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Overhauser Magnetometers – Brief Overview

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Figure 1: Overhauser quantum gradiometer with VLF attachment.

The Overhauser magnetometer, with its unique set of features, represents a pillar of modern magnetometry of the Earth's magnetic field. Its sensitivity matches costlier and less convenient cesium magnetometers, for example. The Overhauser magnetometer also offers superior omnidirectional sensors; no dead zones; no heading errors; or warm-up time prior to surveys; wide temperature range of operation (from –40 to 55 degrees Celsius standard and –55 to 60 degrees Celsius optional); rugged and reliable design; and virtually no maintenance during its lifetime. Other advantages include high absolute accuracy, rapid speed of operation (up to 5 readings per second), and exceptionally low power consumption.

Overhauser magnetometers use proton precession signals to measure the magnetic field – but that's where the similarity with the proton precession magnetometer ends.

Overhauser magnetometers were introduced by GEM Systems, Inc. following R&D in the 80's and 90's, and are the standard for magnetic observatories, long term magnetic field monitoring in volcanology, geophysical ground and vehicle borne exploration, and marine exploration.

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ADVANCED MAGNETOMETERS

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Operating Principles

The Overhauser effect takes advantage of a quantum physics effect that applies to the hydrogen atom. This effect occurs when a special liquid (containing free, unpaired electrons) is combined with hydrogen atoms and then exposed to secondary polarization from a *radio frequency* (RF) magnetic field (i.e. generated from a RF source).

RF magnetic fields are ideal for use in magnetic devices because they are "transparent" to the Earth's "DC" magnetic field and the RF frequency is well out of the bandwidth of the precession signal (i.e. they do not contribute noise to the measuring system).

The unbound electrons in the special liquid transfer their excited state (i.e. energy) to the hydrogen nuclei (i.e. protons). This transfer of energy alters the spin state populations of the protons and polarizes the liquid – just like a proton precession magnetometer – but with much less power and to much greater extent.

The proportionality of the precession frequency and magnetic flux density is perfectly linear, independent of temperature and only slightly affected by shielding effects of hydrogen orbital electrons. The constant of proportionality, $\gamma_{p,}$ is known to a high degree of accuracy and is identical to the proton precession gyromagnetic constant (equation 3).

Overhauser magnetometers achieve some 0.01nT/ √Hz noise levels, depending on particulars of design, and they can operate in either pulsed or continuous mode.

Advantages Over Proton Precession & Other Quantum Magnetometers

To summarize, some of the main differences between Overhauser and proton precession magnetometers are:

- More than an order of magnitude greater sensitivity even in the lowest of Earth's fields. This reflects the fact that Overhauser systems offset a basic weakness of proton magnetometers (i.e. deterioration of signal quality in low magnetic flux density (20μT range)) by creating a small auxiliary magnetic flux density while polarizing.

- Sensitivity that virtually matches cesium sensitivity.

- This is the only quantum magnetometer that offers continuous or sequential operation. With Overhauser magnetometers, it is possible to measure continuously or sequentially due to the use of an RF polarization field. The RF

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field is transparent to the measurement of magnetic field and can therefore, be enabled at all times.

- Cycling speed. Since the liquid can be polarized while the signal is being measured, the sampling rate is higher (as high as 10 Hz possible).

- Energy efficiency. Overhauser magnetometers are significantly more efficient than any other quantum magnetometer due to the low power required for RF signal generation. Power consumption can be optimized to as low as 1W for continuous operation.

- Omnidirectional sensors. No dead zones, virtually no heading errors and no warm up time.

There are also other advantages related to the manufacturing process (which are of less interest to users), such as relative simplicity, reliability of design, relatively low manufacturing cost relative to sensitivity, weight and power consumption benefits.

Sensitivity

The **sensitivity** of quantum magnetometers is determined by the signal-to-noise ratio obtainable from its sensor, the spectral line width it operates on and on the gyromagnetic constant as defined in the following equation:

$$\Delta B = k\, \Gamma / \gamma_n S_n \qquad (4)$$

where k is a constant of proportionality, Γ is the spectral line width, γ_n is the gyromagnetic constant and S_n is the signal-to-noise ratio. Sensitivity does not depend only on Larmor frequency. For example, Overhauser magnetometers with 0.042Hz/nT can be as sensitive as, say Cesium with 3.5 Hz/nT or Helium 4 with 28 Hz/nT depending on parameters stated in (4).

The approximate spectral line widths of quantum magnetometers are as follows:

Cesium	20 nT
Overhauser	4 nT for methanol solvent and free electrons (free radicals) added
Potassium	0.1 to 1.0 nT depending on sensor size and quality
Proton	15 nT for kerosene, depends on sensor liquid

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Any well-designed magnetometer's readings will eventually be limited by a noise level that can't practically be suppressed any further: Sensor thermal noise is typically the limiting factor in the case of Proton and Overhauser magnetometers. In optically pumped magnetometers, the limiting factors are light shot noise and/or heading error.

Recommended Applications

In conclusion one can summarize features of quantum magnetometers as follows

1. **Potassium** offers superior sensitivity to any other method due to its resolved spectral lines and it should be used for most demanding applications (i.e. the most sensitive static observations, high sensitivity airborne surveys, and ground surveys (UXO, mines detection, etc)). Moderate gradient tolerance and dead zones are potassium's weak points.

2. Latest **Helium 4** laser pumped magnetometers have broken 1 pT/$\sqrt{Hz}$ barrier (0.4pT/$\sqrt{Hz}$ has been reported). Helium 4 is excellent for airborne surveys and other applications where high tracking speed is not required.

3. **Cesium** commands good sensitivity of about 10 pT/$\sqrt{Hz}$ and it is appropriate in airborne surveys (with active compensator to correct for heading error). Also in other applications for high resolution and gradient tolerance where control of the sensor orientation is possible. Heading errors and dead zones are the limitations.

4. **Overhauser** magnetometers offer virtually the same sensitivity as Cesium at moderate speeds of operation, very high accuracy and no dead zones and virtually no heading errors. Simplicity of design and moderate costs make Overhauser magnetometers almost ideal for marine surveys, ground mineral and oil exploration, archeological surveys, long term monitoring of magnetic field.

5. **Proton** magnetometers are at the tail of the lineup as for lower sensitivity and speed of operation but with omnidirectional sensors and the lowest cost of production. Ground surveys for mineral exploration, reconnaissance surveys are the recommended fields of applications for this kind of magnetometers.

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