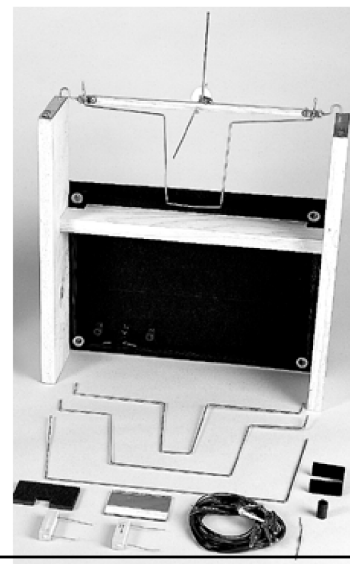
#10-400 Current Balance, External

Purpose:

To investigate the effects of magnetic fields on current carrying wires.

Required Accessories:

Ringstand and clamp
Ruler or centimeter tape
Two variable low voltage power supplies (0 to 6 VDC, 5 A)
Two ammeters (0 to 5 A)



Setup with Accessories

Assembly:

Insert the longest aluminum loop through the Fahnstock clips on the pivoted balance beam. Allow the ends of the loop to protrude approximately 1.0 cm above the clips.

Push the end of the pointer through the center hole of the balance beam. The threaded end of the pointer should extend 6.5 cm from the balance beam. Now tighten the set screw on the pivot bar that holds the pointer in place.

Insert the short vertical rod into its hole on the top center of the pivot bar. Slip a Fahnstock clip all the way onto the vertical rod.

Position the pivot bar assembly on the balance frame plates so that the pointer extends toward you. Adjust the cylindrical counterweight so that the pointer comes to rest in a horizontal position. Repeat this step with the sensitivity clip moved near the tip of the vertical rod.

Position the pivot bar assembly so that the long straight section of the wire loop comes to rest parallel to and approximately 5.0 cm from the fixed coil of wire.

