Quantification of the magnetic dust deposition in the magnetopneumographic diagnostic of the human respiratory tract

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Abstract: *With the help of the SQUID magnetometric system the non-invasive magnetopneumographic quantification measurements were performed. Using groups of samples, models and tested persons, the remanent magnetic induction B_r and relaxation curves of the most important contaminating powdered ferri- and ferromagnetic materials (PFM) were measured. The influence of the affecting physiological processes in the organism and some other factors cause the change of the relaxation process with a decay of B_r. By means of the several compensations the measured data were corrected directly in the computer program.*

Key words: magnetopneumography, powdered magnetic materials, contamination of the respiratory tract, relaxation process, quantification

1. Introduction

The most important information for the clinical practice of the diagnostic and the treatment of specific respiratory diseases (pneumoconiosis, etc.) is the amount and distribution of the contaminating PFM in the human respiratory tract. With the help of a unique SQUID magnetometric system the magnetopneumographic investigation of the specific PFM, such as Fe, Co, Ni or some oxides, was accomplished [1]. This method is based on the measurement of B_r upon the human chest after magnetising the thorax in the static field with the magnetic induction B_a. The value of B_r is essentially proportional to the amount of the deposited PFM. The healthy organism reacts immediately with its defence mechanisms for all these contaminating elements. In the upper respiratory airways it is mostly the stimulation of the respiratory cycle like deepening of the breath, increasing the velocity of ventilation until the process of coughing. In the lower airways the PFM are transported outside the body with the help of ciliary beating and mucus flow. The most complicated defence system is activated in the alveolar area of the lung tissue. The clearance mechanism is based on the activity of the phagolysosomes in the alveolar macrophages [2, 3]. Therefore, the majority of the magnetised particles are in continual movement what influences B_r and leads to the decreasing of the measured signal. It is known as the relaxation process.

2. Subject and Methods

It generally holds, that the smaller is the diameter of the particle, the deeper it penetrates into the respiratory system. The particles with the geometric diameter less than 5 μm [4] penetrate into the alveolar system and can deposit there. Bigger ones (up to 20 μm) settle in the lower airways and the particles of PFM with the diameter above 20 μm remain in the upper airways and the trachea.

The physical parameters of the lung tissue, like the viscosity of the intracellular environment in which the macrophages exists, the elasticity of the cell wall, the surface tension of the thin layer of the alveoli's ephitelium, etc. play the deterministic role. Therefore, after finishing the magnetisation process the individual dipoles immediately change their initial orientation and the magnitude of B_r. Due to the dead time between switching-off the magnetising field and starting the measurement, the vertical component of the total remanent magnetic induction B_{rz} also decreases with time. The complexity of the physiological processes, which dependent on the individual's anatomical regard, do not allow to define the explicit mechanism of movement of the PFM in the respiratory tract.

Somewhat more simple there are the cases when the long-term exposition by contaminated air produces a permanent deposition of PFM. If the clearance mechanism is suppressed, the particles will have only limited movement in the lung; subsequently, the relaxation of B_{rz} will change slower. Then, the mass concentration of contaminants n_p, on the presumption of permanent PFM deposits, can be derived from [5]:

$$n_p = \frac{U_a}{W m_{rs} A_{2g\max}(h)} k_{rx}$$

where U_a is the output voltage of the SQUID system, W is the transfer function of the 2nd order gradiometer, m_{rs} is the specific remanent magnetic moment of PFM, $A_{2gmax}(h) = A_{max}(h) - 2A_{max}(h+b) + A_{max}(h+2b)$, where $A_{max}(h)$ describes the positions of the dipoles towards the sensor, h is the distance between the midpoint of the measured object and the closest pick-up coil of the gradiometer, b is the base of this gradiometer, k_{rx} is the relaxation factor which reflects some of the physiological processes and timing of the magnetising and measuring processes.

