Journal of ELECTRICAL ENGINEERING, VOL 66. NO 7/s, 2015, 161-163

UTILIZING MAGNETIC MICROWIRES FOR SENSING IN BIOLOGICAL APPLICATIONS

Igor Sulla* — Rudolf Sabol — Peter Klein**,*** — Rastislav Varga**, *** — Ján Gálik ******

In the presented short communication the authors refer on the first testing of microwires for monitoring the position of rats. Single piece of microwires was implanted in general inhalatory anaesthesia (by 1.5% Isoflurane with oxygen) via two small surgical incisions into subcutaneous tissue at the back of the rat. By help of the simple contactless coil, produced on the plastic tube, it was possible to assess the position of the rat inside the tube and monitor eventual movements of the animal.

Keywords: sensors, magnetic microwires, magnetic bistability

1 INTRODUCTION

Glass-coated micowires are composite materials (see fig.1) that consist of metallic nucleus (having diameter from 1-50 μm) and glass-coating (thickness 2-20 μm) [1]. They are produced by modified Taylor-Ulitovsky process – drawing and quenching of molten master alloy together with the glass. Having positive magnetostriction, they are characterized by peculiar domain structure: one axial monodomain in the centre of the wire, which is surrounded by many domains with radial magnetization. Moreover, small closure domains appear at the end of the microwire in order to decrease the stray fields.

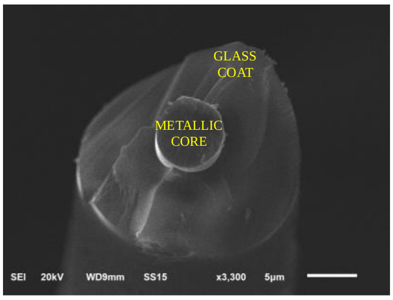

Fig. 1. SEM image of glass-coated amorphous microwire

As a result, magnetization in axial monodomain can have only two stable states $\pm M_S$. The switching between these two stable configurations is driven by the domain-wall propagation in one large Barkhausen jump at the field called switching field H_{SW}.

Glass-coated microwires have several advantages: cheap and easy preparation because from one precursor (master alloy is typically sphere with weight of 2.5 gram) it is possible to prepare 10 km of wire, symmetrical shape, fast response to the change of temperature which is given by the high domain wall velocity, contact-less sensing developed by the group from Technical University in Kosice [2]. Moreover, glass coating serves as chemical (it avoids oxidation at higher temperatures) and electrical insulator.

However, most important advantage of glass-coated microwires is their small dimension that allows embedding of microwire into the studied materials or into living organisms without destroying their mechanical properties and without violation of functionality of tissue or internal organs of animal or human body [3].

In the given contribution, authors deal with application of glass-coated amorphous microwires for contactless monitoring of the rat position. Single piece of microwires is used to detect contactlessly the position of the rat inside the sensing coil. We show that a single piece of 4 cm x 50 μm is necessary for functional sensor and such sensor minimally interferes with inner implant structure.

2 EXPERIMENTAL

The experimental protocol was developed in accordance with the legislation of the Slovak Republic (Animal Protection Act No 15/1995 [4]) and approved by the Ethical Commission of the Institute of Neurobiology, Slovak Academy of Sciences in Košice.

For subcutaneous implantation in presented study was selected an amorphous glass-coated microwire produced by modified Taylor-Ulitovsky technique with nominal composition $Fe_{76}Si_9B_{10}P_5$ with diameter of metallic core 27 μm and total diameter of 40 μm.

The single piece of above mentioned microwire was implanted in a general inhalatory anaesthesia (with which the senior author had positive experience in small laboratory animals) via two small (about 5 mm long) transversal surgical incisions into subcutaneous tissue at the back of the rat (see fig.2). The anaesthesia was induced by a mixture of oxygen with 1.5% Isoflurane (isofluranum, *ie* 1-chlor-2,2,2-trifluoroethydifluoromethyleter, AbbVie s.r.o., Prague, Czech Republic) in a plexiglass box then the animal was placed on a heated plate enabling to keep its rectal temperature between 36.6 and 37.2°C, and the narcosis was further administered by help of a special mask designated for rats (see Fig.2).

* Department of Anatomy, Histology and Physiology, University of Veterinary Medicine and Pharmacy, Komenskeho 74, 041 81 Kosice, Slovakia
** RVmagnetics, Hodkovce 21, 04421 Kosice, Slovakia
*** Institute of Physics, Faculty of Sciences, P. J. Safarik University, Park Angelinum 9, 041 54 Kosice, Slovakia, e-mail:rastislav.varga@upjs.sk
**** Institute of Neurobiology, Slovak Academy of Sciences, Soltesovej 4, 04001 Kosice, Slovakia

ISSN 1335-3632

The advantage of magnetization process in bistable microwire (single large Barkhausen jump) is that one can use a simple induction method to measure the switching field (see Fig. 3).

