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Data Processing of Manganite Sensors Array for Measurements of Non-Homogeneous Pulsed Magnetic Field

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Introduction

In present time the interest in pulsed technologies is increased very much and electromagnetic launchers, magnetocumulative generators, magnetic forming systems are under development [1]. During the operation of these devices, extremely high pulsed magnetic fields with amplitudes up to 50 T can be generated. The measurement of these magnetic fields is a very complicated technical task because the amplitude and direction of magnetic field changes simultaneously. The existing high pulsed magnetic field measurement methods using B-dot, Hall or magneto-optical sensors are applicable in case of known magnetic field direction and the accuracy of such methods is low when the direction of magnetic field is not determined in advance or it is changing during experiment. For this reason the development of sensors able to measure magnitude of magnetic field independently on magnetic field direction is very important task for scientists and engineers.

Since the discovery of colossal magnetoresistance (CMR) in manganites [2], it was suggested to use this phenomenon for high magnetic field (HMF) measurements. It was demonstrated that $La_{0.8}Sr_{0.2}MnO_3$ thin polycrystalline films can be used for pulsed magnetic field measurements with amplitudes up to 50 T [3, 4]. Moreover, it was found that the magnetic field response of these sensors does not depend on the orientation of the sensor to magnetic field direction and measurements of absolute value of pulsed magnetic field with unknown direction can be carried out.

The total efficiency of pulsed actuators strongly depends on magnetic field space distribution which should be taken into consideration in pulsed system design. Therefore, the measurement of the space distribution of the magnetic field in these systems is also very important task as the evaluation of magnetic field absolute value. Actually pulsed power experiment is unique and very expensive. Moreover, it is difficult to repeat identical experimental conditions for series of experiments due to thermal, mechanical and electrical overloads that take place in pulsed system. Therefore, a few sensors are necessary in order to measure magnetic field distribution during one experiment. A relatively simple system for the evaluation of magnetic field distribution can be realized by the application of several sensors and oscilloscopes [5]. This system is applicable if the number of controlled points of field distribution is small. Complex systems require a large number of sensors and the problem of registering apparatus capable simultaneously to record signals from many sensors has to be solved. Moreover, this equipment should be fast in operation and capable to record signals at least from eight and more sensors. Although standard multi-channel measuring units are commercially available they are relatively expensive and the development of non-expensive special measuring equipment in order to control magnetic field distribution and transient processes in pulsed magnetic field systems is a vital engineering task.

In present work the system consisting of eight manganite sensors array and data processing circuit is proposed for measurements of pulsed magnetic field non-homogeneity.

Experimental equipment

The structure of the experimental equipment for measurement of non-homogeneous magnetic field is shown in Fig.1. Pulsed magnetic field generator consists of an energy storage bank 1, high power switch 2 and pulsed inductor 3. In more detail magnetic field generator is described in [6]. The array of eight magnetic field sensors 4 have to be positioned in central area of the pulsed inductor. Discharging the energy bank through the inductor the sinus-shaped magnetic field pulse up to 50 T can be generated. The signal from array of magnetic field sensors has to be primary processed in the digital circuit 5. Finally the data of measurements are processed and memorized in the personal computer 6.

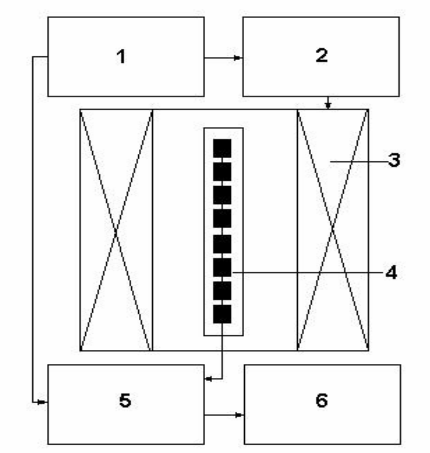

Fig. 1. The structure of experimental equipment for measurement of pulsed magnetic field non-homogeneity

Pulsed magnetic field generator as a magnetic field source with known field distribution was used to test potential abilities of described system to measure non-homogeneity of pulsed magnetic field. Magnetic flux density in any inside point of the solenoid can be evaluated analytically with acceptable accuracy using following equations:

$$B_z(\rho,\theta)=B_0\left[1+E_2\left(\frac{\rho}{r_1}\right)^2P_2(u)+E_4\left(\frac{\rho}{r_1}\right)^4P_4(u)+\ldots\right],$$

$$B_r(\rho,\theta)=B_0\left[0+E_2\left(\frac{\rho}{r_1}\right)^2P_2'(u)+E_4\left(\frac{\rho}{r_1}\right)^4P_4'(u)+\ldots\right], \qquad (1)$$

