Magnetic measurements basing on nuclear magnetic resonance (NMR)

The measurements of magnetic fields by means of nuclear magnetic resonance (NMR) methods is based on the linear dependence of flux density ***B*** on precession frequency ω_p, by which nuclear magnetic moments rotate around the vector of ***B*** according to

$$\boldsymbol{B} = \omega_p / \gamma_p$$

where γ_p is the gyromagnetic coefficient, i.e. the quotient of the magnetic moment and the spin of the nucleus used. The gyromagnetic coefficients of certain nuclei are very well known. The gyromagnetic coefficient of protons in water molecules, for example, is known as a fundamental constant with a very small relative uncertainty of $1.3 \cdot 10^{-8}$. Presently, the most accurate values for magnetic field strengths are obtained by measuring the precession frequency of nuclei in DC magnetic fields.

NMR magnetometers using the absorption method for field strengths above 1 mT

In the PTB the effect of absorption of energy by the precessing nuclei serves to detect the magnetic nuclear resonance at mid range field strengths. The absorption of energy results in a damping of the amplitude of a „marginal oscillator“ which is only slightly oscillating. This damping serves to detect the magnetic nuclear resonance of the NMR probe in the resonance circuit coil of the oscillator:
Absorption of energy occurs if the oscillator frequency coincides with the precession frequency of the nuclei determined by the magnetic field and the gyromagnetic coefficient. Fields down to 2 mT can now be measured with a signal-to-noise ratio of 10 by detecting the proton resonance in slightly paramagnetic water solutions. With a sample volume of about 1 cm^3, a sample absorption line width of about 2 µT, and a measuring time of about 2 s, the instrument allows for quasi-continuous measurements with a resolution of 5 nT.
The NMR magnetometer is used for the calibration of magnetometers based on other physical effects, e. g., Hall-effect sensors. Field coils intended to be used for supervision of the production of magnetic field sensors can also be calibrated with a relative uncertainty of the order of 10^{-4} or less in the range from 1 mT to 100 mT.

NMR measurements using the free precession method for field strengths above 1 nT

In the low field regime and if the relaxation times are long enough, NMR signals of sufficient durations and of suitable frequencies can be obtained and detected by the method of free precession of nuclei. With help of this method flux densities of 1 nT up to approx. 2 mT can be measured. Therefore a pure water sample is polarized by a field pulse (20 mT amplitude, 10 s duration). In the following the sample shortly is excited resonantly by an alternating field. Thus, a phase coherence of the individual nuclear magnetic moments is created for a short time. After switching off the alternating field an exponential decaying alternating voltage can be observed with a frequency according to the field to be measured.

Details on magnetic NMR measuring methods in:

Landolt-Börnstein: Units and Fundamental Constants, Subvolume a: Units
S. 2-275: Quantum effect sensors
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