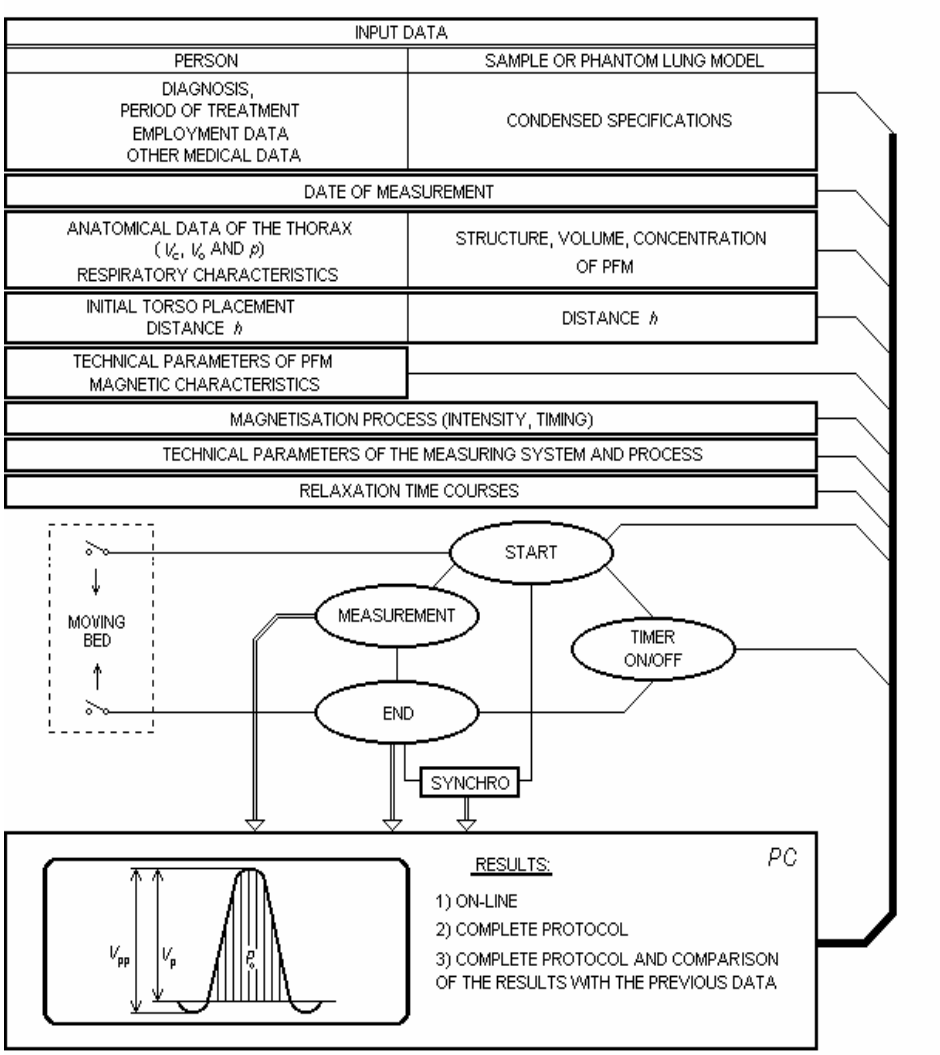

Fig. 1. The diagram of the developed software

The scheme of the computer program prepared for the magnetopneumographical measurements, data acquisition and processing of the results is shown in Fig. 1.
It enables to:

- insert and record basic data about the tested persons, samples and models,
- insert the input data concerning the anatomical parameters of the tested person and its planar position to the sensor,
- apply the technical parameters of PFM, the measuring system and magnetisation apparatus,
- insert the files of relaxation dependences of the B_r,
- correct the resulting signal regarding the time dependence of the measuring process,
- control the whole measuring process,
- gain the list of output data with the possibility to estimate their standard uncertainty,
- gain the base for diagnostic decision and to compare the data with the previous records.

3. Results and discussion

The inspiratory reserve volume of the lungs (V_c), the expiratory reserve volume of the lungs (V_0), the front-to-back diameter of the thorax p and some other parameters obtained from the RTG and CT images are implemented to the program for each measured person. The

estimation of the A_{max} (h) and A_{2gmax} (h) depending on V_c and $V_{0'}$, respectively, was accomplished using a simplified model of the lung with the shape of a circular ellipsoid (Fig. 2). Utilising the gained data, the dimensions of the lung models are corrected according to the used breathing pattern of the tested person. With the help of p, the small-semi axis c and the distance between the midpoint of the ellipsoid and the surface of the chest, the total distance h is defined. The m_{rs} dependences on B_a of the contaminants, which were obtained by measuring of the low-volume and low-concentration PFM samples, are added to the program, too (Fig. 3).