where $B_z(\rho,\theta), B_r(\rho,\theta)$ are axial and radial components of magnetic field in the point with spherical coordinates r,θ, and $P_n(u), P_n'(u)$ are Lesandre polynomial and its derivative, respectively. $u=\cos\theta$, E_n are coefficients for partial field derivative in point z = 0 determined by Teylor's formula

$$E_{2n}=\frac{1}{B_0}\frac{1}{(2n)!}\frac{\partial^{2n}B_z(z,0)}{\partial z^{2n}}\Big|_{z=0}, \qquad (2)$$

$$B_0=\mu_0\frac{NI}{r_1}\left[\frac{F(\alpha,\beta)}{2\beta(\alpha-1)}\right],\ F(\alpha,\beta)=\beta\ln\frac{\alpha+\sqrt{\alpha^2+\beta^2}}{1+\sqrt{1+\beta^2}}, \qquad (3)$$

here μ_0 is magnetic constant, N is the quantity of turns, I is a current, r_1, r_2, l are internal, external radius and the length of a solenoid, respectively, $\alpha=\frac{r_2}{r_1}$, $\beta=\frac{l}{2r_1}$ are relative sizes.

Thin polycrystalline manganite films were used as magnetic field sensors. A polycrystalline $La_{0.83}Sr_{0.17}MnO_3$ (LSMO) film was grown on a lucalox substrate using a MOCVD technique. The thickness (d) of the films was about 400 nm. Electrical contacts were made by thermal deposition of Ag, using a Cr sub-layer, followed by standard negative photolithography. The distance between the contacts was 50 μm. The samples have 0.5 mm x 1 mm dimensions. The active area of the sensor was 0.05 x 0.5 mm^2. The resistance of these sensors was ~6 kΩ. After that they were soldered to bifilar twisted wires and covered by epoxy. In more detail the technology of the preparation of the sensors is described in [7]. The array of 8 sensors positioned on the strip can be used during experimentation.

Data processing circuit

The digital circuit was designed to measure the voltage drop of eight manganite film sensors. Since the duration of the magnetic field pulse in our experiments did not exceed 10 ms, a high performance PHILIPS P89LPC938 8-bit microcontroller with accelerated two-clock 80C51 core (9 MIPS), 8 kB 3 V byte-erasable Flash and eight 10-bit 4 μs-conversion-time A/D converters was chosen. Features mentioned above enable microcontroller to get more than 10000 samples per second for each A/D channel including 5 mV step with 5 VDC power supply and 3 mV step with 3 VDC power supply. The P89LPC938 is based on high performance processor architecture that executes instructions in two to four clocks, six times the rate of standard 80C51 devices. The microcontroller also manages the synchronization of main program starting point and the opening of power thyristor to discharge the battery through the high magnetic field inductor.

After powering up the circuit, the controller is reset and the code execution starts. After this the controller waits for predefined time interval (20–30 s) and sets the SYNC OUT pin to logical one to power-up the thyristor. At the same moment the scanning of all A/D channels begins and lasts for up to 0.5 s. Every last conversion result is written to the flash memory chip during every next conversion. As in 0.5 s experiment is finished, all the raw data are automatically loaded from flash memory to the PC for further processing via COM Port using RS-232 Zero-Modem interface. Taking into account that the microcontroller is capable to perform 250000 10-bit A/D conversions per second and knowing that the experiment lasts not longer than that, ATMEL 4 Mbit capacity AT26DF041 flash memory chip satisfies our requirements. Instead of 4 Mbit flash any other capacity in the range up to 32 Mbit might be chosen. Pin configuration and addressing format is identical. The AT26DF041 is Serial Peripheral Interface (SPI) compatible and SPI with 3 Mbps maximum transfer rate is already hardwired in the microcontroller. That overall improves the communication speed and simplifies the code. The on-chip memory could be addressed by block/page/byte and must be erased before recording to it. The above mentioned time range before the synchronization signal could be successfully used to erase the chip. To reset controller properly before running the main program the MICROCHIP TC1232 Processor Monitor was used. TC1232 forms a 250 ms low state signal at the /RST pin after the power on and then turns to high state but has to receive low on /ST pin at least once in 1200 ms to keep the /RST pin high. When connecting /TD to ground pin the time-monitoring gap could be shortened to 150 ms. LED could be connected to RST pin to signal the failure of microcontroller's function. To convert 0 to 5V signals to ones compatible with COM Port the MAXIM

RS-232 driver/receiver chip was used along with standard capacitor connection. The data transmission rate at 115000 bps could be achieved which is reliable and fast enough to upload the AT26DF041 content to the PC in 1 minute. To avoid over-voltages analog inputs are protected using Zener diodes.