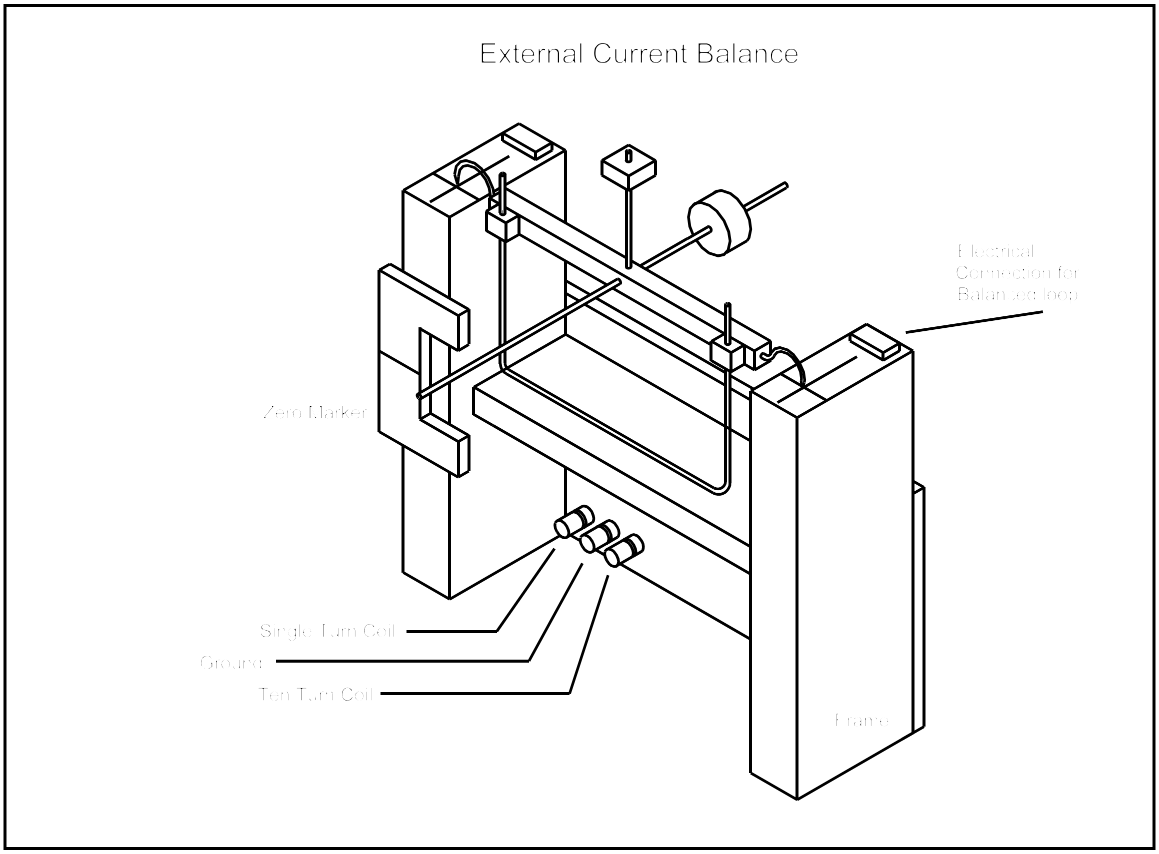


Figure 1
Assembly of the external current balance.

PLEASE NOTE: The Fahnstock clips are used as the sensitivity weights by clipping them to the sensitivity post.

The fixed coil mounted on the frame of the balance consists of two coils; one is a single turn, and the other is a ten turn coil. The center binding post is common to both coils. The left binding post is connected to the ten turn coil. The right binding post is connected to the single turn coil.

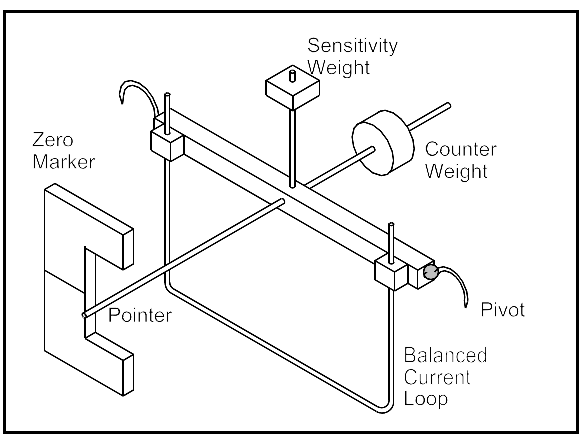


Figure 2
Detail of balance beam.

Discussion:

The current balance measures the force on a horizontal rod suspended so that it is free to move at right angles to its length. You can study the forces

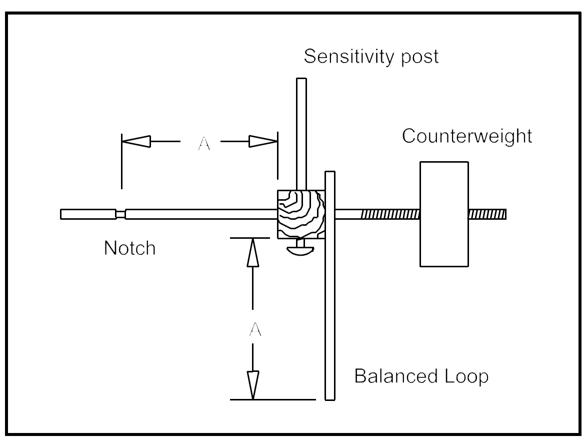


Figure 3
Cross section of the balance beam.

exerted by a magnetic field on a current by bringing a magnet up to this rod while there is a current in it. A force on this current carrying rod causes it to swing away from its original position.

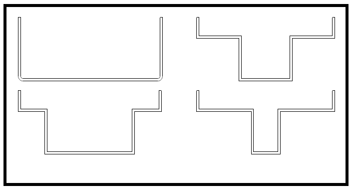


Figure 4
Various shapes for the balanced loops.

Before running any experiments, the balance must be assembled and adjusted for maximum sensitivity. The four non-magnetic metal rods bent into various shapes are referred to as the balanced loops. Set up the balance with the longest loop clipped to the pivoted horizontal bar. Adjust the loop so that the horizontal part of the loop hangs level with the bundle of wires (the fixed coil) on the pegboard frame. Adjust the balance on the frame so that the loop and coil are parallel as you look down at them. They should be at least 5 cm apart. Make sure the loop swings freely.

Adjust the counterweight cylinder to balance the system so that the long pointer arm is approximately horizontal. Mount the zero indicator in a clamp and position the plate so that the zero line is opposite the horizontal pointer.

Set the balance for maximum sensitivity by moving the sensitivity clip up the vertical rod on the pivot bar until the loop slowly swings back and forth. These oscillations may take as much as 4 or 5 seconds per swing. If the clip is raised too far, the balance may become unstable and tip to one side or the other without righting itself.

