Magnetizing System for Magnetopneumography

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Abstract. *For magnetopneumography a new magnetizing system with two coils and three-phase power supply was made. With the power consumption about 1400 W it is able to generate the magnetic field ranging from 14.9 to 19.8 mT in the space of the volume of 3000 cm^3.*
Keywords:. Magnetopneumography, SQUID system, magnetizing the biologic subject

1. Introduction

Magnetopneumography is a special high-sensitive technique for measuring the ferromagnetic portion of retained dust in the lungs [1, 2, 3]. The method is based on measuring of the total remanent magnetic field (RMF) after magnetizing the human thorax. The magnitude of RMF is proportional to the amount of the deposited powdered ferromagnetic particles (PFP). Since the concentrations of PFP in the lungs and the respiratory tract are generally of the orders of micrograms per cm^3, the RMF measured at the adjacent body surface are of the orders of pT. On that account these weak magnetic fields can be detected only by a high-sensitive SQUID magnetometric system. Due to effective using magnetopneumography in clinical practice it is needful to deal with many problems. One of them is also the construction of the magnetization apparatus and magnetization processes of PFP in the human lungs.

2. Results and discussion

In magnetopneumography the biological organs, as the human lungs and respiratory paths with contaminated PFP, are magnetized by an external field usually generated by the dc current in the two coils. This field should be uniform over the lungs and oriented normal to the chest. The special sets of measurements with low-volume samples of dispersed PFP (Ni, Fe, Co) in epoxy showed that their RMF saturation are in the range from 50 to 120 mT [4]. Therefore the magnetization of the lungs is aimed at obtaining the highest level of the RMF. In order to achieve the homogeneous magnetic field in entire volume of the thorax, large-dimensional Helmholtz coils should be used. For example, if it is needed the magnetic induction of the uniform field of 15 mT in the volume of about 5000 cm^3 between a pair of coils (mean diameter 60 cm) with the axial distance 30 cm, the power consumption is approximately 4000 W. We decided for a compromise and designed the magnetization system consisting of a pair of circular coils with the mean diameter 33 cm, each wound with 200 turns, connected in series. The coils are powered by three-phase one-way dc supply with the peak voltage 90 V (Fig. 1.). In the parallel position at the axial distance of 30 cm they generate the mean magnetic field B_{mo} 14 mT in the midpoint of the system, i.e. the peak magnetic induction B_{po} about 17 mT. Obviously, this construction of the magnetization system increases the inhomogeneity of the generated field. In the center of this coil system in the space of the cube of the side length of 18 cm (total volume 5832 cm^3) the peak magnetic induction of the field B_{p} varied from 13.8 to 20.7 mT. Figure 2 shows spatial distribution of $B_{\mathrm{p.}}$

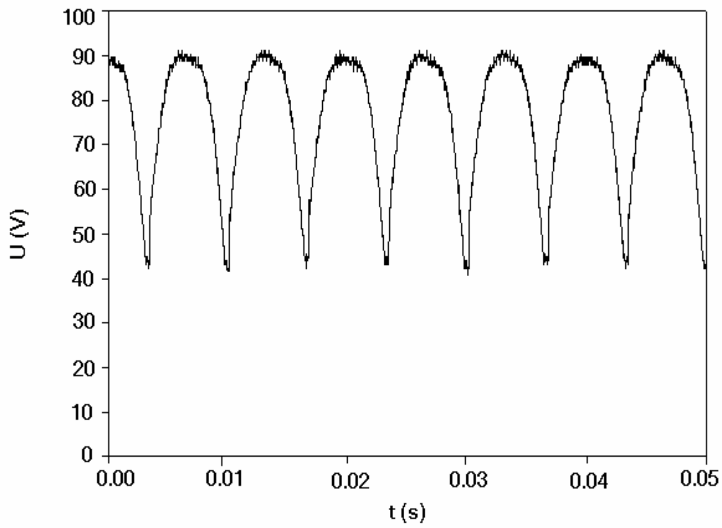

Fig.1. Time course of the pulsating output voltage U.

