APPLIED MAGNETOMETRY FOR MATERIAL RESEARCH AND MAGNETIC SENSORS

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ABSTRACT

The article provides a brief presentation of the magnetic sensors, magnetometers and namely the method and some examples of magnetometry in material research.

Keywords: *relaxation magnetic sensor, applied magnetometry, research of ferromagnetic materials, magnetometers*

1. INTRODUCTION

At Faculty of Aeronautics TUKE we have been involved in applied magnetometry namely the problems of measurement of weak magnetic fields mostly from the aspects of navigation, remote monitoring and detection, ELF EMF compatibility and ecology. Other solved problems were those of the magnetic sensors, magnetometers for research and special industrial systems. The third aspects are material research – magnetic characterization of special materials for sensors and electric industrial devices.

2. MAGNETIC SENSORS

Relax-type sensors belong to the family of flux-gate sensors, based on the principle of flux-gathering, i.e. the parametrical amplification of magnetic flux in the ferromagnetic core of the sensing solenoid and its gating - comparation at the level of saturation – i.e. flux-gating. Relax-type sensor is a pulse energy converter with saturated core, at which the primary quantity proportional to the external magnetic field is the relaxation current I_0, which is independent of the load characteristics:

$$I_0 = \frac{l}{N\mu_0}\left(\frac{B_S}{\mu_{ef}} - B_a\right); \tag{1}$$

where l is the length of the ferroprobe, N the number of windings, B_S the core saturation induction, B_a the measured ambient field and μ_{ef} the effective core permeability. The output relaxation current may be considered as the characteristics of the load converted into a time interval or voltage as shown on Fig. 1. Detailed analysis and the concrete structure was made in [1] and its brief description is contained in [4].

Relaxation sensor, because of stimulation with short time current pulses, has very low energy consumption. This, along with other good characteristics, as well as the directly digital or analog form of the output signal, allows for a wide variety of applications.

Further development and application of relaxation sensors requires new materials to cores, which in general are required to have a higher saturation inductivity value, at high permeability, neglectable coercivity and extreme permeability – i.e. characteristics approximating the ideal soft ferromagnetic materials. This paper is to present some of the examples of research into materials for sensor - core with Institute of Physics SAS conducted in the period of 1985 – 2003 and provide an introduction into the characteristics of new relaxation sensor, developed under cooperation with Institute of Experimental Physics SAS as of today [5].

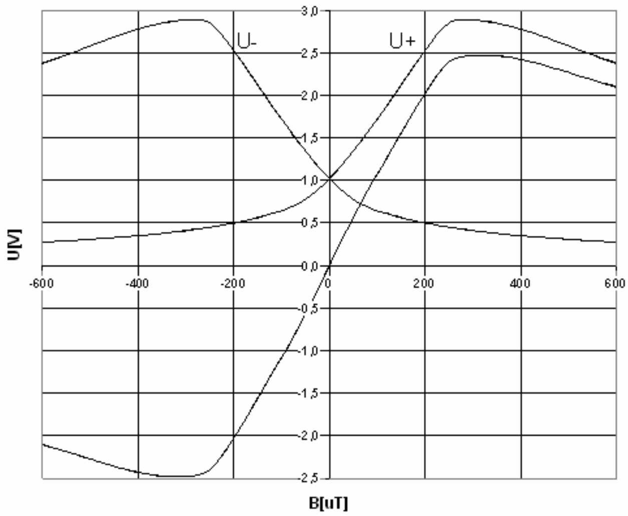

Fig. 1 Relaxation sensor characteristics obtained with core of material $Fe_{63}Co_{21}B_{15}Cu$ annealing at 593 K by using impulse exciting current 50 mA

3. MAGNETOMETERS

The original magnetic sensors described here were implemented into many magnetometers or into magnetometrical systems developed in cooperation with the EDIS Košice research institute. They are in use with the VSZ (USS), FA TUKE, institutes of SAS and IS Košice, STU Bratislava, MUS Most, SD Kadan, UK Praha, VUT Brno etc.

