A Progression of Magnetic Instrumentation over the Years

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Geophysical magnetics instrumentation has come a long way over the last hundred years. The original magnetometer, which is no longer used, was a dip needle. Currently, three types of magnetometers are used: fluxgate magnetometers, proton-precession magnetometers, and optically pumped magnetometers. Various technological developments have also been made over the years. This includes the development of marine and airborne magnetic instrumentation. Also, significant advances have been made with computers.

The first magnetometer was the simple dip needle. The dip needle contains a magnetic needle that revolves about a center of gravity on a vertical axis. A counterweight is attached to this needle. To take a reading, the dip needle is oriented so that the vertical plane is parallel to the magnetic median (Swanson 1936). With a single dip needle, one is unable to measure individual components of the Earth's magnetic field. Swanson (1936) showed that one can find the components of the Earth's magnetic field from the measurements of two dip needles.

During World War II, the fluxgate magnetometer was developed as a way of tracking submarines. This device consists of two cores, each with primary and secondary windings. The core is usually made of a material that has high permeability at low magnetic fields, like mu-metal, permalloy, or ferrite (Telford 1990). The coils are driven by a low frequency source, and the maximum current pushes the magnetic cores to saturation twice each cycle. The secondary coils are connected to a differential amplifier. The pulse height from this amplifier is proportional to the amplitude of the biasing field of the Earth. This device has a few sources of error: the inherent unbalance between cores; thermal and shock noise in the cores; drift in biasing currents; and temperature sensitivity. The advantages include direct readout, no azimuth orientation, coarse leveling requirements, light weight, small size, reasonable sensitivity, and any component of the magnetic field can be measured (Telford 1990).

The proton-precession magnetometer grew out of the discovery of nuclear magnetic resonance in 1945. The instrument consists of a proton source, a polarizing magnetic field considerably stronger than that of the Earth, a pickup coil tightly coupled to the source, and a frequency counter. Some nuclei have a net magnetic moment that causes them to precess about an axial magnetic field. In a proton-precession magnetometer, a high power direct current (DC) or low frequency signal provides a polarizing field. The removal of the polarizing field causes the protons to precess. This precession of protons induces a voltage in the coil that varies with the precession frequency, which is proportional to the magnetic field. The proton source is usually a bottle of water or some organic fluid rich in oxygen, like alcohol. This instrument has three main advantages. First, it has a high sensitivity. Second, it requires no orientation or leveling, which makes it attractive for aerial and marine applications. Finally, it is practically free from drift. It also has two main disadvantages: it can only measure the main field, and it requires a second or more between measurements (Telford 1990).

A newer sub-type of the proton-precession magnetometer is the Overhauser proton-precession magnetometer. It is very similar to the original proton-precession magnetometer except for a couple of key differences. First, the proton-rich fluid also contains free radicals. This helps increase the responsiveness of the protons to electricity. Also, instead of applying a high power DC or low frequency signal to the fluid, it uses a low power Radio Frequency (RF) magnetic field around the fluid. The main advantage of this instrument is that it has a much higher data collection rate. The main disadvantage is that it is sensitive to heat (Environmental Magnetics 2003).

The next instrument type is the optically pumped magnetometer. It uses a gaseous alkali metal from the first column of the periodic table. Light polarization shifts electrons from level 2 to unstable level 3. The electrons in level 3 decay to level 1 and 2, eventually completely populating level 1. RF energy corresponding to the difference between levels 1 and 2 is applied to shift electrons from level 1 to level 2. The frequency of the RF energy varies with the ambient magnetic field (Gemsys). The main advantage of this instrument type is its high sensitivity (Telford 1990).

The final instrument type, the magnetic gradiometer, is actually made up of other magnetic instruments. This type usually consists of two detectors vertically separated by 35 meters. The Geological Society of Canada improved this instrument by reducing the separation to 1 or 2 meters and made the connection between the two sensors more rigid (Telford 1990). Gradiometers have some significant advantages. First, they are very immune to diurnal and minor magnetic storms. They can also enhance near-surface, small, or weakly magnetic anomalies and provide improvements in spatial resolution. Finally, one of the sensors in the gradiometer can be used to obtain total field data.

The advent of computers has greatly aided geophysical magnetics instrumentation. These digital computer systems enable easy collection of large amounts of data. Humans can’t possibly record the amount of data that computers can, nor can they record data points as frequently as an electronic system can. Smith (1972) showed that CRT monitors on a computer can be used to represent magnetic data visually. Visual representation makes interpretation of data easier. Smith (1972) also showed that 3-D data can be represented on a CRT monitor. Computers also make data processing much easier.

Some of the same magnetic instruments that are used for land surveys have been adapted for aerial and marine surveys. For aerial work, fluxgate and proton-precession magnetometers are capable of measuring magnetic anomalies to one or two gammas (Reford 1964). Aerial work also introduces new challenges: the flight path of the plane or helicopter must be known fairly well. Early work used aerial photographs with maps to determine the flight path. Modern instruments now have the capability to use Global Position Satellites (GPS) to determine the flight path very accurately. Marine work has the problem of susceptibility to diurnal magnetics activity. Eggers (1984) showed that a gradiometer could be used to reduce the effect of diurnal magnetic activity.

In retrospect, geophysical magnetics instrumentation has come a long way since the original dip needle. There are now 4 types of magnetics instrumentation: fluxgate magnetometers, proton-precession magnetometers, optically pumped magnetometers, and gradiometers, each with their own advantages and disadvantages. Computers have also greatly enhanced magnetic instrumentation, whether by processing power or the capabilities to visually represent data in 2-D and 3-D. Finally, magnetics instrumentation has been successfully adapted to use in aerial and marine surveys.

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