

new instruments measured the current generated by a rotating copper plate. As the plate is spun perpendicular to the plane of the magnetic field, a weak current is produced. Weber replaced the copper plate with a coil of wire that could be rotated, and a deflection caused by the current appeared on a galvanometer dial. This type of magnetometer allowed scientists to measure a changing strength and direction of a magnetic field, and is still used.

4.5 Proton Precession magnetometer

This magnetometer design can only measure the total magnetic field strength, but is often used for underwater location of metallic objects such as submarines. The operating principle here is that protons in a liquid (like ordinary water!) have a precession frequency of about 2000 Hertz in a 50 microTesla field. The precession frequency depends on the applied field strength. To sense the precession frequency, a non-ferromagnetic container with hydrogen-rich liquid such as alcohol is surrounded by a coil of wire. A current is passed through the wire to magnetize the liquid, then the field is turned off, and the current produced by the low-frequency radio signal from the gyrating protons is measured.

Although this device sounds complicated, in fact it is well within the skill of an amateur scientist/hobbyist to produce. There are several designs for this kind of instrument on the Web.

V. The fluxgate magnetometer

Although it was mainly built to detect submarines during World War II, the fluxgate magnetometer provides information about both the intensity and orientation of a magnetic field. It has become, by far, the most widely used instrument both for prospecting on Earth and for space-based research applications. This is the type of magnetometer used in the THEMIS ground-based observatories, including the education stations.

5.1 Operating principles

Consider an electromagnet with wires wrapped around a nail and attached to a battery. When the circuit is completed and the electricity flows, the coils produce a magnetic field. The iron nail is not necessary for an electromagnet, but it is used to enhance the magnetic field. A fluxgate magnetometer uses some of these same concepts, plus more.

A fluxgate magnetometer measures an external magnetic field in any direction by determining the amount of electric current needed to reduce the magnetic field strength in the core to zero along that direction. The core is in the center of the fluxgate sensor (like the iron nail in the electromagnet) and usually consists of a nickel ring wrapped with magnetic material, as shown in Figure 31. If there is an external magnetic field, a magnetic field in the core will exist before the fluxgate magnetometer is turned on. If there is no external magnetic field, there will be no magnetic field in the core before the fluxgate magnetometer is turned on. Around the core is a primary coil of wire (like the wire around the nail in the electromagnet) that magnetizes the core, in addition to any external magnetic field magnetization. A secondary coil is wrapped around the core to detect signals coming from it.

To magnetize the core, a fluxgate magnetometer applies an oscillating magnetic field (one that changes quickly and periodically in time) around the core that alternately produces a magnetic field parallel and antiparallel to the "sense" axis. An example of a sense axis is the x-axis on the THEMIS magnetometers. This oscillating magnetic field reverses the core's polarity (its orientation of the North and South magnetic poles). If the average magnetic field is zero in the core, the secondary coil shown in Figure 31 picks up a symmetric signal. This signal arises when the current in the primary coil drives the magnetic material to saturation on each reversal of the core's polarity. Saturation is the maximum magnetic field the magnetic material can hold. If there is some steady magnetic field in the core from an external magnetic field, the saturation produced by the primary coil will be asymmetric and a signal will be produced in the secondary coil at double the frequency of the signal in the primary coil.

To determine the amount of electric current needed to reduce the magnetic field strength in the core to zero, the current is increased until the asymmetric signal becomes symmetric again, signifying a zero field in the center of the sensor. The strength of this current is a measure of the magnetic field being studied.

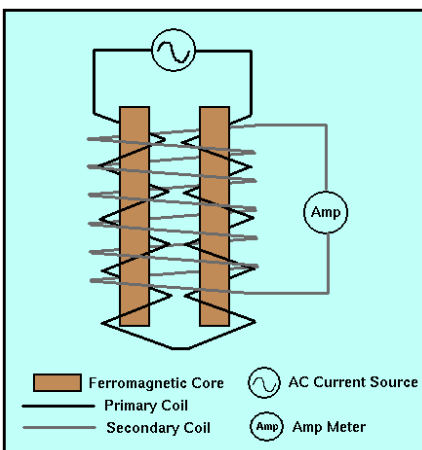


Figure 31 - A diagram showing one type of fluxgate magnetometer. A primary coil is wound around the iron bars and an alternating current is run through this wire. A secondary coil is wrapped around the iron bars to measure any changing magnetic fields due to magnetic saturation of the iron bars. An external magnetic field aligned parallel with the bars will influence the signal measured by the secondary coils. Some fluxgate magnetometers use rings of iron instead of bars.

5.2 Applications in science, medicine and industry

There are many applications of fluxgate magnetometry to science, medicine and industry. Here are some of the surprising ones!

Lung Research

Dr. David Cohen at the Massachusetts Institute of Technology (MIT) published a paper in 1979, concerning his findings on the human lungs. Air passages in the human body are lined with hair-like cilia, constantly waving back and forth and thus slowly sweeping out any dirt or debris deposited in them (Cohen called them "the moving carpet"). Cohen had a dozen volunteers inhale small amounts of iron oxide dust, which is harmless but can be magnetized. Over a year's time, each subject stood between a pair of coils, through which a large current was briefly passed. This magnetized the dust grains inside the lungs and aligned them with each other. The subjects then climbed into the shielded room, where the strength of the magnetization of their chest area was measured. During the year of observations the amount of dust declined steadily to about 10% of the original level. (For smokers, however, their lungs cleaned themselves much more slowly, and after one year, about 50% of the dust still remained.)

Cytology:

When Peter Valberg and later Jim Butler, both accomplished physicists, arrived at the Harvard School of Public Health, they invented Magnetic Twisting Cytometry to study the mechanical properties and motility of pulmonary macrophages - organisms that eat viruses. Ferromagnetic particles got "eaten" by a small sample of macrophages, then the particles were magnetized and subsequently twisted in a homogeneous magnetic field. Depending on the macrophages' rheological properties, the magnetic particles rotated faster or slower. This rotation was measured with sensitive fluxgate-magnetometers by measuring the particles' small magnetic field (on the order of 1 nanoTesla)

VI: The THEMIS Magnetometer

6.1 Design and block diagram

The THEMIS mission studies substorm signatures on the ground and in space with time resolutions less than 30 seconds. Existing and new