If linked to a computer, the described sensors enable vectored measurement and visualization of low intensity magnetic field. The whole range of measurement is typically 100 μT (200 μT). Full sensitivity without changing the setting is about 5 orders [4]. For example the system VEMA 032 on Fig. 2 wordily visualizes and displays magnetic field.

Fig. 2 Two channel magnetometer for materials research at IoP SAS

Vema calculates and presents the average filtering value at the given time interval and it´s time-bound development, presenting the AC component and is also capable of displaying the amplitude frequency spectrum of the measured magnitude or downloading values to the databases for reuse, secondary DSP included. Industry magnetometers, for example the HFT system, indicate ferromagnetic trump metals on the belt of conveyers, excavators on Fig. 3 etc.

Fig. 3 RK 5000 Excavators at Mostecké uhelné Most equipped with the HFT system indicating ferromagnetic substances – result of the research team FA TUKE, SAS, developed and manufactured by EDIS Košice

4. MEASUREMENT OF STATIC MAGNETIC CHARACTERISTICS OF OPEN FERRO-MAGNETIC SAMPLES

4.1. Method of measurement

The method of measurement static magnetic characteristics of open ferromagnetic samples has been developed for the VÚ VSŽ Oceľ a.s.. The basic idea of measurement consists in making use of the linear proportionality existing between the dispersion field of the open sample and its internal magnetic characteristics. A similar principle was used for measure static coercivity of samples. When measuring the dispersion field from a sufficient distance, the open sample can be considered for a induced magnetic dipole, the dipole moment of which is proportional to the magnetic polarization of the sample and the volume of the sample.

Measured values at various external field values, it is not only possible to reconstruct the magnetization characteristics of the open sample, but also pure material characteristics in case the coefficient of demagnetization is known.

The principal diagram of the measurement sample is on Fig. 4 consisting of a couple of identical, geometrically parallel air solenoid coils which are connected so as to generate a magnetically well-compensated area between them (in view of the exciting, external field). The sample is exactly oriented in direction West-East, i.e. vertically to the Earth´s magnetic field, which can considerable affect measurements of the sample characteristics if it acts in direction of line in with the magnetic field of the sample measured. The sample is to be inserted into any arbitrary air coils. The voltage flowing through the winding of the coil is generating a homogenous magnetic field inside the hole at variations of $\mp 2\%$ in an area of $10\text{cm} \times 1\text{cm} \times 1\text{cm}$ where the sample is positioned. The sample is polarized and the sensor is measuring its dispersion field.

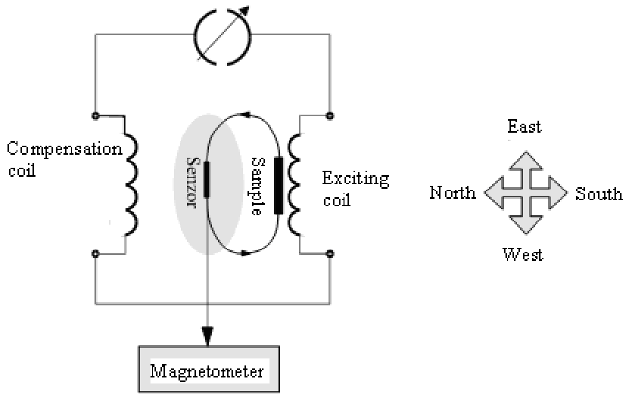

Fig. 4 Principal diagram of the sample for measurement of static magnetical characteristics of open samples

Arrangement and distribution of the magnetic field between the coils is shown in Fig. 5.