Microcontroller's In-System or In-Application programming is not foreseen. Therefore this could be done using either separate circuit or the same circuit extended for these functions. To save raw data to the PC's hard drive and to process it to get experiment results special software using Delphi or C++ code should be written. As chip AT26DF041 has a byte memory organization, two adjacent bytes store one A/D conversion value: the lower byte carries 8 lower bits of 10 bit word and higher byte carries 2 higher ones in its 2 lower bits while bits from 2 to 7 are filled with zeros. Such way to store data on a chip is not economical but very convenient when processing it in the PC. Only few left shifts and an addition operation are needed to compose a 16 bit word value. Redundant bits in every higher byte could be filled before loading data to the PC and carry other information. If experiment lasts longer than mentioned conversion results could be written to memory bit by bit. After having data written to file every two bytes represent a channel conversion value followed by two other bytes representing next channel's conversion value and so on up to 8 -th channel. Every 16 bytes form a frame. Since time interval between two conversions is known 8 values might be added to Amplitude-Time diagram. Next 16 bytes would give information on next 8 conversion results (next frame) and since time interval between the end of last and the beginning of the next conversion is known values could also be added to the diagram, and so on.

Manganite sensors are always calibrated before any experiment and their amplification coefficient is known. By multiplying every before mentioned value by its own coefficient we get a magnetic field amplitude - time characteristics. It has to be understood that there are no values sampled at the same moment and every value in frame is shifted by time interval between two conversions or (always 8^{th} and 1^{st} value) by time interval between two frames and to compare two values at the same time moment the interpolation of every characteristics between every adjacent amplitude values must be performed. As time intervals between these two values are relatively short compared with the length of the pulse (less than 1/100 of the pulse), results obtained would be reliable and valuable enough for any further analysis. All possible results would be presented in graphical form. For all the operations described above and for the other end RS-232 Zero-Modem communication special interactive software should be written.

Discussions

The application of polycrystalline manganite films as the sensors of magnetic field gives the great possibility to measure the magnetic field of unknown direction and configuration. As it was shown in the previous works the resistance of such films does not depend on direction of the magnetic field and it depends only on its value. However, resistance of LSMO depends on temperature too. Furthermore, a change in the temperature changes the sensitivity to the magnetic field. The increase of the temperature leads to decrease of the resistance of the film and the slope of the curves *R(B)*. Furthermore, it is evident that with change of the temperature the curves could have sub-linear, linear or super-linear character. In Fig.2 the resistance of film is shown.

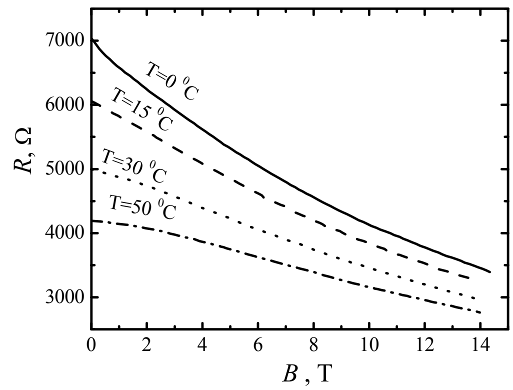

Fig. 2. Sensor's resistance dependence on magnetic field at four different temperatures: 0, 15, 30 and 50 ^{0}C

The identity of the characteristics of sensors is another problem. Although the films are grown in one process, however it is not possible to obtain absolutely identical sensors with the identical initial resistances and the sensitivity, which shows slope of curve *R(B)*, to the magnetic field. The dependences of resistances on the magnetic field for several sensors are shown in Fig.3.

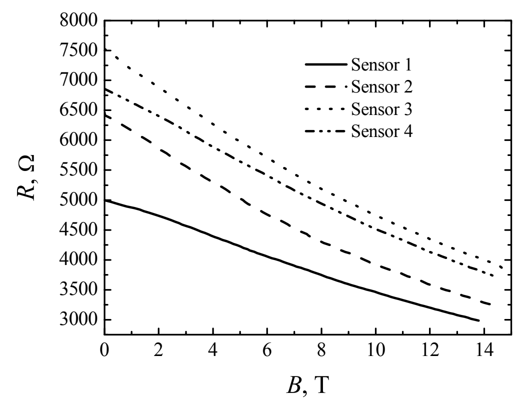

Fig. 3. Resistance *vs*. magnetic field inductance for four sensors cut from the same 20x20 mm^2 area of the film

In addition, calibration data of each sensor will be recorded into the computer and introduced into final data processing. Computer program for final data processing is under development using Delphi or C++ code. The complete picture of magnetic field distribution of magnetic field will be able visually and in digital code.

