Magnetic Field Measuring Devices for Low Field MARY Spectrometer

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Abstract. *The paper reports the development of magnetic field measurement system for MARY spectrometer specifically intended for studies of chemical reactions in low magnetic fields. The MARY spectrometer has a scanning magnetic system (up to 50 mT) and a system for compensation of the residual magnetic fields (~ 0.1 mT). We discuss Hall sensor, fluxgate meter and magnetoresistive sensor as the transducers for measuring magnetic field in these ranges. The details of construction and testing of the actually built measurement devices based on these sensors are provided.*

Keywords: MARY Spectroscopy, Low Magnetic Field, Magnetoresistive Sensor, Hall Sensor, Fluxgate Meter.

1. Introduction

The influence of weak magnetic fields on chemical reactions passing via short-lived paramagnetic intermediates is intriguing both from chemical and biological points of view. The method of Magnetically Affected Reaction Yield (MARY), or level-crossing, spectroscopy as developed in the authors' lab takes advantage of narrow resonance-like lines on the dependence of the intensity of recombination fluorescence from X-irradiated sample on external static magnetic field. The lines arise in zero and in weak (1-10 mT) magnetic fields due to coherent evolution of the spin systems of radical ion pairs that are formed upon ionization of molecules in the sample [1]. Of particular interest now is the region of very weak magnetic fields comparable to Earth's field (0-0.5 mT) [2]. A dedicated MARY spectrometer optimized for the region of weak magnetic fields is currently being developed, and its magnetic system has been described in [3]. In this work we describe the systems of measurement and control of the field created by MARY spectrometer in 0-50 mT range.

2. Subject and Methods

The scanned DC magnetic field in the MARY spectrometer is swept along one axis from -50 mT to +50 mT with accurate passage through the zero of the field. As the developed spectrometer has no ferromagnetic elements, the stabilization of the created field can be conveniently performed by stabilization of the currents through its coils. Although this approach avoids the feedback loop locked on the magnitude of the field, a careful control of the created field is still an essential feature of the spectrometer. The main problem for the field measuring device here is the wide dynamic range of field changes, as it is necessary to measure with relative accuracy of at least 10^{-2} both rather weak (of the order of 0.1 mT) and rather high (of the order of 50 mT) magnetic fields almost simultaneously. The sensors should also have good linearity and be compact (not larger than 1 cm^3). The field is swept along the z axis of the spectrometer, and the remaining two components (x and y) of the residual magnetic field are compensated by a dedicated subsystem. The setting of the compensation system also requires measuring magnetic field, but the requirements here are somewhat different. In this case it is sufficient to provide a stable and sensitive (sensitivity at least 1 μT) indicator of the zero of the field.

Unfortunately a single magnetic field sensor meeting all these requirements is still not available. We thus decided to combine several magnetic field transducers based on different physical principles and divide the task of magnetic field measurement into three ranges: linear measurement of the scanned magnetic field in the range 0.5 – 50 mT, linear measurement of the field in the range 0 – 0.5 mT, and a stable zero field indicator.

3. Results and Discussion

Hall sensors are convenient transducers for wide range of measuring magnetic field strength. They are easy to use, compact, have good linearity, but suffer from poor temperature stability and zero offset. Furthermore, sensors with rather large working surface are required to measure the sub-gauss fields, which are not commercially available. Control sensor temperature helps improve its parameters, and special schematic solutions are used to compensate the offset [4]. Several chips are now commercially available that integrate the sensor with the compensating solutions to substantially improve specifications of the transducer. One of the producers of chopper-stabilized linear Hall sensors is Allegro MicroSystems Inc. To measure magnetic field in the range 0.5 – 50 mT we selected their Linear Hall sensor A1321 having sensitivity 5 mV/G, temperature stability and zero offset at room temperature about 10^{-2} [5]. However, the intrinsic noise of up to 40 mV (Peak-to-Peak) of the sensor makes it unsuitable for measurement of the lower fields.

