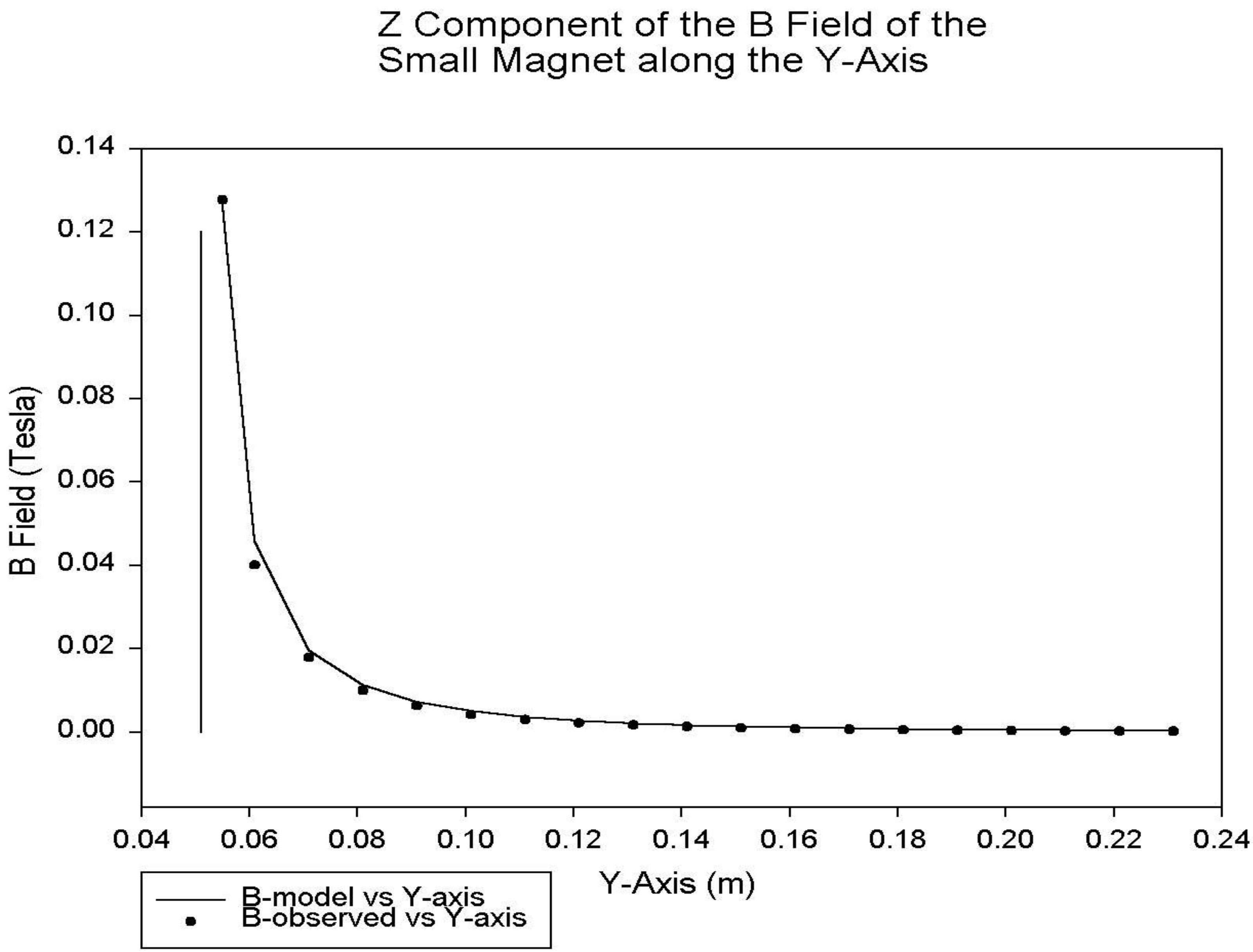
Thin Ceramic Magnet 0.5" x 4" x 6"   I = 2700 A



Thin Ceramic Magnet 0.5" x 4" x 6"   I = 2700 A



Thin Ceramic Magnet 0.5" x 4" x 6"   I = 2700 A



Conclusion

- The ceramic magnet has a magnetic field characteristic of uniform magnetization.
- The magnetic field is produced by the bound surface currents of the magnetization field.
- The magnetization field in the 1 inch thick ceramic is about 2.5×10^{5} A/m.
- The surface current of the 1 inch thick ceramic is about 6300 A.
- The magnetic fields of the ceramic magnets are modeled well by an infinitesimally thin rectangular coil.
- This experiment provides an excellent application of the magnetization field for the advanced laboratory.

If you would like information about making or buying one of these magnets contact me.

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