

## MAGNETIC LUNG DIAGNOSTICS USING FLUXGATE

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*Abstract: Magnetopneumography is a method of detection of ferromagnetic dust respired into the lungs by means of their remanent magnetic field. Our target is to develop low-cost ambulatory system based on fluxgate gradiometer, suitable for routine examination of exposed workers. We have built 40 cm airgap, 80 mT field electromagnet for magnetization of the whole lungs in vivo and fluxgate gradiometer to be used for scanning measurements. The in-vivo measurements had shown that the fluxgate gradiometric system has sufficient sensitivity and spatial resolution to detect particles of grinding dust and welding fumes. Measured gradients were up to 280 nT/m.*

*Keywords: lung diagnostics, magnetopneumograph, fluxgate gradiometer*

### 1 INTRODUCTION

Magnetopneumography as a method to detect the ferromagnetic dusts deposited in the human lungs was introduced by Cohen [1]. The standard gradiometer instrument is SQUID magnetometer. Our aim is to replace this expensive instrument by fluxgate gradiometer. Another field of interest is interpretation of the measured data, construction of the models such as [2] and solving the magnetometric back problem to find the location, shape and magnitude of the field sources. The knowledge of the magnetic properties of the inhaled dusts and fumes may then allow to estimate the dust load.

### 2 INSTRUMENTATION

Three-channel fluxgate magnetometer used for our measurements was described in [3]. We have shown that the use of pair of individual field sensors is preferable to single-core gradiometer [4] as the system astatization may be performed automatically and the measurement setup is more stable. Procedures developed for the calibration of the sensors are described in [5].

Another problem of the measurement stability is the crossfield effect [5]. In order to reduce the crossfield error we plan to use modified race-track sensors, which are resistant against perpendicular and normal fields due to their shape anisotropy [7]. In order to increase the sensor sensitivity and reduce the power, we utilize the nonlinear resonant modes both at the sensor output [8] and in the excitation circuits [9].

### 3 MEASUREMENTS IN VITRO

The magnetic properties of the industrial dust and fumes were discussed in [9] and [11].

Specific remanent magnetic moment was measured on the set of lung tissue samples forming three groups:

- i) black-coal miners
- ii) welders and metal grinders
- iii) metropolitan population (large checkgroup)

The main results are:

- i) Magnetic properties of the coal dust are very variable, the uncertainty in concentration of magnetic particles does not allow to estimate the total dust load from magnetopneumographic measurements. Contrary to that, magnetic measurements are very indicative in case of welders and other metal workers.
- ii) The magnetic signature in professional groups seems to depend on the exposition length. However, the dependence is complex and statistical processing would need higher number of

samples. The basic dependence is affected by numerous effects such as physiological autocleaning of lungs, chemical processes, etc.

ii) There is no significant dependence of the specific magnetic remanence on the age in the checkgroup. The specific remanence values are statistically significantly higher for male sub-group. In general, the spread of values for checkgroup of metropolitan inhabitants was much lower than that of professional groups.

