19. Measurement of the horizontal component of the magnetic field of the earth.

Assignment

1. Measure the horizontal component of the magnetic field of the earth.
2. Analyze source of errors in your measurement.

Theoretical part

The phenomenon of magnetic properties of the matter was known around the VIII. century. In 1750 John Michell used a torsion balance to show that magnetic poles exert attractive or repulsive forces on each other and that these forces vary the inverse square of their separation. Although the force between two magnetic poles is similar to the force between electric charges, there is important difference. Electric charges can be isolated, whereas magnetic poles cannot be isolated. The magnetic poles are always found in pairs. No matter how many times a permanent magnet is cut, each piece will always has a north and a south poles.

In the 1820's, Faraday demonstrated further connections between electricity and magnetism. He showed that an electric current could be produced in a circuit either by the motion of a magnet near the circuit or by the change of current in circuit. These observations demonstrate that a change of magnetic field produces an electric field. Later the theoretical work by Maxwell showed that changing electric field gives rise to a magnetic field.

We take an interest in the magnetic field of the earth. As we know, the earth acts like a huge magnet. A sketch of its magnetic field is shown in Fig.3.1. Because a compass needle points northward on the earth, the magnetic field must be in the direction shown. But, the lines come out of north poles and go into south poles.

Therefore, the earth`s magnet has its north pole at the south end of the earth, whereas the earth` magnet has its south at the north end of the earth. As we see in Fig.3.1, the earth`s rotation axis does not line up perfectly with the earth`s magnet. The earth`s north magnetic pole (a south pole) is currently in the Arctic ocean 1000 miles south of the north geographic pole toward Nebraska. The earths`s south magnetic pole (north pole) is in the Antarctic Ocean 1500 miles north of the south geographic pole toward Australia. These poles generally slowly drift for unknown reasons.

Although the magnetic field pattern of the earth is similar to that which would be set up by a bar magnet deep within the earth, it is easy understand why the source of the earth's field cannot be large masses of permanently magnetized material. The earth has large deposits of iron ore deep beneath its surface, but the high temperatures in the earth's core prevent the iron from retaining any permanent magnetization. It is considered more likely that the true source is charge-carrying convention currents in the earth's core. Charged ions or electrons circling in the liquid interior could produce a magnetic field, just as a current in a loop of wire produces a magnetic field. It indicates that the strength of a planet's field is related to the planet's rate of rotation. For example, Jupiter rotates faster than the earth and its magnetic field are stronger then the earth's magnetic field, which has a value 0.5×10^{-4} T , approximately.

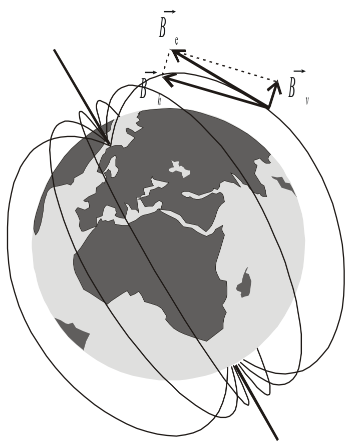

Fig.3 1

If the compass needle is suspended in bearing that allow it to rotate in a vertical plane as well as in horizontal plane, the needle is horizontal with respect to the earth's surface only near the equator. As the device is moved northward, this needle rotates such that it points more and more toward the surface of the earth. The difference between true north, defined as the geographic North pole, and north indicated by a compass varies from point to point on the earth. The difference between them is referred to as magnetic inclination. From this reason is very important resolved the magnetic field of the earth B_e into two perpendicular components: vertical component B_v and horizontal one, B_h

$$B_e = B_v + B_h \qquad (3.1)$$

as is shown in Fig.3.1.

The method-practical part

The experimental method of the measurement of the horizontal component of magnetic field of the earth is based on the composition of two magnetic fields. One is the magnetic field of the earth and second one is the magnetic field produced by the current in the coil.

The magnetic field at any point in the space around current-carrying conductor is defined by the vector physical quantity B given by Biot-Savart law

$$\vec{B} = \frac{\mu_0}{4\pi} \int \frac{I \mathrm{d}l \times r}{r^3} \qquad (3.2)$$

where I is the current passing trough the conductor, $\mathrm{d}l$ is the current element directed in the dirrection of the current, r is the position vector of the point in which we calculate the magnetic field to the current element, r is the distance between the current element and the given point and $\mu_0 = 4\pi \times 10^{-7}$ Wb.A^{-1}.m^{-1} is the permeability of the free space. The dirrection of this magnetic field vector is determined by the right hand rule.

Magnetic field inside the coil is homogenous and parallel to the axis of symmetry of the coil and from Biot-Savart law is given

$$\left|\vec{B}_c\right| = N\frac{\mu_0 I}{2R}, \tag{3.3}$$

where N is the number of the turns of the coil, I is the current trough the coil and R is the radius of the coil.

If the compass is placed at the center of the coil so that magnetic field of the earth is perpendicular to the axis of symmetry of the coil (i. e. magnetic field of the coil), the compass needle due to these magnetic fields is deflected in the resultant magnetic field (see Fig.3.2). This resultan magnetic field is given by

$$B = B_h + B_c, \tag{3.4}$$

where B_h is the horizontal component of the magnetic field of the earth and B_c is the magnetic field of the coil.

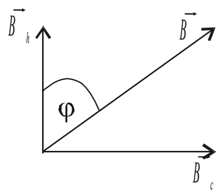

Fig.3 2

From the Fig.3.2 we can see that the ratio between the components of the magnetic fields B_c and B_h is given by the tangent of the angle between them as

$$\tan\varphi = \frac{\left|B_c\right|}{\left|B_h\right|}. \tag{3.5}$$

From this equation we can determine the value of the horizontal component of magnetic field of the earth if we know value of magnetic field of the coil. Inserting eq.(3.3) into eq.(3.5) gives

$$\left|\vec{B}_h\right| = \frac{\mu_0 NI}{2R\tan\varphi}. \quad (3.6)$$

Measurement -

Apparatus: compass, coil, ammeter, rheostat, source of voltage, commutator, meter stick.

Experimental procedure: Connect the apparatus according to block diagram as is shown in Fig.3.3. Direct the compass needle along the horizontal diameter of the coil. Switch on the source voltage. Measure the current of I_1 and the angle of φ_1 of the compass needle. Then change the direction of I_1 by the commutator. Read the values of I_2 and φ_2 .Note these values must be approximately equal to values of I_1 and φ_1 . Repeat these measurements for various value of I . Record all data into data table Tab.3.1. Measure the diameter of the coil. The number of the turns is introduced on the using coil.

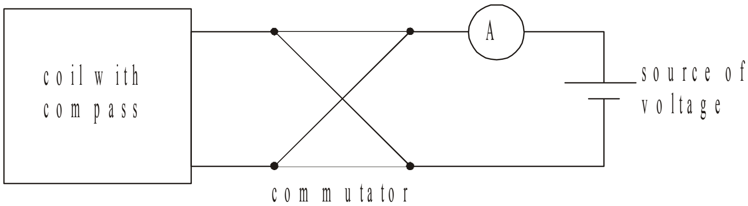

Fig.3 3

Calculation: Using eq.(3.6) calculate the value of B_h for each pairs of measured values of current I and corresponding value of angle φ . Calculate the average value of the B_h . Discuss about the sources of the errors in your measurement.

i	I_1	φ_1	I_2	φ_2	$I = \frac{I_1 + I_2}{2}$	$\varphi = \frac{\varphi_1 + \varphi_2}{2}$	B_h

Tab.3.1.