

Modul Electricity II

Earth's magnetic field

In the present experiment, the earth's magnetic field is measured for different axes of rotation of induced voltage. From the amplitude and the frequency of the recorded signal, the respective effective communication component of the geomagnetic field can be calculated. The goal of the evaluation is the total amount of the horizontal component and the inclined angle of the earth's magnetic field.

Experiment IIE3 - Earth's magnetic field

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1.1 **Preliminary Questions**

- What is the law of induction?
- What is meant by the terms field strength and magnetic flux density?
- What are oriented surfaces?
- What does Lenz's law say?
- Make yourself familiar with possible causes of the emergence and maintenance and some effects of the earth's magentic field.
- What is declination and inclination?

1.2 Theory

1.2.1 The Earth's magnetic field

The earth's magnetic field is a general term for the earth's magnetosphere. This term denotes the region of space around an astronomical object in which the essential part of the magnetic field dominates. Above it, there is the magnetopause, therefore, below is limited by the ionosphere. The main magnetic field is about 95% produced from the earth's core by the so-called geodynamo. The latter refers to the so-called *dynamo theory* described mechanism, which nowadays the most common theory and represents the formation of the main magnetic field. The magnetic field near the surface can be approximated by a magnetic dipole, as illustrated in Figure 1.1 . Above the earth's atmosphere, it is deformed by the solar wind, inside it is interacting by various non-trivial operations to a quadrupole, and is changed a multipole field. Essentially, the magnetic field lines occur on the southern hemisphere from the earth and through the northern hemisphere and back into the ground.

The pole in the northern hemisphere corresponds to the direction of the magnetic lines of the magnetic south pole, and vice versa. In general, however, the magnetic pole of the northern hemisphere is designated as the north pole and the magnetic pole in the southern hemisphere is designated as the south pole net.

The dynamo theory

The inner core is solid and consists of nearly pure iron. It is made of a liquid and is enclosed by a strongly ferrous outer core of the earth. The prevailing temperatures at the earth's core of 5000° C (about the temperature of the sun's surface) are above the Curie temperatures of iron and nickel.¹

Therefore, they are non-magnetic and merely have a function as electrical conductors. The temperature gradient between the hot core of the earth and less hot outer areas cause liquid material in the outer areas to flow, where it cools and eventually gets hotter again in the inner areas. These currents are called convection currents and are forced by the prevailing Coriolis force on helical paths forced. This heli-shaped movement of the electrically conductive material is due to the movement in the existing weak magnetic field generates an induction current and leads to a gain of the magnetic field. This in turn creates a stronger induction current and thus, by a reinforcement of the magnetic field it is reached again until a stable state is achieved.

¹This material-specific size means the temperature above which all ferromagnetic and electric properties of a material are completely gone, and therefore, this is only para- magnetic and -electric.



Figure 1.1: The dipole field of the earth.

Responsible for the formation of the earth's magnetic field current is thus done with the help of the earth's magnetic field generated by you.

The dynamo theories are unable to describe all the characteristics of the earth's magnetic field, but their accuracy is confirmed and supported to a large extent by various experiments, simulations, and computer calculations.

Characteristics of the earth's magnetic field

The direction of the magnetic field in space is described by the terms *inclination* and *declination*. The angle between the magnetic field direction and the geographical north pole direction is called *declination*. *Inclination* describes that the angle which schematically meets extending field lines of the earth's magnetic field on the earth's surface. The inclination of the northern hemisphere is mainly positive and negative in the southern hemisphere. At the equator, the inclination is exactly zero because there the magnetic field runs parallel to the surface and at the magnetic poles is 90°. Figure 1.2 shows the global distribution of the inclination and declination in 2° increments for the year 2010. As the position of the magnetic pole always migrates this distribution.

1.2.2 Measurement of the earth's magnetic field

After FARADAY'S Induction Law, a change in the magnetic flux density \vec{B} resulted in the formation of an electric field:

$$\operatorname{rot}\vec{E} = -\frac{\partial\vec{B}}{\partial t} \tag{1.1}$$



(a) Distribution of the inclination



(b) Distribution of the declination

Figure 1.2: Inclination (a) and declination (b) of the earth's magnetic field in $^{\circ}$ (Source: *http://www.ngdc.noaa.gov*)

The magnetic flux Φ passes through an orientated area *A* is given by:

$$\Phi = \int_{A} \vec{B} \cdot d\vec{A} \tag{1.2}$$

In the case of a homogeneous flux density and a non-curved surface is simplified with this formula:

$$\Phi = \vec{B} \cdot \vec{A} \tag{1.3}$$

and the flow with the scalar product of the flux density and the surface vector can be expressed. A change in the magnetic flux induces a voltage:

$$U_{ind}(t) = -\frac{d\Phi}{dt}.$$
(1.4)

The property to measure the earth's magnetic field is done in this experiment . Considering a circular coil of *N* turns and cross-sectional area *A*, which is penetrated by the magnetic flux Φ , the voltage induced is:

$$U_{ind}(t) = -\frac{d\Psi}{dt} \approx -N \cdot \frac{d\Phi_n}{dt}$$
(1.5)

wherein Ψ is the flux leakage and Φ_n is the magnetic flux through one turn the coil. The coil rotates with the angular frequency ω and for the induced voltage in the coil is:

$$U_{ind}(t) = -N \cdot A \cdot B \cdot \frac{d}{dt} \cos(\omega t)$$

= $N \cdot A \cdot B \cdot \omega \cdot \sin(\omega t)$
= $U_0 \sin(\omega t)$ (1.6)