Make sure that the pivots (pointed contacts) are clean and shiny, and remain that way throughout the experiment. You can clean them using a fine grade sandpaper. Connect a 6 volt 5 ampere power supply to an ammeter. From the other terminal of the ammeter, connect one wire to one of the flat horizontal plates on which the pivots rest. To limit the current through the balance, connect the second horizontal plate to one or two 1 ohm resistors or a high power rheostat then back to the power supply ground. Set the power supply for minimum output, then turn it on. If the ammeter deflects in the wrong direction, swap its input leads. When you're confident that everything is operating correctly, slowly increase the current to about 4.5 amps. Bring a small magnet close to the balanced current loop. What happens? What orientation of the magnet produces the greatest deflection of the current loop?

Connect the fixed coil to a circuit similar to the balanced loop (power supply, rheostat, and ammeter). Make sure that the fixed coil and the balanced current loop are independent (there is no change in the balanced loop current when the fixed loop current is changed).

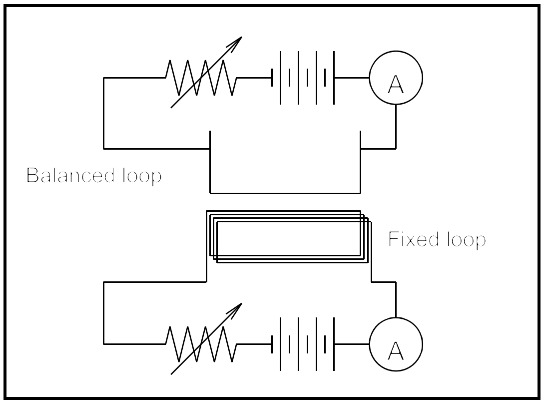


Figure 5
Wiring diagram for the fixed current loop and balanced loop.

Turn the current on in both circuits and check to see which way the pointer rod on the balance swings. You would like the pointer to swing up, if it doesn't, what do you have to change in your setup? When changing the wiring in your circuit, always note the direction of the current in each of the loops. Do currents flowing in the same direction attract or repel each other?

Make weights from some thin wire cut to lengths 1 cm, 2 cm, 5 cm, and 10 cm, by bending them into small "S" shaped hooks. Hang them from the notch on the pointer or from each other. The distance from the axis of the balance to the notch on the pointer is the same as the distance from the axis of the balance to the bottom of the loop. Therefore, when there is a force on the horizontal section of the balanced current loop, this will equal the total weight hanging on the pointer at the notch.

How Force Depends on Current in the Wires:

Set the balance on the frame so that the loop and the coil are parallel and approximately 1 cm apart as you look down on them. Increase the current in the balanced loop to 3 amperes. Once set, do not change this value for the duration of the experiment. With this current in the balanced loop and no current in the fixed coil, line the zero mark up with the pointer end.

Begin with a relatively small current in the fixed loop (0.5 to 1 ampere). Hang weights on the end of the pointer to bring it back to the zero mark. Record the current in the fixed wire and the amount of weight added to the pointer arm. The added weight is a measure of the force between the wires. Increase the current in the *fixed* loop in steps of 0.5 amperes (remember to verify that the balanced loop is still carrying 3 amperes). Balance the pointer again by adding more weights. Record the current and the total weight. Continue to increase the current in the fixed coil until you reach 5 amperes.

Plot the force between the wires as a function of the current in the fixed loop. What is the relationship between the current in the fixed coil and the force on the balanced loop? How would the force on the balanced loop change if the current in the fixed coil were held constant and the current in the balanced loop varied?

Force as a Function of Distance Between Wires:

Place a ruler or other centimeter scale on the wooden shelf below the balanced loop. Because there is a gap between the loop wire and the scale, the number you read on the scale will change if you move your head from side to side. This is called parallax. To eliminate parallax, place a small mirror on the shelf then lay your ruler on top of that. You will be able to measure the correct separation when the wire lines up with its image in the mirror.

Set the zero mark with a current in the balanced loop of about 4.5 amperes and no current in the fixed loop. Separate the two coils by approximately 0.5 cm. Adjust the current passing through the fixed coil to 4.5 amps. Hang weight at the notch in the pointer arm until the pointer is again at the zero position. Record the weight and the separation between wires. Repeat this procedure using 4 or 5 greater separations (say, every 0.5 cm). Make sure that the balanced loop and the fixed coil are parallel, that there are 4.5 amperes in each loop, and that the needle is at the zero position before each trial.