To measure magnetic field in the range 0-0.5 mT with accuracy better than 10^{-2} we used magnetoresistive sensors HMC1052 from Honeywell [6]. The sensor has working range ±0.6 mT and sensitivity 12 nT, with linearity in the field range ±0.3 mT of at least 10^{-3} and temperature coefficient 10 ppm/ºC. The transducer itself is a bridge of four thin-film Ni-Fe magnetoresistive elements, complemented by proprietary integrated electronics for remagnetization of the material of the magnetosensitive resistors. This approach allowed the producer exploit the linear portion of the dependence of sensor elements resistance on external magnetic field and thus substantially improve the parameters of the device. To turn the sensor HMC1052 into a computer-controlled measurement system we developed a controller with RS 232 interface for a PC and the required software. Fig. 1 shows a picture of the working prototype.

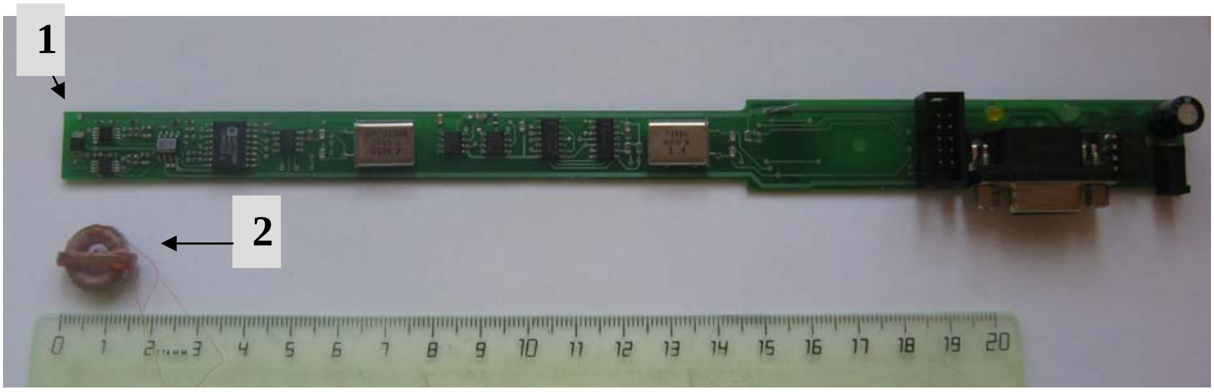

Fig. 1. Photo of magnetic field meter based on magnetoresistive sensor (1) and fluxgate sensor (2).

Both Hall sensor and magnetoresistive sensor require the compensation of the zero offset and sensitivity calibration. The offset was measured by placing the sensor in a mu-metal screen.

To calibrate the sensitivity we built a solenoid with a large aspect ratio to calibrate longitudinal sensitivity, and a system of coils with a clearance in-between to calibrate the transversal sensitivity. The latter was required to calibrate the second half of the magnetoresistive sensor (the crystal of HMC1052 contains magnetoresistive bridges measure two mutually orthogonal field components). Both calibration systems were calculated to provide the relative field homogeneity better than 10^{-3} over the size of the sensor (within ±5 mm from the center) allowing for manufacturing tolerances and thus allowed to perform the calibration with the required accuracy. To take into account the presence of the residual external fields the calibration was performed with reversal of the current in the coils.

The performed measurements demonstrated that the actual magnetoresistive sensor used in our meter had quite low deviations from the nominal sensitivity and offset values as provided in its technical specifications, with the relative values not exceeding $3x10^{-3}$.

A fluxgate was chosen as the zero indicator for regulation of current in the compensation coils. The fluxgate that we built is a coil of thin annealed mu-metal foil (3 x 200 mm, thickness 30 µm) on a 13 mm quartz former for mechanical stability, with the excitation coil having 100 turns of 0.1 mm copper wire. The detection coil was wound over the ring and has 50 turns of 0.1 mm copper wire. The picture of the transducer is also shown in Fig. 1. The fluxgate was tested in the Geophysical Survey SB RAS, Novosibirsk, on a working fluxgate meter and showed the sensitivity of about 10 nT. Currently we are building the stand-alone fluxgate meter based on this transducer to be used as the zero field detector.

4. Conclusions

While developing the systems of magnetic field measurement and control for the low field MARY spectrometer we analyzed the available field sensors and chose those most suitable for the particular tasks in the spectrometer. The meter for the scanned field of the spectrometer was built using an A1321 Hall sensor (Allegro MicroSystems Inc) and a HMC1052 magnetoresistive sensor (Honeywell). A fluxgate transducer was built and tested for compensating the transversal components of the residual magnetic fields in the working region of the spectrometer.

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