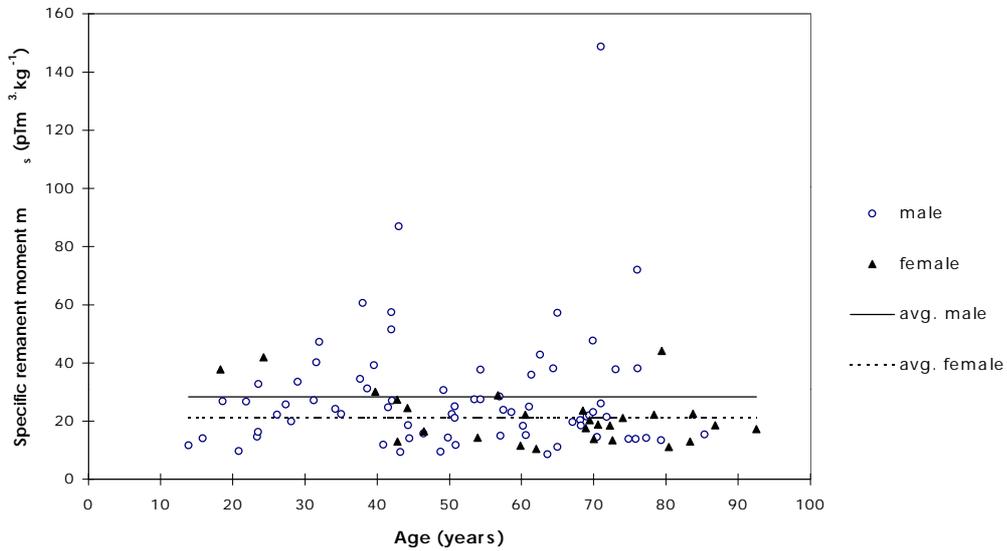


Figure 1. Specific remanent moment of lung samples of the checkgroup

#### 4 MEASUREMENTS IN VIVO

A pilot measurement on 4 objects was performed. Our laboratory is located in the university building close to DC cables and rails of underground and trams. The magnetic pollution in the daytime is up to 200 nT p-p. When measuring the first gradient, the pollution is still 20 nT/m p-p, which makes the measurement impossible. The pollution drops well below 30 nT p-p in homogenous field and 4 nT/m p-p in first gradient in the night time between 1 and 4 a.m. , when the underground is out of performance. At that time we made our measurement. The magnetic field measured by two sensors B1 and B2) and their difference is shown in Fig. 2.

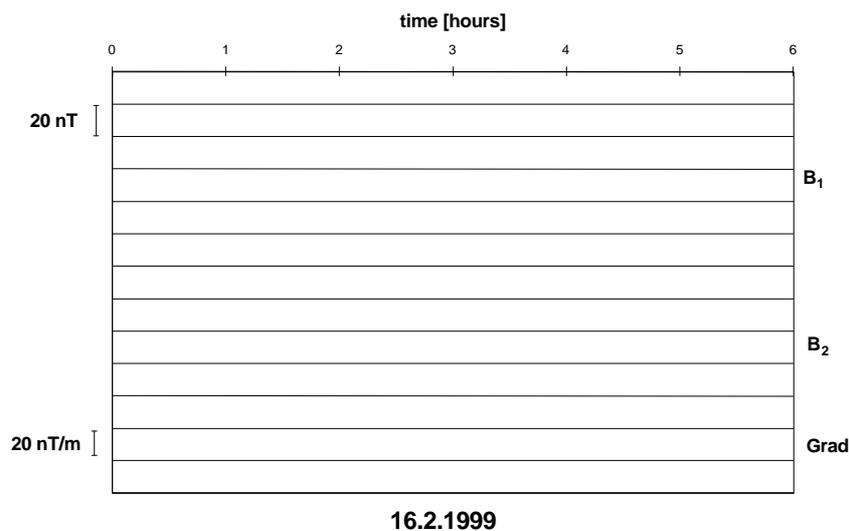
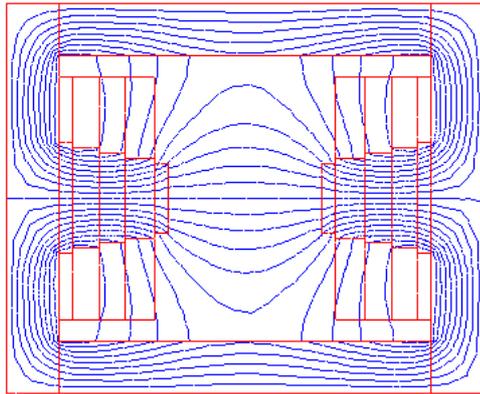
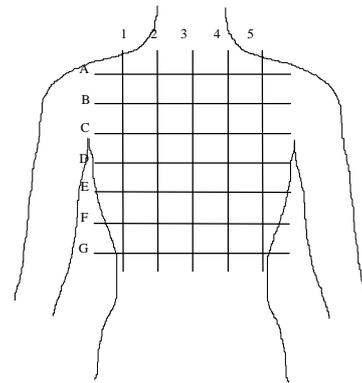


Figure 2. Background field in the laboratory measured by sensors 1 and 2 and their difference (Grad)