In general, the described data processing circuit has a flexible architecture. The relative simplicity, reliability and highly integrated design provide a good platform for data processing in various areas of applied sciences.

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The application of manganite sensors array for measurements of magnetic field non-homogeneity and further digital data processing are described. The measuring system consisting of the array of 8 sensors, the digital circuit for primary signal processing, personal computer for final data processing and pulsed magnetic field source is offered. The measurement of magnetic field distribution can be carried out by the application of polycrystalline $La_{0.83}Sr_{0.17}MnO_3$ manganite sensors, which magneto-resistance has no saturation effects in high magnetic fields and does not depend on of magnetic field direction. Described digital circuit for data processing includes 8-channels 10-bit A/D converter, 8-bit microcontroller, flash memory and it is connected with PC via RS-232 interface. Taking into account difference of sensor's characteristics and temperature dependence, the calibration should be done with further data memorization for final data processing. A special program for data processing is under development using Delphi and C++ codes. Offered digital circuit for experimental data processing has flexible architecture, is relatively effective and potentially applicable Ill. 3, bibl. 7 (in English; summaries in English, Russian and Lithuanian).

С. Барткевичюс, Ю. Новицкий, В. Станкевич, П. Циммперман. Обработка данных массива манганитных датчиков при измерении неоднородности магнитного поля // Электроника и электротехника. – Каунас: Технология, 2006. – № 4(68). – С. 69–72.

Рассматривается возможность применения массива датчиков для измерения распределения импульсного магнитного поля с последующей обработкой информации. Предложена структурная схема измерительной системы, состоящей из массива 8 датчиков, цифровой схемы первичной обработки информации, персонального компьютера для окончательной обработки информации и импульсного источника магнитного поля. Измерение магнитного поля осуществляется с помощью поликристаллических манганитных $La_{0.83}Sr_{0.17}MnO_3$, датчиков, магнитосопротивление которых в диапазоне магнитных полей до 35 Т имеет практически линейный характер и не зависит от ориентации датчика в магнитном поле. Цифровая схема включающая в себя 8-канальный 10-бит аналого-цифровой преобразователь, 8-бит микропроцессор и блок промежуточной памяти, соедена с персональным компьютером через RS-232 порт. Принимая во внимание неидентичность характеристик и температурную зависимость сопротивления, данные калибровки датчиков хранятся в памяти и используются дла последующей обработки информации. Окончательный алгоритм обработки данных на языке Delphi и C++ находится на стадии разработки. Предложенная цифровая схема обработки данных отличается универсальностью и сравнительно проста и эффективна. Ил. 3, библ. 7 (на английском языке; рефераты на английском, русском и литовском яз.)

S. Bartkevičius, J. Novickij, V. Stankevič, P. Cimmperman. Manganitų jutiklių masyvo informacijos apdorojimas magnetinio lauko nehomogeniškumo matavimuose // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2006. –Nr. 4(68). – P. 69–72.

Nagrinėjama galimybė pritaikyti jutiklių masyvą impulsinio magnetino lauko nehomogeniškumo matavimams bei skaitmeniškai apdoroti matavimo rezultatams. Pateikta matavimo sistemos struktūrinė schema, susidedanti iš aštuonių jutiklių masyvo, skaitmeninės elektroninės schemos, skirtos pirminiam eksperimentinių duomenų apdorojimui, asmeninio kompiuterio antriniam informacijos apdorojimui bei impulsinio magnetinio lauko šaltinio. Magnetinio lauko pasiskirstymas matuojamas polikristaliniais $La_{0.83}Sr_{0.17}MnO_3$ jutikliais, kurių magnetovarža neįsisotina iki 35 T ir nepriklauso nuo magnetinio lauko krypties. Elektroninę schemą sudaro aštuonių kanalų 10 bitų analoginis skaitmeninis keitiklis, 8 bitų mikrovaldiklis ir tarpinės atminties blokas. Schema RS-232 sąsaja sujungta su asmeniniu kompiuteriu, kuriuo atliekamas galutinis eksperimentinės informacijos apdorojimas. Manganito jutiklių charakteristikos yra nevienodos ir priklauso nuo temperatūros. Todėl jutiklių masyvo kalibravimo charakteristikos yra saugomos atmintyje ir naudojamos eksperimentinei informacijai apdoroti. Speciali informacijos apdorojimo programa yra rašoma Delphi ir C++ programavimo kalba ir bus pateikta kitame eksperimento etape. Pasiūlyta informacijos apdorojimo schema turi lanksčią architektūrą, yra efektyvi ir gali būti plačiai taikoma. Il. 3, bibl. 7 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).