Defining $a = N \cdot A$ and U_x , U_y , U_z the peak values of the potential coming from the sinusoidal fitting of experimental data for the three different axis of rotation, the magnetic field components B_x , B_y , B_z are defined as:

$$B_{x} = \frac{1}{\sqrt{2}a} \sqrt{-\left(\frac{U_{x}}{\omega_{x}}\right)^{2} + \left(\frac{U_{y}}{\omega_{y}}\right)^{2} + \left(\frac{U_{z}}{\omega_{z}}\right)^{2}}$$

$$B_{y} = \frac{1}{\sqrt{2}a} \sqrt{\left(\frac{U_{x}}{\omega_{x}}\right)^{2} - \left(\frac{U_{y}}{\omega_{y}}\right)^{2} + \left(\frac{U_{z}}{\omega_{z}}\right)^{2}}$$

$$B_{z} = \frac{1}{\sqrt{2}a} \sqrt{\left(\frac{U_{x}}{\omega_{x}}\right)^{2} + \left(\frac{U_{y}}{\omega_{y}}\right)^{2} - \left(\frac{U_{z}}{\omega_{z}}\right)^{2}}$$
(1.7)

and the amount of the magnetic field *B* is given by:

$$B = \frac{1}{\sqrt{2}a} \sqrt{\left(\frac{U_x}{\omega_x}\right)^2 + \left(\frac{U_y}{\omega_y}\right)^2 + \left(\frac{U_z}{\omega_z}\right)^2}$$
(1.8)

With similar considerations, the inclination angle can be found:

$$\vartheta = \arctan\left(\sqrt{\frac{\left(\frac{U_x}{\omega_x}\right)^2 + \left(\frac{U_y}{\omega_y}\right)^2 - \left(\frac{U_z}{\omega_z}\right)^2}{2\left(\frac{U_z}{\omega_z}\right)^2}}\right)$$
(1.9)

Figure 1.2 shows the global distribution of magnetic field components in 1000 nT increments for 2010.



(a) Distribution of the x-component of the earth's magnetic field



(b) Distribution of the y-component of the earth's magnetic field



(c) Distribution of the z-component of the earth's magnetic field

Figure 1.3: X-component (a) Y-component (b) and Z-component (c) of the earth's magnetic field in nT. (Source: *http://www.ngdc.noaa.gov*)

1.3 Experiment

1.3.1 Equipment

| Components | Number |
|--|--------|
| Helmholtz Coil (N =320, \emptyset = 13.5cm) | 2 |
| Experimental motor | 1 |
| Control unit for experimental motor | 1 |
| Digitalmultimeter | 1 |
| Sensor CASSY | 1 |
| μV-Box | 1 |
| Windows-PC | 1 |
| Experiment cable 32 A, 200 cm, red | 1 |
| Experiment cable 32 A, 200 cm, blue | 1 |

1.3.2 Experimental Setup and Adjustment

- Attach the Helmholtz coil in the experimental motor and connect the cables according to Figure 1.4.
- Set the speed of the experimental motor to zero.
- Start the engine and gently turn the speed slowly up until about 0.3 revolutions per second has been reached. By hand, the two connecting leads should wrap around the coil axis, and they are not on tangled in the construction.
- Once the cables are fully wound around the axis of the spool, the motor should be stopped by turning the directional key in the middle position.

• The speed of the motor should no longer be changed. By turning the same button in the other direction, the rotation of the motor is changed to unwind the cord.



Figure 1.4: Schematic Experimental Setup

1.3.3 Implementation

- Start your Windows PC.
- Start the program CASSY Lab. 2 by double clicking the icon on the desktop
- Click in the appearing Menu from Close.
- Load the file IIE3_Erdmagnetfeld from the hard drive by pressing the F3 button pressing and select on the L: drive in the directory L: ap data II_E_5_Erdmagnetfeld.
- Click in the appearing Menu from Close.
- Position the coil according to Figure 1.4 in the z-direction.
- Start the experiment to measure the induced voltage as a function of time by pressing the F9 key and confirm by clicking on the Yes button.
- Now start the engine. The measurement is automatically stopped after 20s.
- Switch the motor off after the measurement. Reverse the direction of rotation order and let it run until the starting point is reached again.
- Make a fit now of the measured curve by it by pressing ALT + F.
- Choose in the menu the function $f(x, A, B, C, D) = A \cdot \sin(360 \cdot B \cdot x + C)$ and initialize the parameters.

- Click Select Next with the field and choose the largest possible value, but it should be possible to start a regular range with a mouse click to start and mark the curve and then select the button on the area to the right.
- Include the presentation and the results added to the fit parameters, by hitting ALT-T and clicking on OK.
- The fitted curve can now be a highlighted color by clicking the upper right of the menu settings under the standard voltage and then adapt in the color style the evaluation.
- Save the picture and repeat the measurement four times with the same angular speed.
- Rotate the coil axis in the y-direction and repeat the measurement.
- Turn the engine now to 90°, so that the measurement with the coil axis in the x-direction can be repeated.

1.3.4 Tasks for Evaluation

- Derive the following equations (1.7),(1.8),(1.9).
- Form the mean values and standard deviations of the measured values.
- Determine the components B_x , B_y , B_z , the horizontal component, and the amount *B* of the earth's magnetic field.
- Determine the inclination angle ϑ of the earth's magnetic field.
- Compare your values with those of the international data of Figures 1.2 and 1.3. What do you notice it?

1.4 Literature

- J. D. Jackson, "Classical Electrodynamics", Third Edition, John Wiley & Sons, Inc.
- D. Meschede, "Gerthsen Physik", Springer Verlag, Heidelberg