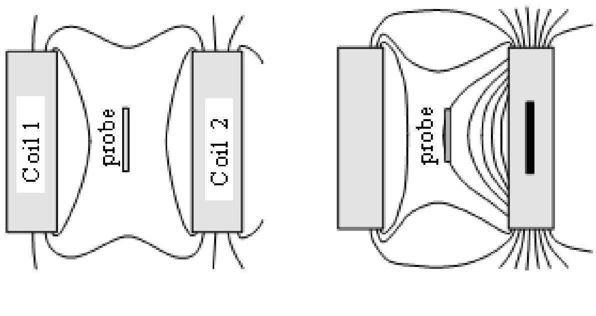

Fig. 5 Arrangement of magnetic field between the coils before and after the measured ferro-magnetic material has been inserted

The process of the measurement itself is automatic computer controlled which is programme-generated via the D/A output stimulation signal. This signal is controlled by a power bipolar current/power source feeding the serial exciting and compensating coil of the measured sample. The dispersion magnetic field of the sample is measured with a relax magnetometer, which in return is communication with a computer via a suitable port. The programme structure consists of several parts as seen in Fig. 6.

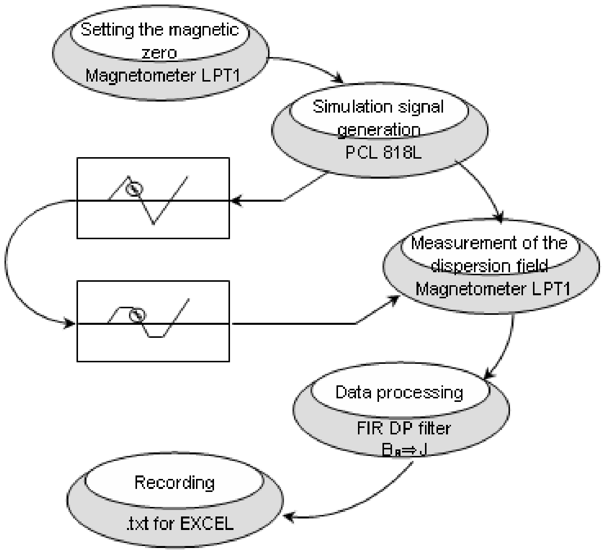

Fig. 6 Structure of the program to measure static magnetic characteristics

The procedure consists of firstly from setting the sample into East-West direction, i.e. vertically to the local magnetic field with an accuracy of 10nT, generating voltage of triangular form/shape with a 12 bit resolution in 500 steps for the entire hysteresis loop and by a subsequent measurement of the dispersion field with a DP FIR filter and 14 bit resolution. The time delay between setting the stimulation quantity and the measurement of the dispersion field is adjustable in line with the required dynamics of measurements, by standard 30 seconds for a complete hysteresis loop. On completion of the measurement, the data are reduced to 255 items and recorded into text files for further processing in the EXCEL program.

4.2. Magnetometry applications in material research and selected results of measurements

New development of amorphous materials for sensors was conducted in cooperation with the team of researchers of IoP SAS in the period of the 80s and 90s. To select for the suitable material for the ferro-probe, more than 50 commercially available and experimental amorphous materials were measured prepared by the IoP SAS. For illustration purposes, a selection of graphs was made that serve for further analysis in terms of the optimization of material selection fopr the ferro-probe core for the relaxation magnetometer. Materials showing linear characteristics with intensive/violent/ rapid transitions into saturation are fit best to relaxation magnetometers. The requirements were well met, for example by the material designated as the Vitrovac 6025X, Fig. 7.

