Electronics for MI Current Sensor

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Abstract-This paper deals with an electronics developed for controlling of contactless current sensor based on magnetoimpedance (MI) effect. The demands required on design of the electronics came from current sensor structure, which takes into account suppression of temperature dependences of impedance of MI material. The electronics, due to its advantageous design, can serve also as the electronics of single and double-cored MI sensors in general.

I. Introduction

Giant magnetoimpedance [1,2], although was firstly observed in the thirties, has been increasingly studied in last two decades. The MI effect is the change observed in the impedance driven by an AC current flowing through a ferromagnetic conductor when an external magnetic field is applied. Large changes in impedance appear for rather low field values, so magnetic sensors based on this effect have very high sensitivity and can be used for many technological applications. Many various configurations have been observed since re-discovery of MI. Although the MI effect was observed in more ‘conventional’ materials like permalloys, the most ‘popular’ MI materials remain amorphous materials of various composition and different configuration. Finally, those materials are usually treated employing the annealing processes to obtain nanocrystalline structures with well-defined magnetic anisotropy. Hence, vast range of mechanical and magnetic agents is usually present during annealing processes. Investigations of the MI properties of those materials depend then on number of conditions eg. frequency, amplitude and shape of driving (excitation) current. For the purpose of development of prototype sensor and investigation of new material, a control device with adjustable parameters of excitation signal is suitable.

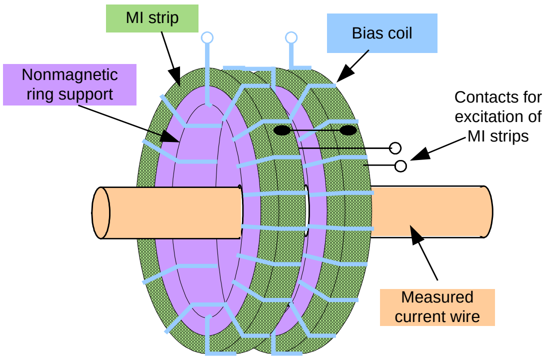

Figure 1. Sensor design

Two Co-rich materials were prepared for MI sensing applications [3, 4]. Firstly, current sensor with one MI strip (single-core) was developed and the results were presented in [5]. Following investigations of the materials showed that temperature dependences of impedance are not negligible. The circumferential permeability takes main responsibility for this behaviour [4]. Therefore temperature dependence was taken into account in the development of double-core sensor. The sensor (see figure 1) consists of two MI strips, wound on two non-magnetic rings, being connected in series and excited by RF current. Two toroidal coils connected in antiseries are wound around the rings to generate two opposite bias magnetic fields of the strips. When measured current flows through a wire, induced circular magnetic field is superposed to the bias fields and so the total magnetisation field of one strip lowers whilst the second one increases. Two voltage drops over the two impedances are detected and than subtracted. The subtraction of the voltages is believed to suppress the temperature influences on MI properties and increase the sensitivity. Also the linearity in open loop probably increases. Similar principle was used for design of magnetic field sensor [6].

II. Electronics of MI current sensor

As the electronics is prepared for utilisation in connection with several types of MI sensors, it was designed as versatile and hence more complicated than dedicated instrument. The whole electronics could be divided into three functional sections: an excitation unit, a biasing unit and a signal conditioning part.

To maintain a portability of electronics within sensor prototypes, the sensors are constructed being connected via three coaxial cables and one shielded cable. One cable serves for excitation of the two strips in series, the two remaining coaxial cables sense the voltage drops over the two MI strips and bring them to the signal conditioning unit. The shielded cable, carrying only DC signals, is linking the antiserially connected bias coils with the bias unit.

A. Excitation unit

Excitation unit is in fact a generator of RF current, which supplies the MI strips (see figure 2). This unit can work in two basic regimes.
The first one is dedicated to the investigations of influence of the excitation parameters. In this case, the parameters of driving current are adjusted by means of external laboratory generator, which is connected via coaxial cable to the board. The output signal of the external generator is firstly boosted to assure the amplitude stability and then is led directly to the sensor (to MI strips), see figure 2.
The second regime works with fixed parameters of excitation current of 1 MHz/10 mA and squarewave shape. It is aimed for reaching of comparable results within different samples and also for measurements with absence of external generator. An on board generator comprises the quartz oscillator from which the frequency of driving current is derived by dividing in Altera CMOS programmable logic device (CPLD). Altera outputs control HEXFET power MOSFET switches connected in bridge of which diagonal is leading to the MI strips. The magnitude stability of squarewave current is assured by voltage references in the MOSFET bridge circuitry.

