Biomedical Applications of Fluxgate Sensors

P. Ripka
Czech Technical University
Faculty of Electrical Engineering, Dept. of Measurement
Technicka 2, 181 00 Praha 6, Czech Republic
ripka@feld.cvut.cz

Abstract

We show that fluxgate sensors can be used instead of SQUIDs to map the distribution of the ferromagnetic fumes and dusts in human lungs. Fluxgates are suitable also for other medical application such as position tracking and detection of markers.

1. Introduction

Fluxgates are the most sensitive and precise room-temperature magnetic field sensors [1]. They are more noisy than SQUIDs, but they have much higher dynamic range (from 100 pT up to 1 mT) and they are cheaper and easy portable devices. Traditional applications of ultrasensitive fluxgate sensors were deep space research, submarine detection and localization of UXO (un-exploded ordnance). Use of fluxgate was reported in magnetopneumography and magnetocardiography, but this was only using medium-performance commercially available sensors.

We have developed race-track fluxgate sensors with 8 pT rms noise (2.6 pT/√Hz@1Hz power spectral noise density). The sensor is also suitable for gradiometers, as it is highly linear (typically 10 ppm linearity error for full-scale of 100 μT). The sensor was made of as-cast amorphous alloy – further improvement is possible by inducing uni-axial anisotropy [2]. The only disadvantage is the sensor size: but 70 mm length can be accepted in many applications. 30 mm sensors with adjustable feedthrough were described in [3].

We have shown that fluxgate sensors can be used for mapping the distribution of ferromagnetic particles in the lungs after they are magnetized by strong DC field [4]. This technique was developed using SQUIDs and because of high cost of instrumentation, magnetopneumography never became a routine diagnostic tool, although it was proven to be more specific and early than X-ray screening [5].

2. Magnetopneumometry

The measurements on the dust samples collected from one-stage and two-stage respiratory filters in the workplace of welders and grinders have shown specific remanence of between 0.8 and 1.5 for aerosols and up to 3 nTm³/kg for dust. Specific remanence as a function of the magnetization field is shown in Fig. 1. It is clear, that 10 to 50 mT field used in previous studies is by far not strong enough to saturate the dust.

Measurements with similar results were also made with pathological samples of lungs of metal workers (grinders and welders) and miners. Although the dust load of miners is higher, the magnetic properties of the dust are very variable, so that the scaling in this case is extremely difficult.
Large set of verification measurements were made on physical models and phantoms which were assembled from small magnetized cubes. The model was scanned in x-y plane by the fluxgate magnetometer. One example of such measurement on phantom having the shape of human lungs is shown in Fig. 2.

The ideal solution for the magnetization device would be magnetic circuit consisting of NdFeB permanent magnets. To lower the costs of the development phase we used electromagnet, which has many disadvantages: large power consumption, high weight and lack of safety. In our case the airgap was 40 cm and power consumption 3.6 kW for field of 0.63 T at the pole surface, but only 0.044 T in the middle between them. Even with this simple magnet we were able to map the lung remanent field in vivo using computer-controlled fluxgate gradiometer with 0.4 m gradiometric base. An example of the values measured on life-time grinder is shown in Fig. 3.

Magnetic dust was detected in the lungs of miners, welders and grinders, but also in general public. We performed both mathematical and physical modeling, in vitro studies and in vivo evaluation. We have found that even the dust and aerosols originating from non-magnetic stainless steel can be
detected, as they become ferromagnetic during the welding or grinding process. At present we started to find solutions of the back problem.

Figure 3 Gradient map (nT/m) measured in vivo on grinder

3. Other medical application of magnetic sensors

Another possible medical applications of precise fluxgate sensors include tracking devices and systems for monitoring magnetic markets such as magnetic “biscuits” and microbeads. Magnetic biscuits can be used for functional tests of digestive tract, while microbeads are used as markers in biotechnology. New types of fluxgate microsensors are being developed for these applications [7]

Tracking devices using fluxgate sensors can be used for monitoring the 3-D position and also orientation of small permanent magnet which can be attached to body or medical instrument (such as catheter). The sensor field is stable and corrections can be made for external fields and field gradients from ferrous objects and electric currents. Another configuration is being used for tracking the motion of the body at further distances: signals from sensors attached to the body are collected and processed. An artificial magnetic field is being used, because the Earth’s field alone is not sufficient to determine all position and orientation parameters. Such systems are being designed for virtual and augmented reality systems, but may be also useful for orthopaedics and biokinematics.

For applications requiring small sensor size a number of other sensor types such as AMR, GMR, SDT, GMI, can be used [8]. From them the most precise are AMR sensors. 40 ppm linearity error, 10 nT resolution and 20 ppm/K temperature coefficient can be achieved using proper flipping [9].

REFERENCES