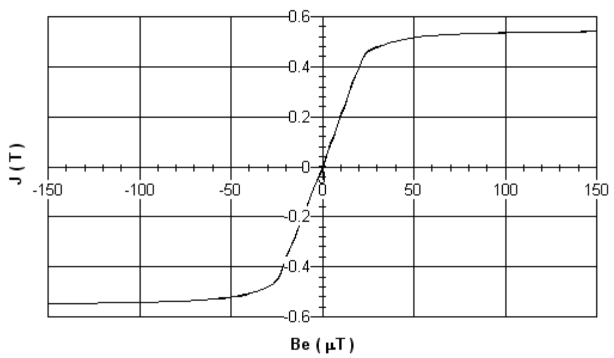

Fig. 7 Linear characteristics of the open sample of Vitrovac® 6025X 100 × 5 × 0.03 mm with a rapid transition into saturation

Examples of BH characteristics of materials not suitable for relaxation sensors are on fig. from 6 to 9.

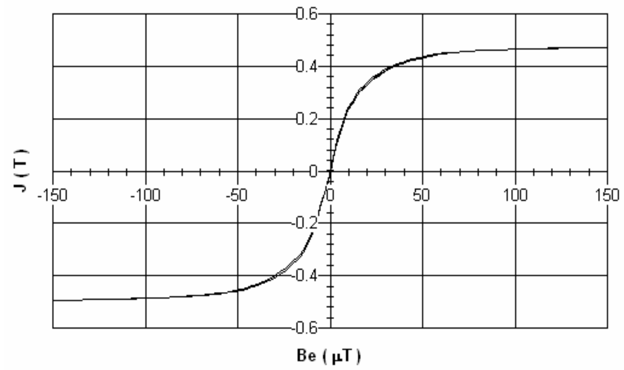

Fig. 8 Smooth, almost linear static characteristics of the open sample of Vitrovac®6025 100 x 5 x 0.025 mm

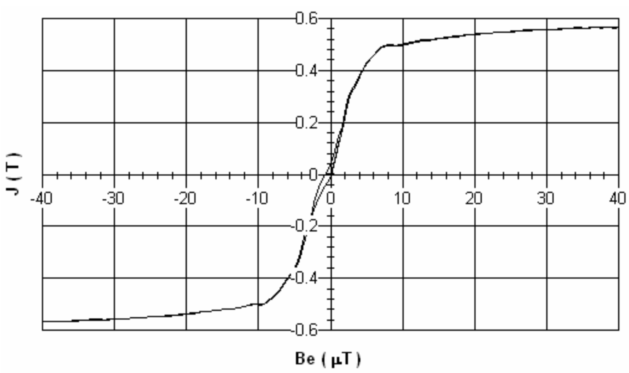

Fig. 9 The remarkably non-linear, hysteresis static characteristic of the open experimental sample of material 6025ZN 100 x 1 x 0.025 mm

Even without using the mathematical apparatus, from the graphs presented as above, it is obvious that , from the materials available, the most suitable ones were those from Germany desgnated as **Vitrovac® 6025X and 6030**, i.e. the cobalt alloys with almost zero magnetostriction. The 6025X belt has been eventually recommended by the manufacturer as suitable for magentic sensor applications.

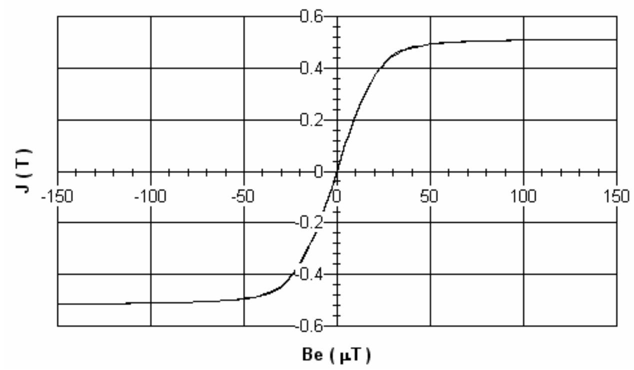

Fig. 10 Smooth (‘exponentially’) non-linear static characteristics of the open sample of Metglass® MG2714A 100 x 5 x 0.02 mm