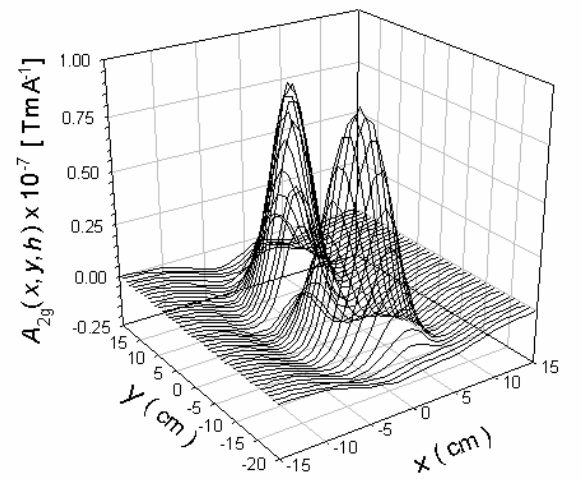

Fig. 2. The calculated $A_{2g}(x,y,h)$ for a simple ellipsoidal lung model of the volume $V = 4000$ cm^3 in the xy plane.

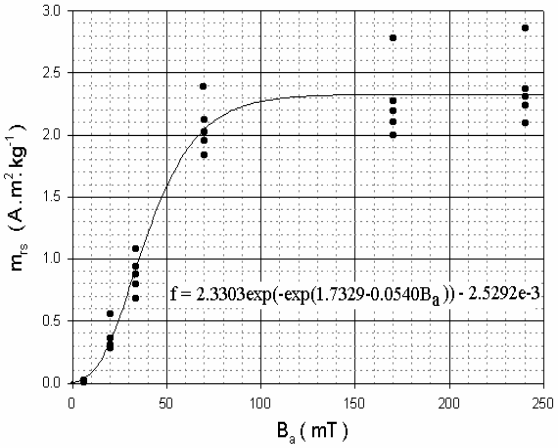

Fig. 3. The dependence of m_{rs} on B_a for Fe particles embedded into solid epoxy.

Automatic compensation of the disturbing magnetic fields caused by the moving bed and by the movement of the worm gear unit is also incorporated into the system. To ensure the conditions for the standard quantification process the thorax is magnetised with B_a = 32 mT ±15% for 5 s and afterwards for 30 s with B_a = 17 mT ±15%. The shorter time period serves for magnetisation of PFM and the longer one to align the magnetic moments of the particles, with the maximum diameter of 20 μm, towards the direction of B_a. It is assumed that the liquid blanket viscosity of the airways is not higher than 60 Pa.s. The relaxation courses of Fe_3O_4 particles dispersed in the experimental samples, recorded 20 s after the magnetic field switch-off, are plotted in Fig. 4. Using similar records, the correct results of n_p are determined using k_{rx} that is derived from the relevant inverse relaxation curves.

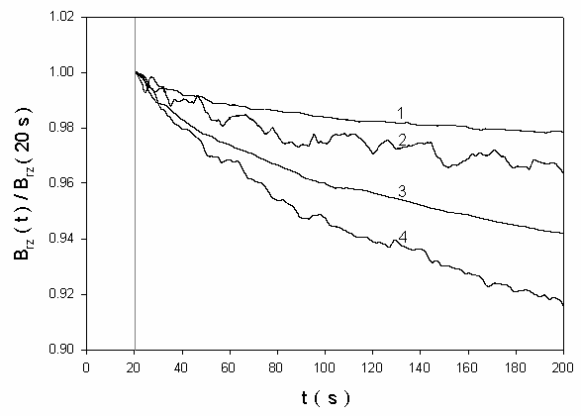

Fig. 4. Typical relaxation curves of Fe_3O_4 particles with the surface density of 1) $\rho_A = 10 \times 10^{-3}$ g cm^{-2} 3) $\rho_A = 1 \times 10^{-3}$ g cm^{-2} embedded into fluid epoxy of viscosity η = 60 Pa s, and 2) $\rho_A = 10 \times 10^{-3}$ g cm^{-2} 4) ρ_A = 1 mg cm^{-2} in solid epoxy after the magnetisation in the field of induction B_a = 17.25 mT during 30 s.

The program was equipped with the files of relaxation characteristics gained after the measurement of PFM particles homogenously dispersed in suspensions with the various viscosities. The whole measurement process during the 6 s time interval of the measurement is also controlled by the program.

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