

HIGH SENSITIVITY SENSORS FOR THE LOCALIZATION OF MAGNETIC MICROSPHERES

G. Durin, G. de Milato, A. Stantero, & M. Coisson

Istituto Elettrotecnico Nazionale Galileo Ferraris, str. delle Cacce 91, 10135 Torino, Italy

INTRODUCTION: In recent years, a large number of different clinical applications of magnetic microspheres has been proposed, mainly connected to disease treatments. On the contrary, only a few authors have proposed to use nanoparticles for the reliable detection and localization of tumors. The simple idea is to inoculate a certain quantity of particles and use a high sensitivity sensor to locate them. One of the most promising methods appears to be the detection of susceptibility artifacts in magnetic resonance, as proven recently in rats [1]. As a matter of fact, the drawback of this methodology is related to the use of a magnetic resonance setup together with the high magnetic field required for particle alignment. All these facts can seriously limit the spreading and clinical use of this type of technique.

In principle, an alternative and less-expensive method would be the detection of the small dc field produced by an ensemble of *interacting* superparamagnetic nanoparticles. Commercial superparamagnetic microbeads, such as the ones used in cell separation, are small enough to remain dispersed and thus do not interact. After the application and subsequent removal of an external field, they do not show any residual magnetic field (usually called remanence). Establishing when a particle ensemble can produce a detectable remanence is not easy, because many different parameters, such as particle size and distance to the detector, contribute to the particles' interaction. We are presently investigating such a complex issue by considering different particle concentrations and measuring hysteresis loops up to 1.5 T with a vibrating sample magnetometer.

The magnetic field produced by the particle ensembles is negligible with respect to the magnetic field of the earth and other magnetic disturbances. Therefore, the use of a sensor with high background reduction and insensitivity to spatially constant external fields is thus necessary. One of the most promising solutions to this problem is the use of a gradient field detector based on the magneto-impedance properties of magnetic wires [2,3].

METHODS: Some families of magnetic wires show large variations of impedance when small external fields are applied. In particular, we have investigated the properties of an amorphous

$\text{Co}_{68.25}\text{Fe}_{4.5}\text{Si}_{12.25}\text{B}_{15}$ wire having a diameter of 110 μm , properly annealed under dc current to improve the magneto-impedance response (Fig. 1) [4]. As seen in fig. 1, the wire sensitivity is a non-uniform function of the field. It is worth noting that around $H \sim 300$ A/m, the curve is approximately linear: in particular, we obtained a percentage sensitivity of $0.3/\text{Am}^{-1}$. Working around this field by using a suitably designed solenoid integrated into the sensor, any external constant field of some tens of A/m or lower (e.g. earth field) does not influence the magneto-impedance response of the wire. The response is thus insensitive to any fluctuation of background field. We are currently investigating other types of magnetic wires and different thermal treatments in order to maximize the overall field sensitivity of the sensor.

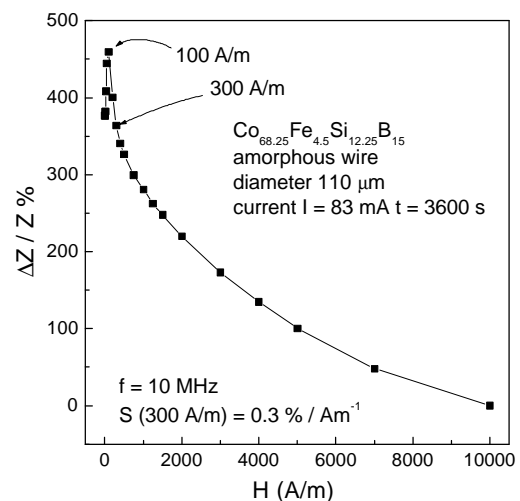


Fig. 1: Magneto-impedance response of an amorphous $\text{Co}_{68.25}\text{Fe}_{4.5}\text{Si}_{12.25}\text{B}_{15}$ wire annealed under dc current. The sensitivity around the working point of 300 A/m is also reported.

A detailed description of the electrical circuit of the sensor can be found in [2]. Briefly, a couple of short magnetic wires are aligned at a distance of a few centimeters, and fed by a 10 MHz ac voltage. Non-uniform magnetic field sources produce different impedance variations in the wires: the sensor circuit is able to produce a dc voltage proportional to the field gradient. In our system, two 3 mm magnetic wires are glued on a small bar at a distance of about 3 cm. In this configuration, if the field source is approximately a magnetic dipole 1 cm far from the first wire (which is reasonable in

most applications), the second farthest wire will measure a field of less than 3% with respect to the former. This means that the signal measured by the sensor is approximately the field produced by the magnetic source.

This type of configuration cannot only detect a small magnetic source such as a particle ensembles, but also identify it with good accuracy. In fact, considering the distribution of the measured field in a plane, it is possible to calculate the position and the dipole moment of the source with good approximation. The measurement requires that the field be relatively close to the source over a grid of uniformly spaced points of a plane. In order to calculate position and intensity of the source, we then need to solve a typical 'inverse problem'. To this end, we have developed a proper code for optimal localization, using the methodology of biomagnetism for current dipole localization [5-6]. The code is reasonably fast, and permits a localization of the source with an approximation sufficient for any possible clinical application.

DISCUSSION & CONCLUSIONS: The sensor we are currently using is reasonably simple and stable. Measurements in a RF shielded room showed no significant improvements. Therefore, no particular environment is required for its practical use.

Apart from the studies on particle ensembles, we are currently considering the use of the sensor for the localization of *known* magnetic sources which have been previously inserted in a human body. These sources can be small ferromagnetic markers, previously magnetized under fields of a few tesla, with a known residual dipole moment. They can be used in clinical application where it is necessary to localize the site of previous operations, even in the case of large time delay. In particular, it represents a simpler and valid alternative to the use of damaging techniques, such as radiography or endoscopy.

REFERENCES:

- ¹ C.W. Jung, J.M. Rogers, E.V. Groman (1999) *J. Magn. Magn. Mat.* **194**:210-216.
- ² T. Uchiyama et al. (1997) *IEEE Trans. Magn.* **33**:4266-4268.
- ³ K. Bushida et al. (1996) *IEEE Trans. Magn.* **32**:4944-4946.
- ⁴ L. Brunetti, M. Coisson, P. Tiberto, F. Vinai, *J. Magn. Magn. Mat.* (in press).
- ⁵ F. Brauer, G. Stroink (1985) *IEEE Trans. Biom. Eng.* **32**:386-391
- ⁶ G. Stroink (1987) *Physics in Medicine & Biology: the Biomagnetic Inverse Problem*, **32**:53-58.