GSMP-20 Potassium Magnetometer Technical Description

Overview

The GSMP-20 is an optically pumped alkali vapour magnetometer. It operates on principles similar to other alkali vapour magnetometers such as Cesium and Rubidium, but benefits from the unique nuclear properties of Potassium.

Figure 1 shows how a typical alkali vapour magnetometer works. A glass cell containing the evaporated alkali metal is exposed to light of a specific wavelength. According to quantum theory, in every population of alkali atoms, there is a set distribution of valence electrons between two energy levels, represented by 1 and 2 in figure 2. The wavelength of light that is applied to the cell is specifically selected to excite electrons only from level 2 to level 3. This is called polarization. As the amount of atoms with electrons at level 2 decreases, the cell will stop absorbing light, and will turn from opaque to transparent.

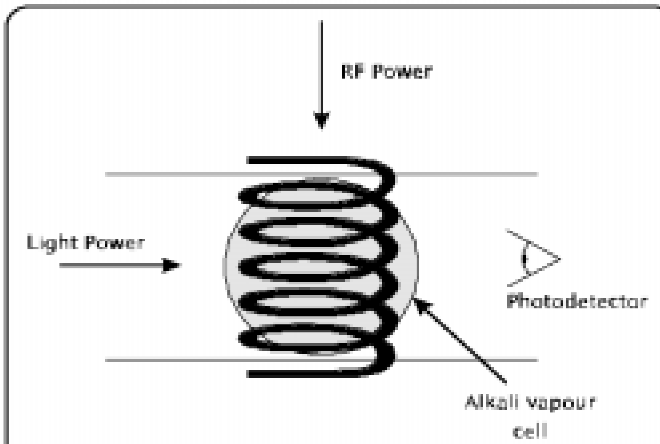

Figure 1: Generic alkali-vapour magnetometer

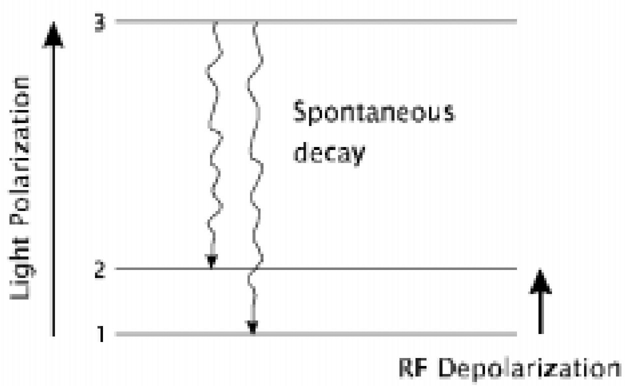

Figure 2: Quantum mechanics of alkali-vapour system

Electrons at energy level 3 are not stable, and will spontaneously decay back to levels 1 and 2. Eventually, level 1 will become fully populated, and level 2 will become depopulated, and the cell will be completely transparent. That's where RF depolarization comes into play. RF power of wavelength that corresponds to the energy difference between levels 1 and 2 is applied to the cell to move electrons from level 1 back to level 2. The significance of this act is that the energy difference between levels 1 and 2 is proportional to magnetic field.

Therefore, by measuring the wavelength of RF that depolarises the cell, one can measure magnetic field.

The optical sensor in figure 1 acts as a feedback mechanism, to keep the cell balanced between transparent and opaque states. Fortunately, depolarization happens very quickly; often within the first quarter-period of applied RF power. This allows the signal from the optical sensor to be fed directly back to the RF coil, and the system can self-oscillate.

Spectral Lines

The energy level system depicted in figure 2 is not unique in any alkali metal. Both Cesium and Potassium contain four such practical systems, called spectral lines. In each system, the nominal energy change between levels 1 and 2 is slightly different. In addition, this energy difference is not exactly discrete. It varies slightly within a population of atoms, giving the line a width. Each line also has an amplitude, which is proportional to the signal that can be generated at the photodetector.

With Cesium, these lines are strong, but also very wide, and they overlap. With Potassium, the lines are more than an order of magni tude narrower, and do not overlap. The significance of this becomes apparent when a practical system is constructed.

Terraplus Inc.
52 West Beaver Cr. Rd. #12, Richmond Hill, ON. Canada L4B 1L9
Tel: 905-764-5505 Email: sales@terraplus.ca
Fax: 905-764-8093 Website: www.terraplus.ca

The optimum way of measuring magnetic field with a system such as figure 1 is to have the polarizing light radiation travelling parallel to magnetic field direction, and depolarizing RF radiation travelling perpendicular to it.

This, however, creates an extremely direction sensitive instrument, and in practice some type of compromise must be reached. In almost all practical instruments, the light and RF are applied in the same direction, and the magnetic field should be applied at a 45 o angle for optimal performance.

The fact remains that magnetic fiend direction will affect the performance of the system. This materializes as an increase or decrease in the amplitude of the individual spectral lines of the alkali vapour.

Because they overlap, Cesium's spectral lines can be thought of as being 'lumped' together. In static conditions, a peak becomes apparent, and the system will self-oscillate at this peak. When magnetic field direction changes, however, the position of this peak will change because the spectral line amplitudes will change.

As a result, the selfoscillating frequency will shift, producing a heading error. Since Cesium's spectral lines are spread over more than 20nT, the heading error could be that severe. Split-beam techniques attempt to stabilize the lump over different magnetic field directions, but still cannot achieve better than ±1nT. Potassium's spectral lines do not overlap. In fact, each line is less than 0.15nT wide.

When magnetic field direction changes, the spectral line that the system is locked to will change in amplitude, but the locked frequency will not change, regardless of the orientation of the RF coil and light direction with respect to magnetic field.

Accuracy and Sensitivity

Absolute accuracy is defined as the proximity of a measured value to the true value. A GSMP-20 Potassium magnetometer can guarantee an absolute accuracy of ±0.1nT, which is limited only by the accuracy of the constants that are required to convert frequency to magnetic field. Since Potassium's spectral lines are so narrow, a Potassium magnetometer gives virtually zero heading error, and can theoretically provide sensitivities as high as 0.01pT.

That means that multiple Potassium magnetometers will produce results that are consistent with each other, allowing them to be used as very accurate gradiometers.

No Calibration

Cesium's spectral line configuration causes the orientation of the RF coil and light direction with respect to each other to be extremely critical. Even a small shift or displacement of themechanics of the system can cause severe absolute accuracy and heading error shifts. Over time, the RF coil will move slightly in the instrument. This is the reason that all Cesium mags require periodic and costly calibration. Potassium magnetometers do not require calibration. The orientation of the RF coil with respect to the rest of the instrument does not affect the absolute accuracy of the instrument. The sensor is therefore simpler, and does not require periodic maintenance.

Practical Implementation

To date, GEM Systems is the world's only manufacturer of commercially available Potassium magnetometers. Two versions are available. The standard system gives 1pT sensitivity, a sampling rate of 10Hz, and requires about 20W of power. This version requires only DC power, and provides Larmour frequency and lock detect outputs. A super sensitive version is also available that uses larger sensors and a precise counter that gives 0.05pT sensitivity and a sampling rate of 20Hz.

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