Plot the force as a function of the separation between the balanced loop and the fixed coil. Is your plot a straight line? If not, try using some other function of the separation ($1/d$, $1/d^2$, or d^2) to use on the independent axis that will give you a straight line plot. Once you arrive at a straight line plot, you will have the relationship between the force on the balanced loop and the separation between the loops.

How Force Varies with the Length of Wire:

By keeping constant currents I_f and I_b and a constant separation d, you can investigate the effects of currents on the differing lengths of the wires. Different lengths of wire are provided for the balanced loop. In the current balance setup, it is the bottom horizontal section of this loop that interacts most strongly with the fixed coil.

To measure the distances between the two wires, place the mirror on the shelf below the loops. With your ruler on top of this mirror, look down on the two loops. When the reflected image of the loop and the real loop lines up, read their separation from the ruler. Adjust the distance to about 0.5 cm. With a current I_b of about 4.5 amperes in the balance loop and no current I_f in the fixed coil, set the pointer at the zero mark. Begin the experiment by passing 4.5 amperes through both the balance loop and the fixed coil. Hang weight on the notch in the pointer arm until the pointer is again at the zero position. Record the value of the currents, the distance between the wires, and the weight added. Turn off the currents, and carefully remove the balance loop by sliding it out of the holding clips. Measure the length of the horizontal segment of the loop.

Insert the next smaller loop. Adjust it so that it is level with the fixed coil and the distance between the loop and the coil is just the same as you had before. *This is important*. The loop must also be parallel to the fixed coil, both as you look down at the wires from above and as you look at them from the side. Also reset the clip on the balance for maximum sensitivity. Check the zero position, and see that the currents are still 4.5 amperes. Repeat your measurements for each additional balance loop. What is the relationship between the length L of the loop and the force F on it? Can you convert the force, as measured in centimeters of wire hung on the pointer arm, into force in Newtons? If the force on the balance loop is F, what is the force on the fixed coil?

Force on currents in a constant magnetic field.

In this experiment you WILL NOT use the fixed coil. Attach the longest of the balance loops to the wooden pivot bar. Balance the loop. Place two small ceramic magnets on the inside of the iron yoke so that the two near faces attract each other when they are moved close together. Place the yoke and magnet unit on the platform so that the balance loop passes through the center of the region between the ceramic magnets.

Check whether the horizontal pointer moves up when you turn on the current. If it moves down, change your setup so that the pointer swings up. With the current off, mark the zero position of the pointer arm with the indicator. Adjust the current in the coil to about 1 ampere. Hang wire weights at the notch in the pointer arm until the pointer returns to the zero position. Record the current and the weight hung on the pointer arm. Repeat the measurements for at least four greater currents. Between each pair of readings, check the zero position of the pointer arm.

Try plotting a graph of the force (weight) required to balance the beam as a function of the current in the balanced loop. If the magnet exerts a force on the current, do you think the current exerts a force on the magnet? How would you test this? How would a stronger or weaker magnet affect the force on the current? Use different magnets or double the number of pole pieces if you have time. Plot F as a function of current on the same graph. How do these plots compare?

Interaction between the earth and an electric current

Set the balance with the longest loop to maximum sensitivity by sliding the sensitivity clip to the top of the vertical rod. The sensitivity can be increased further by adding a second clip; be careful not to make the balance top heavy so that it will tip over.

With no current in the balance loop, align the zero mark with the end of the pointer arm. Turn on the current and adjust it to about 5 amperes. Turn off the current and let the balance come to rest. Turn the current on again and observe carefully: does the balance move when you turn the current on? Since there is no current in the fixed coil, and there are no magnets nearby, any force acting on the current in the loop must be due to an interaction between it and the earth's magnetic field.

Set up the experiment so that the pointer swings up when you turn on the current. With the current on, hang weights at the notch in the pointer arm and adjust the current to restore balance. Record the current and the length of the wire on the pointer arm. Repeat the measurement of the force needed to restore balance for several different values of current. If you have time, repeat your measurements of force and current for a shorter loop. What force (in Newtons) does the earth's magnetic field exert on the current in the balanced loop?

Time Allocation:

To prepare this product for an initial experimental trial, and gain sifficient familiarity should take less than thirty minutes. Actual experiments will vary with needs of students and the method of instruction, but are easily concluded within one class period.