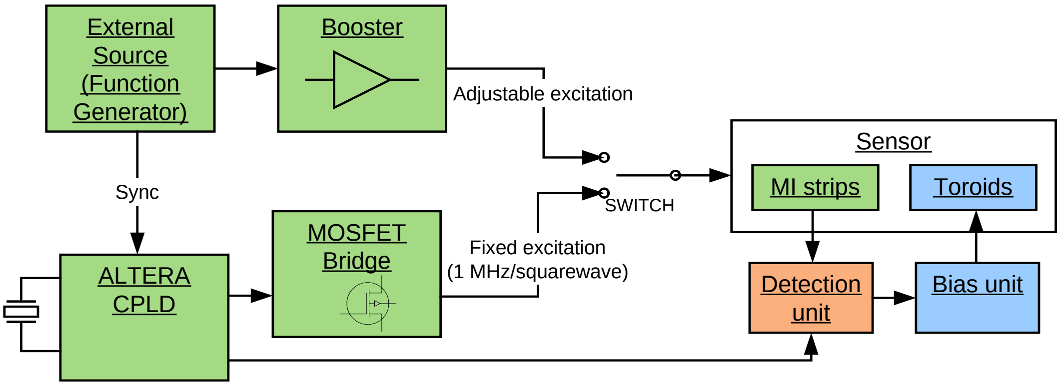

Figure 2. Block diagram of the excitation unit

B. Signal conditioning unit

Second part of the electronics, the signal conditioning unit, comprises four main blocks (figure 3). The first, the sensing part, consists of two high-speed differential amplifiers, which detect voltage drops along MI strips. In the next block, these voltages are subtracted by the other differential amplifier. AC voltage, with amplitude corresponding to the difference of the impedances and thus to the measured current, is then synchronously demodulated in the third block by switching type detector comprising high-speed 4:1 multiplexer of which first two inputs are active and the other two are grounded. The control signals of the demodulator are generated in CPLD circuit linked to its clock signal, even in case of external generator regime. In this case, the Sync output of the generator serves as the clock signal. Several demodulation techniques comprising insertion of grounding to the demodulated signal when transients might occur can be performed in connection with the CPLD mainly due to availability of insystem programming (ISP) of the CPLD. The figure 5 shows dependences of complex components of impedance *Z* on external magnetic field *H*. These results were obtained on an amorphous specimen with induced axial anisotropy. The one-peak shape of $|Z|(H)$ curve is more suitable for sensing application purpose and is typical for MI amorphous materials with this kind of anisotropy. It can be seen from the graphs, the real component of impedance *Re Z* takes major part in impedance change whereas the imaginary part *Im Z* in addition to its lower changes observes also double peak shape. Therefore the phase of the synchronous demodulation is set to zero, but can be easily re-programmed in the CPLD if needed. The demodulated signal is then passing through the last stage of the signal conditioning unit, the 5th order lowpass filter. The output voltage of the unit, which corresponds to the measured current, can be connected to the bias unit to use sensor in closed loop regulation setup.

