MAGNETIC FORCE ON A CURRENT CARRYING WIRE

Introduction

Maricourt (1269) is credited with some of the original work in magnetism. He identified the magnetic force centers of permanent magnets and designated them as north and south poles, referring to the tendency of the North pole to seek the north geographic pole of the earth. A generalization of the interaction between these so-called force centers can be summarized as: opposite poles attract, and similar poles repel. Gilbert (1600) recognized that the earth itself was a natural magnet, with magnetic poles located near the geographic poles, only the north geographic pole is a south magnetic pole.

The magnetic field \( B \) as it was originally conceived, designated the direction and magnitude of the force (per pole strength) on a North pole of a permanent magnet. This was directly analogous to the electric field \( E \) which was defined as having the direction and magnitude of the electric force (per unit charge) on a positive test charge. The magnetic field emanates from the North pole of a magnet and appears to end on the South pole.

Ampère determined that a current carrying wire is affected by a magnetic field. Both magnitude and direction of the magnetic force is described by the cross product

\[
\Delta F = i\Delta l \times B
\]  \hspace{1cm} (1)

where the direction of \( \Delta l \) is in the direction of flow of positive current \( i \). The direction is ascribed to the spatial variable \( \Delta l \) rather than the current \( i \) for the convenience of integration. If we consider infinitesimal lengths the expression can be rewritten without loss in generality as:

\[
dF = idl \times B
\]

Figure 1 shows the vector relationship between the magnetic force \( dF \) and the magnetic field \( B \) and current direction \( dl \).

In this experiment we will use high strength Neodymium permanent magnets to create an intense magnetic field in a localized region of space. We will place a current carrying conductor in this region, measure the resulting magnetic force, and compare our experimental value with the force predicted by force equation.

The magnetic field created in the pole gap will be uniform within the gap but will drop
off over a finite region just outside the gap. It is necessary to know approximately where
the field drops off, to define where along the wire the magnetic field exists, and thus
contributes to the magnetic force.

\[
\mathbf{F} = i \int \mathbf{dl} \times \mathbf{B}(l)
\]

Figure 1: Magnetic Force Cross Product

![Diagram](image)

Figure 2: Magnetic Field in Magnet Gap

If one had detailed information about the strength of the field as a function of position
through the gap, one could do a calculation of the integral

\[
\mathbf{F} = i \int \mathbf{dl} \times \mathbf{B}(l)
\]

Figure 2 shows a diagram of the typical magnetic field produced in the gap between
two strong Neodymium magnets. A profile of the magnetic field through the gap is
shown in Figure 3. You will obtain an approximate profile of your specific gap using
a Hall probe to measure the B field every half centimeter along a line through the
center of the gap. For finite segments of distance through the gap we can
approximate equation (2) with

\[
\mathbf{F} = i \Delta l \times \mathbf{B}
\]

where \( \Delta l \) is the unit of length of resolution used to map the magnetic field. A good
approximation to the total force can be estimated by summing the components over
the range of measured B field values. Since the same values of \( \Delta l \) and \( i \) apply to
each segment, equation (3) reduces to
Two neodymium permanent margents are placed in the gap of a soft iron yoke to create a very intense magnetic field in the gap between the magnets. The strength and extent of this field will be mapped using a Hall probe. Take a reading of the field strength in the very center of the gap. Record this number, and then using the probe, determine how far out from the center of the gap the field drops to half of this maximum value. This distance will be used to define effective the limits of region of magnetic field the wire is exposed to.

![Graph of Magnetic Field](image)

Figure 3: Profile of Magnetic Field in Magnet gap.

Secure the Hall probe to the lab jack with the clip provided, and position the lab jack base against the ruler such that the Hall probe can be passed through the center of the gap of the magnet. Move the jack along the ruler to position the probe at the center of the gap. Observe the strength of the magnetic field with the Hall probe. Now move the probe out of the gap until the reading of the magnetic field drops to a tenth of the maximum. Record the magnetic field and note the position of one edge of the jack on the ruler scale. Now move the jack a half-centimeter along the rule and record the magnetic field again. Repeat the operation through the gap until the probe has scanned the entire gap. A Drawing of the setup is shown in top view looking down on the apparatus in Figure 4.
Record the magnetic field values in a table. Evaluate the term $\Delta I \sum B$ by summing the column of $B$ values in your table and multiplying by the interval you used while making the measurement. It is also possible to enter these values into the Graphical Analysis program and obtain a plot similar to Figure 3. Then use this software to evaluate $\Delta I \sum B$ by integrating the area under the curve. This will also yield an uncertainty that can be used to compare this value to later calculations.

**The Experiment**

The magnet is attached to a support bar and oriented as shown in Figure 5. An electronic balance, whose pan has been fitted with a non-ferromagnetic non-conducting wire support, is set on a lab jack and the conductor placed in the slot of the wire support as shown in Figure 5 and in greater detail in Figure 6. The conductor and balanced is raised into position such that the conductor is in the center of the magnet gap. A pointer indicates the center of the gap. The balance will be used to measure the force of magnetism on the conductor as it conducts a current in the magnetic field.
Use the compass provided to determine the north and South Pole pieces in the magnet, and therefore the direction of the magnetic field in the gap of the magnet. The north pole of the compass is painted red. Note the balance to read zero grams. Set the power supply to 3.0 amps and note the movement of the conductor. Does the balance read positive or negative mass? Verify that the force due to magnetism is in the correct direction as predicted by the cross product in equation (1). Adjust the position of the conductor so that it is centered in the gap as indicated by the pointer, and read the effective mass as indicated by the balance, and multiply this number by the acceleration of gravity. This is the magnetic force due to the current of 3.0 amps passing through the conductor in the magnetic field. Take several readings of this force for different currents. Be sure to note the balance for zero current each time and then take a reading with the current turned on.

Make a plot of the force versus the current. Verify that the force is directly proportional to the current. Find the Least Square’s Fit to the line and obtain the slope of the force vs. current line. Also record the uncertainty in the slope. The slope of this line should be equal to the value obtained by evaluating $\Delta I \Sigma B$. Do the values agree with the error limits of your data?
Using equation (4) and your magnetic field profile, calculate an expected value for the force F for each current setting and make a table comparing the expected value of the force F with those you measured for each current setting. Comment on the quality of the agreement.

**Question** Following is a list of questions intended to help you prepare for this laboratory session. If you have read and understood this write up, you should be able to answer most of these questions. Some of these questions may be asked in a quiz preceding the lab.

- What are the units of magnetic force?
- What are the units of magnetic field?
- How is the direction of the magnetic force oriented with respect to the directions of magnetic field and current which produced it?
- What is the Hall probe used to measure in this experiment?
- If a current is moving along a wire aligned with a magnetic field, what is the magnitude and direction of the force of magnetism on the wire?
- How is the magnitude of the force of magnetism related to the magnitude of the current I carried in a wire?
- How is the magnetic force experimentally related to other measurable forces?
- Why is it important to keep the pulley string horizontal when measuring the force to displace the trapeze a given distance?