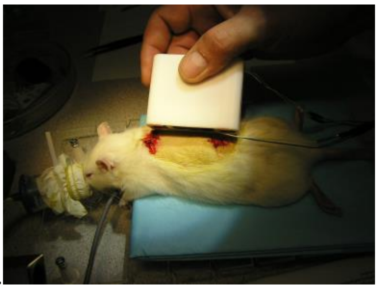

Fig. 2. Single piece of microwires was implanted into subcutaneous tissue at the back of the rat in the inhalatory anaesthesia administered via a special mask

The primary coil is fed by sinusoidal or triangular shape signal in order to produce excitation magnetic field. When the external field exceeds the switching field, domain wall propagates along entire length of the wire and *emf* maximum is induced in the pickup coil. Finally, value of the switching field can be easily estimated from the position of maximum.

A specially designed pick-up system has been developed to monitor the position of the rat. It consists of primary coil with inner diameter 4 cm and length of 20cm. We use a pair of pick-up coils connected anti-series in order to reduce the effect of excitation field. The diameter of the coil is 54 mm and width 5 mm.

3 RESULTS AND DISCUSSION

One month after implantation of the microwire the rat was tested in behavioural laboratory using system described in experimental part. The amplitude of excitation sinusoidal magnetic field was 1000 A/m and its frequency was 400Hz. When the rat entered the pick-up system, sharp maxima appeared on the pick-up coil (see fig. 4). These maxima corresponded to the single Barkhausen jump of closure domain wall in magnetic microwire. The amplitude of the maxima reached up to 3 mV without any amplification and was well distinguished from the background. In bistable microwires, the signal to noise ratio depends mainly on the volume of the wire. The higher is the volume of the wire, the higher is the maximum to background ratio.

From measurement point of view, the amplitude of the peak depends on the position of the rat being highest when the microwire was perfectly centred with respect to the pick-up coil centre. When the rat shifted out of the centre of the pick-up coil, the amplitude of the induced maxima decreased (not shown here).

The advantage of the given system is that it allows us not only to detect the presence of the rat in the pick-up system, but also to distinguish between various rats. It has been shown that there are many parameters that controls the switching field in glass-coated microwires [5].

The switching field is sensitive to the dimensions, ratio between the metallic nucleus and total diameter of the wire, as well as to the chemical composition. Hence, application of different microwires into different rats allows us to recognize the presence of particular rat. In case of many rats, the series of microwires can create a binary code for each rat [6].

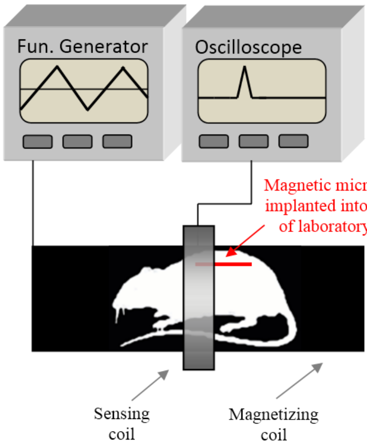

Fig. 3. Schematic drawing of the apparatus for measuring of the switching field in magnetic glass-coated microwire implanted into body of living organism (laboratory rat in our case).

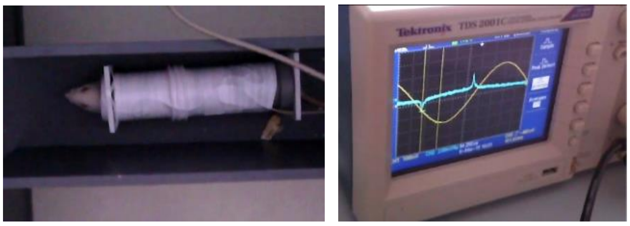

Fig. 4. When the rat enters the pick-up system (left), sharp maxima appear on the pick-up coil (right)

On the other hand, the temperature dependence of the switching field is possible to be applied to sense the temperature of the animal body. Using special chemical composition (FeMoBCu) and thermal treatment, it is possible to obtain the strong dependence of the switching field in the vicinity of 40°C [7].

The size of the wire was so small that it was not visible on the X-ray image of the experimental animal (see Fig. 5). However, all organs of the rat can be perfectly recognized. These points to another advantage of microwires – their application does not deteriorate other frequently used techniques in medicine.

Following passing the designated survival time (30 days) and finishing experimental procedures the experimental animal was euthanized in a deep general anaesthesia induced by isofluranum with oxygen in the plexiglass box and maintained by “Thiopental” (thiopentalum natricum - “Thiopental Valeant” Swiss Pharma Czech Republic s.r.o., Prague) administered in a dose of 0.5 g intraperitoneally by transcardial perfusion with 500 ccm of saline and fixation with the same volume of 4% solution of paraformaldehyde in 0.1 M phosphate buffer. The piece of subcutaneous tissue with the implanted microwire was embedded in wax support and studied under the light microscope. No histopathological changes or tissue reactions were observed (see fig.6). This points up to high biocompatibility of Pyrex-glass coated microwires.

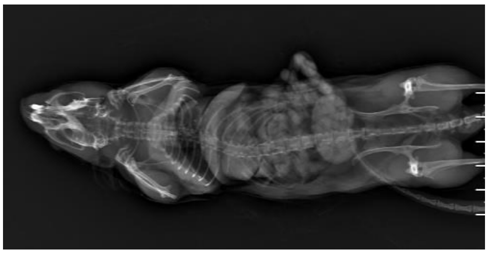

Fig. 5. X-ray image of a rat with implanted microwire. Due to the size of microwire, it is not visible, however all details of rat body are clearly visible.