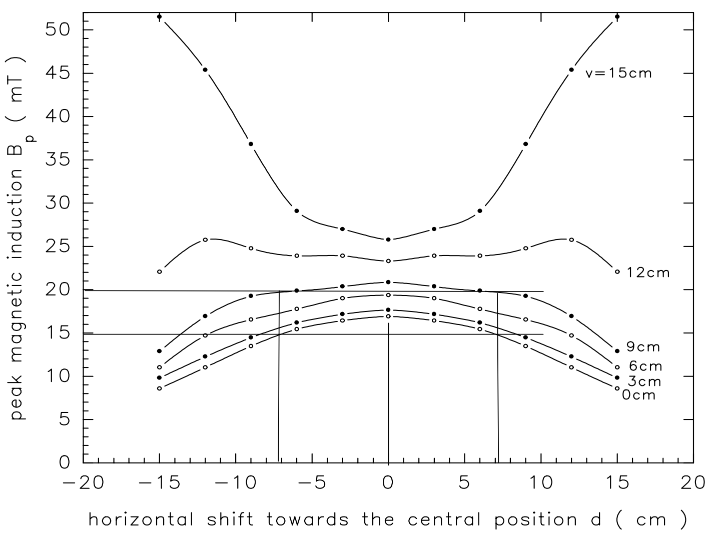

Fig.2. Peak magnetic induction B_p vs. the horizontal shift the to the central position *d.* Parameter *v* defines the vertical distance to the central position in the magnetized space.

The major inhomogeneity of the field is positioned to peripheral regions of the lungs which are ventilated essentially less than in the center, therefore these regions are not so intensively occupied by PFP. In the human lungs the majority of contaminated PFP is collected in the central position of the thorax, which can be defined approximately by the volume of 3000 cm^3 (cube side length of 14.5 cm). In this space B_p ranges from 14.9 to 19.8 mT.

Inhaled PFP may be deposited in the conducting lower airways or they may enter the gas exchange alveolar regions. For both deposition and clearance the structure of the lower airways coating and the surface properties are important. Analysis of the forces acting on the particles deposition and their motion is complicated. It is known that only small particles (diameter < 10 µm) may enter and long-time remain to alveolar surface. The time of the magnetization process must provide that the majority of PFP become magnetized and rotate toward alignment with the applied field. On the other hand regarding the magnetized subject the exposure period should take the shortest time. If we suppose that in the lungs tissues the spherical particles with 10 µm diameter are submerged in the surfactant film with viscosity about 50 Pa s then the time *t* of the particle rotation in the magnetic field is according to[5, 6]

$$t = -\tau \ln\left(\frac{\tan\left(\frac{\vartheta}{2}\right)}{\tan\left(\frac{\vartheta_0}{2}\right)}\right) \qquad \tau = \frac{k.\eta}{B_p.M_p}$$

where ϑ is the instantaneous angle between the directions of $\boldsymbol{B}_\mathbf{p}$ and $\boldsymbol{M}_\mathbf{p}$, ϑ_0 is the initial angle between the directions of $\boldsymbol{B}_\mathbf{p}$ and $\boldsymbol{M}_\mathbf{p}$, M_p is remanent magnetization of the particles, *k* is geometric factor depending on the particle shape and η is viscosity of surrounding fluid, which resists twist of the particle and produces a hydrodynamic retarding torque.

If measured specific remanent magnetic induction of powdered Ni (magnetized by 20 mT) is $M_{sr} = 0.75$ A m^2 kg^{-1} then $M_p = 6674{,}9$ A m^{-1}. Using factor $k = 6$ (sphere), $B_p = 20$ mT and $\eta = 50$ Pa s, the t, needed for rotation by 179°, is approximately 25 seconds. This result was used as one condition of the magnetization time period of the human thorax, so the magnetizing exposure period was determined to at least 30 seconds.

As the entire magnetization system has no forced cooling, the temperature of the winding was checked. On the assumption that the magnetopneumographic process consists of the magnetizing exposure period of 30 seconds and the mapping of B_p from the human subject by the SQUID magnetometric system takes about 15 minutes (magnetizing system is switched off) the temperature of the winding during the repeated magnetization routine was stabile. In case of the ambient temperature of 18° C the winding temperature at the beginning of each magnetizing procedure was in the range from 35.7 to 36° C.

The magnetizing system is supplied by the pulsating current with the peak value 21.5 A and power consumption of about 1400 W. The power supply was fabricated by VINUTA s.r.o., Rajec, Slovakia and adapted in our laboratory. The magnetizing procedure was carried out with subjects in a stand-up position and the magnetic field was applied normally to the frontal plane of the chest. The coils were fixed in parallel; internal dimension of the coils was 30 cm. The current in the coils can be switched over and subsequently the subject was magnetized in the reverse direction.

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