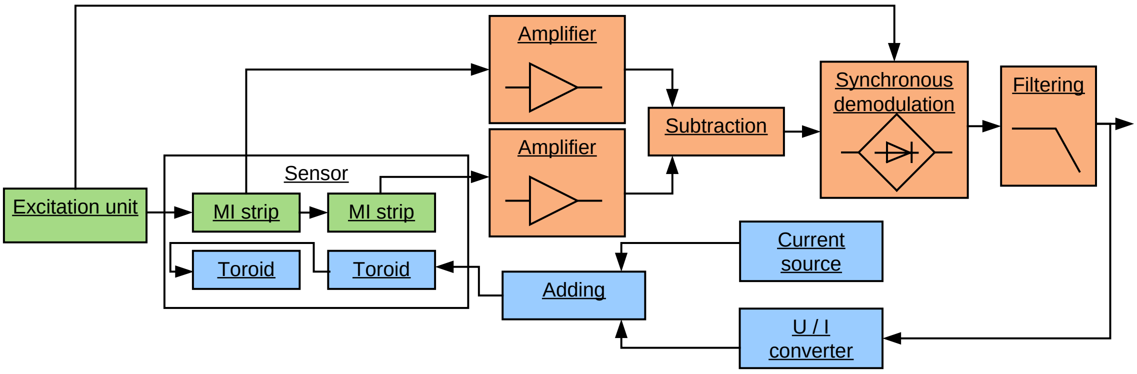

Figure 3. Block diagram of the bias unit and signal conditioning unit

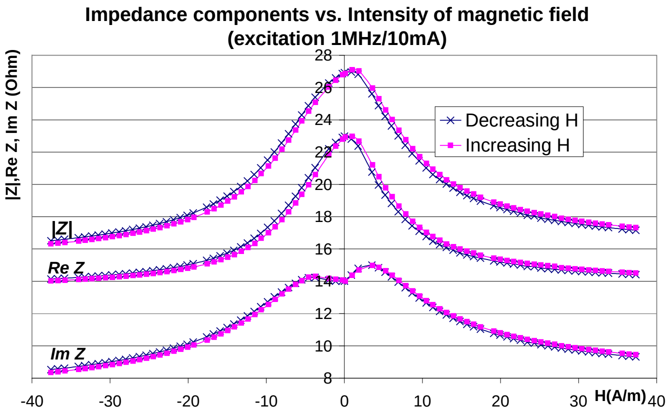

Figure 4. MI curves of amorphous material

C. Bias unit

Bias unit, the last block of the electronics, is in fact a simple temperature stable power source that supplies the antiserially connected toroidal coils by DC current and so induces two opposite bias fields in the strips. From the figure 4 one can recognise, with the bias fields the working points on the MI curves are shifted to their lateral parts and thus have bipolar response to external magnetic field. Without biasing no bipolar response is possible due to zero field symmetry of the MI characteristics.

The stability of bias current is the most important parameter here and is assured by embedding of band-gap voltage reference to the circuitry. The amplitude of the bias current is adjustable by external resistors and is set accordingly the parameters of bias coil of certain prototype. There is also a possibility of generation of low-frequency (up to 500Hz) bias current [7] what should suppress offset of the sensor but also lowers the frequency range of the sensor. This feature is performed by insertion of precision quad SPST CMOS analogue switches, controlled by CPLD signals, into the bias current path. Due to direct responsibility of magnitude of the bias field for the position of the working point of the sensor, the driving of the working point can serve also as an actuator in feedback connection of the sensor. This is achieved by conversion of the output voltage to the current, which is then superposed to the constant level bias current. So that the bias current varying in accordance with the output voltage behaving as decreasing of bias field when induced external magnetic field of measured current increases and vice versa. Hence, the sum of all magnetic fields acting to each MI strip remains constant.

III. Versatility of the electronics

The developed electronics has many different kinds of utilisation, although it was proposed for current sensors, the principle of operation is the same for MI field sensors [7].

The sensors can be connected either in closed or in open loop, even in case of non-biased sensors the whole bias unit can be disconnected. This feature is also suitable for testing of single MI specimens. The electronics can be also used for testing of single-core sensor applications, in that case the inputs of the second differential amplifier are grounded and the output voltage behaves in similar way as with double-cored assembly, only the difference is in output offset of the signal, thus it is not suitable for closed loop connection. When closed loop is required a dummy resistor must be connected in series with MI strip of the sensor. Value of such resistor should be equal to the real part of the impedance of the MI strip under the bias field.

Although the mainstream in industry is focused on miniaturisation of the sensors as well as the electronics, this device is proposed for laboratory use therefore the design was performed on PCB.

There are no demands on versatility in real industrial applications, therefore the design of the electronics becomes much easier for certain application but still the frame will be similar to proposed device. This device works in frequencies up to 50 MHz limited mainly by its PCB performance.

IV. Conclusions

The electronics, suitable for investigations and laboratory testings of newly designed current sensors, was developed. The electronics, with ability of external generator control, can connect the sensor either in open loop or in closed loop. Additionally, the AC biasing is implemented and could be used for improvement of some parameters of the sensor.

The developed electronics is in manufacturing and the first results will be presented on the conference.

Acknowledgment

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References

[1] M. Knobel, M. Vazquez, L. Kraus, *Giant Magnetoimpedance in Handbook of Magnetic Materials,* Vol. 15, Ed. K.H.J. Buschow, NORTH-HOLLAND 2003, pp. 497-563

[2] P. Ripka (ed), *Magnetic Sensors and Magnetometers*, Artech House Publ. 2001, ISBN 1580530575

[3] L. Kraus, M. Malátek, K. Postava, D. Janičkovič: "*Asymmetric giant magnetoimpedance in stress-field annealed CoFeBSi amorphous ribbons*" Accepted for JEMS 2004, Dresden

[4] M. Malátek, L. Kraus, P. Ripka : *Temperature Drift of Offset of MI Sensors:* Accepted for EMSA 2004, Cardiff

[5] M. Malátek, A. Platil and P. Ripka: "GMI Current Sensor" *In: Eurosensors XVII. Guimaraes*: University of Minho, 2003, pp. 418-419. ISBN 972-98603-1-9

[6] P. Ripka, A. Platil, P. Kašpar, A. Tipek, M. Malátek, L. Kraus: *Permalloy GMI Sensor*. In: Journal of Magnetism and Magnetic Materials. 2003, no. 254-255, p. 633-635

[7] A. Platil, M. Malátek, P. Ripka, L. Kraus: "GMI Sensor". *In: Eurosensors XVI. Prague*, 2002, vol. 1-3, pp. 341-342. ISBN 80-01-02576-4