GEM Systems, Inc.
135 Spy Court
Markham, ON CANADA L3R 5H6
Ph. 905 752-2202 Fax 905 752-2205
info@gemsys.ca www.gemsys.ca

Short Review of Nuclear Precession Scalar Magnetometers

Magnetometers can be divided into two categories that vary dramatically both in terms of functionality and principle of operation. Vector magnetometers measure the magnetic lux density value in a specific direction in 3-dimensional space whereas scalar agnetometers measure only the magnitude of the vector passing through the sensor regardless of the direction.

GEM delivers both vector (observatory models) and scalar magnetometers, but we limit this discussion to scalar magnetometers and specifically nuclear precession varieties which differ from their optically pumped counterparts as discussed in other GEM scientific and technical papers.

Nuclear Precession Magnetometers

Nuclear precession magnetometers polarize the atomic nuclei of a substance causing the nuclei to precess temporarily around a new axis. As the behavior of the nuclei returns to normal, the frequency of precession of the nuclei is measured, and can be correlated to magnetic flux density.

The purpose of this short paper is to review some of the common scalar nuclear precession magnetometers as follows:

- Helium-3
- Proton Precession
- Overhauser Effect

Helium-3

Helium 3 is a rarely produced magnetometer, and is probably not produced for the commercial market at all. The helium nucleus' precesses for a very long time - often hours or even days after polarization. This creates a nice continuous, low frequency signal that can be sampled easily by inexpensive electronics.

The drawback is that polarization requires large amounts of energy that must be supplied quickly to the sensor. The gyromagnetic constant is only 3.2435kHz /G causing a large rotational Doppler errors in measurement.

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Proton Precession

A proton precession magnetometer uses hydrogen as the precession atom. Liquids such as kerosene and methanol are used because they offer very high densities of hydrogen, and they are not dangerous to handle. A standard proton precession magnetometer, such as the GSM-19T or GSM-8, uses a high intensity artificial DC magnetic field around the sensor to polarize the protons. Removal of the DC magnetic field causes the protons in the liquid to precess around the ambient Earth's field. A simple coil can detect the precession of the protons.

The signal lasts for 1-2 seconds. The power required to polarize is much less than for Helium-3, but is still significant. Nevertheless, the standard proton precession magnetometer has long had a niche as an inexpensive portable magnetometer.

The Overhauser Effect

The Overhauser Effect is an enhancement to the proton precession principle, taking advantage of a quirk of physics that affects the Hydrogen atom. An Overhauser magnetometer uses RF power to excite the electrons of a special chemical dissolved in the hydrogen-rich liquid. The electrons pass on their excited state to the hydrogen nuclei, altering their spin state populations, and polarizing the liquid, just like in a standard proton magnetometer but with much less power and to greater extent.

Actually, the total magnetization vector of the hydrogen liquid is larger in an Overhauser magnetometer, which allows sensitivity to be improved as well. Also, since the liquid can be polarized while the signal is being measured, Overhauser magnetometers have a much higher speed of cycling and sensitivity than standard proton precession magnetometers.

Overhauser magnetometers are without question the most energy efficient magnetometers available with sensitivities suitable for Earth field measurement. Power consumption can be optimized to be as low as 1W for continuous operation, yielding sensitivities between 0.1nT to 0.01nT, and sampling rates as high as 5Hz. Also, no warm up time is required, so for slow reading rates, the sensor can be shut down to save power. *Continuous* Overhauser magnetometers, like the GSM-19 or GSM-11, operate with continuous polarization, and offer sampling rates up to 10Hz, but require more power (few watts) to operate.