Positive influence on the material characteristics was exerted by their thermo-magnetic and thermo-mechanic pre-treatment (TMF), just below the Curie temperature, in this ways, it is possible to achieve a really ideal, linear (part-to-part) characteristics with a steep transition into saturation and minimum para-processes/vapour processes. The TMF process, however, requires high-quality technical and operational laboratory equipment; otherwise the results are barely reproducible, even though they lead to results exceeding commercial levels. The linear characteristics in the area of weak fields (20000nT) leads to certain qualitative appreciation/improvement/ in terms of suitability for using the individual materials via the regression coefficient and the magnitude of effective permeability. For the purpose of evaluation, among the materials selected were the ones such as the Vitrovac® 6025, 6025X, 6030, Metglass® MG2714A and the experimental materials as the 579 and 309. Linear regression was taken from the area of behaviour of the hysteresis loop zero, using the EXCEL program.

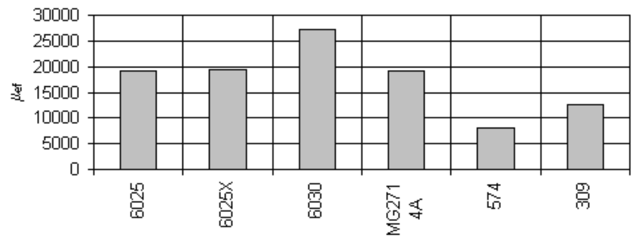

Fig. 11 Comparison of the effective permeability of the selected samples of materials

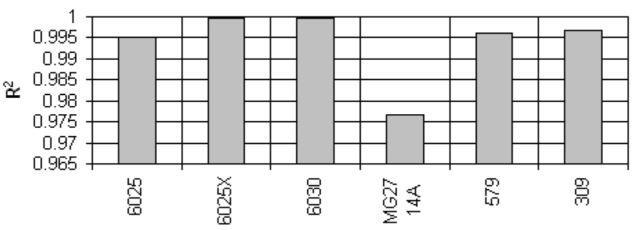

Fig. 12 Regression coefficient of selected samples

Results of the quantitative analysis are shown in Fig. 11 and 12 proving the excellent properties of materials, namely the Vitrovac® 6025X and particularly the 6030, i.e. the materials with highly efficient permeability and good linearity in the 20000nT band. Consequently, for decades, our laboratory has been realizing all relaxation magnetic magnetic sensors on the basis of the materials as above.

At the beginning of the new century, research continued in cooperation with the SAS focused on materials of the Finemets group [2] and currently are subject to investigations within the framework of the APVV 0454-07 Project in cooperation with the FA TUKE and the IoEP SAS Košice in search for new materials for sensors with approximately a doubled extent of measurements The remarkable results have been demonstrated by the appropriately thermo magnetically treated material of Fe CoBCu [5].

5. CONCLUSIONS

Development of magnetic sensors is a never-ending process, with its progress is substantially dependent also on the development of new magnetic materials. The contribution is showing a closed cycle within which the newly-developed sensors, magnetometers and the methods of measurements serve also in the process of further development of materials of new generation. The researches of the Department of the Aviation Technical Preparation in cooperation with the institute of the SAS have long been involved in the research of magnetic materials for sensor technology. The results obtained are then directly applied in cooperation with the EDIS research company in the development and manufacturing of special-purpose magnetometers for both laboratory and industrial applications.

New or modernized methods of measurements and processing of signals are used in applied magnetometry in wide spectrum of activities. The method and apparatus presented in the article have been successfully applied for example in the development of electro technical steel plates in the VSŽ Košice (measurement and comparison of magnetic properties of steels of all experimental smelts in the course of a two-year period of time). Further, our place of work performed measurements of characteristics for research of new materials conducted at the IoMS SAS. Finally, these days, in cooperation with the FE TUKE and the IoP SAS Košice, solutions are under way as part of the APVV 0454-07 Projects focused on modern magnetic sensors for industrial applications, with research based on new materials subjected to special thermo magnetic treatment.

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