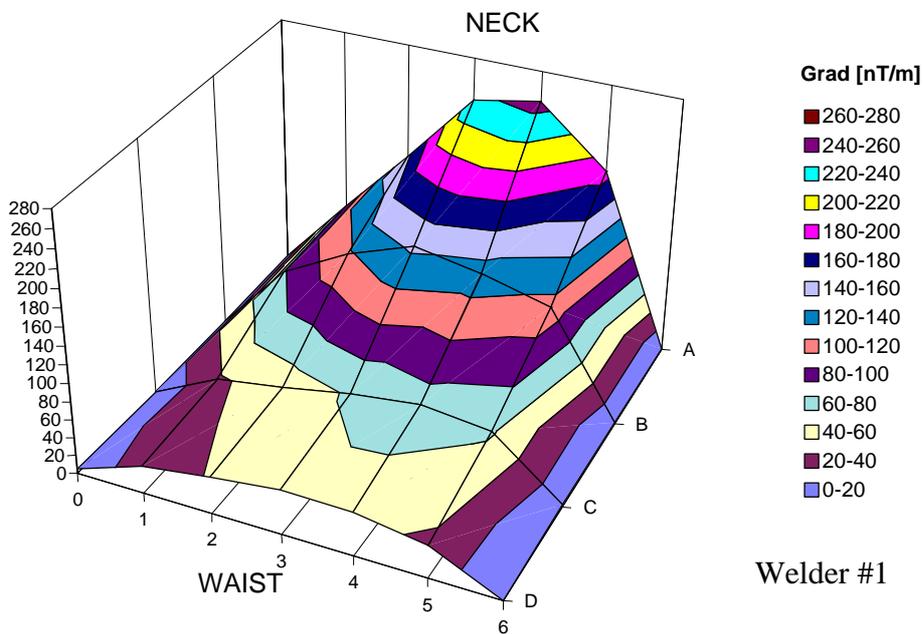
**Figure 3.** Field in the electromagnet



**Figure 4.** Matrix of measured points

The magnetisation field is generated by newly reshaped electromagnet. Fig. 3 shows the magnetic field lines in both the airgap and the yoke. Proper design allows to generate 200 mT field even without cooling the magnet. The higher flux during magnetization process and higher field homogeneity are key to sufficient sensitivity and give reproducible results.

After magnetization, the remanent lung field was measured in the raster of points (Fig. 4) for one sensor at front side and the other at the back side and also for both sensors on the same side. An example of the measured results is shown in Fig. 2 for lifetime welder. The magnetic field gradient is decreasing in the density of the direction towards the waist as the dust is filtered out by the lung tissue. In contrast to his, the field profile of the unexposed test object (PhD student) was flat.



**Figure 5.** Remanent field of lungs of the the lifetime welder. Both sensors were on the front side of the body.

## 5 CONCLUSION

Our measurements, which are in agreement with measurement of the remanent curves of Fe and Co powders [12] have shown that 200 mT magnetization field is sufficient for obtaining strong and reproducible remanent field in the range of 1 to 300 nT. If the magnetization field is weaker, the remanence is not saturated; the measured field is also much weaker so that it should be measured using SQUID magnetometer. Freedman et al. used 42.5 mT magnetizing field and they observed remanent fields from 2 to 1100 pT [13].

The pilot measurements in vivo had shown that both the magnetic grinding dusts and welding fumes deposited in the lungs are detectable in the nighttime even in the laboratory environment without any magnetic shielding. We have observed field gradients as high as 280 nT/m in case of whole-life welder. This field value is high enough to be reliably detected by fluxgate magnetometer.

The interpretation of the measured values is a complex problem, which includes finding the dust distribution from the field maps, taking into account the particular dust properties, retention, clearance and also relaxation processes [14].

Further experiments will be necessary to decide which sensor configuration is preferable. We plan to perform the measurements with 3-channel magnetometer and later to further increase the number of channels. In order to increase the resolution and to be able to perform the measurement in the daytime, we plan to build a simple cylindrical shielding. The non-magnetic positioning device allowing to perform fast and precise scan will be constructed in the future.

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