In order to check possibility of microwires application in medicine, we have also tested the influence of microwires signal on Magnetic Resonance Imaging (MRI) response.

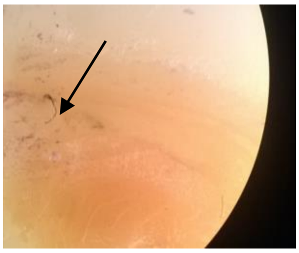

Fig. 6. The lightmicroscopic Image of rat subcutaneous tissue with the embedded microwire (arrow) without histopathological changes

Figure 7 shows two MRI images of human knee with (upper) and without (bottom) microwires placed on the surface of the knee. The position of microwire is shown by the centre of the white circle. It is clear that microwire influence the MRI response in its vicinity within 1 mm. Apart from this zone, the MRI image is not affected by the microwire application. This fact strongly increases the applicability of microwires in bio-applications as MRI is nowadays frequently used method for diagnostics.

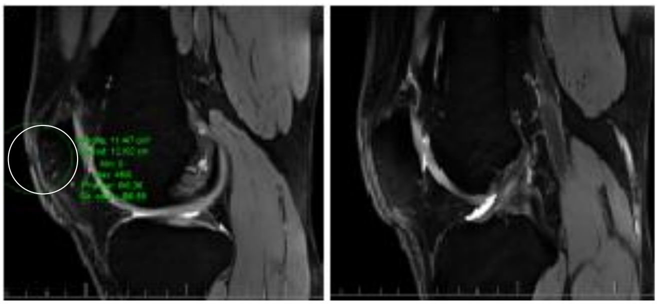

Fig. 7. MRI images of human knee with (up) and without (bottom) microwires placed on the surface skin of the knee shows very little influence of microwire on standard medical procedure ─ microwire is placed in the middle of the shown white circle.

4 CONCLUSIONS

In the presented paper we deal with the possibility of biological application of glass-coated bistable microwires. The microwire was used to monitor contactlessly the position of the rat inside the sensing system. Due to their small dimensions, the microwires can be implanted into the body without influencing classical diagnostic method like X-ray imaging. Pyrex-like glass-coating produced biocompatibility is such that no histological changes appear in the tissue surrounding the microwire. Simple pick-up system gives induced maxima up to 3 mV, well distinguished from the background.

Moreover, we have shown that signal from microwire does not deteriorates the MRI response in the zone 1mm out of the microwire. This proves the possibility for microwires to be used as bio-sensors for monitoring the position of the rat. Employing different microwires (with different switching fields), it is possible to recognize a particular rat from the group. Moreover, employing the microwires sensitive to stress or temperature, this system could allow the estimation of temperature or pressure inside the organs or tissues. In future, we plan to introduce the microwires to Ti implants for human body for sensing the temperature or inflammatory process after implantation [3,7].

Acknowledgements

Authors would like to express their gratitude to prof. M. Vazquez for supplying the microwires. This work was supported by Project NanoCEXmat No. ITMS 26220 120019, Slovak VEGA under Grant 1/0060/13, Grant APVV-0027-11 and APVV-0266-10.

REFERENCES

[1] VAZQUEZ, M.: Handbook of Magnetism and Advanced Magnetic Materials (Wiley, Chichester, U. K., 2007), p. 2193.

[2] PRASLIČKA,D. ─ BLAŽEK, J. ─ ŠMELKO, M. ─ HUDÁK, J. ─ ČVERHA, A. ─ MIKITA, I. ─ VARGA, R. ─ ZHUKOV, A.: Possibilities of Measuring Stress and Health Monitoring in Materials Using Contact-less Sensor Based on Magnetic Microwires, IEEE Trans Magn. 49 (2013), 128

[3] HUDAK, R. ─ VARGA, R. ─ ŽIVČÁK, J. ─ HUDÁK, J. ─ BLAŽEK, J. ─ PRASLIČKA, D.: Aspects of Computational Intelligence: Theory and Applications (Springer, Berlin, 2013), p. 413.

[4] Animal Protection Act of the Slovak Republic No 15/1995, part 39, p. 1250-1255 (In Slovak)

[5] VARGA, R.: Magnetization processes in glass-coated microwires with positive magnetostriction, Acta Phys. Slovaca. 65 (2012), 411.

[6] ZHUKOV, A.: Glass-coated magnetic microwires for technical applications, J. Magn. Magn. Mater. 242-245 (2002), 216.

[7] HUDAK, R. ─ VARGA, R. ─ POLACEK, I. ─ KLEIN, P. ─ SKORVANEK, I. ─ KOMANICKY, V. ─ DEL REAL, R.P. ─ VAZQUEZ, M.: Addition of Molybdenum into amorphous glass coated microwires usable as temperature sensors in biomedical application, Phys. Stat. Sol. A accepted for publication in 2016.

Received 30 November 2015