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Novel Magnetic Field Meter Based on Giant Magneto-impedance (GMI) Effect

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Abstract

A novel magnetic field GMI-sensor/meter has been invented and designed. Its laboratory model was constructed and tested, demonstrating the sensitivity of 1×10^{-8} T (100 μGs). The principle of operation of this meter is based on changes of the quality factor of the resonance circuit a part of which is a magnetic GMI sensing element. These changes are due to variations in the real component of the impedance of this element caused by an external DC-field. The sensing element is in the form of a piece of the "non-magnetostrictive" amorphous ribbon. Magnetic field modulation of an acoustic frequency and feedback circuit (compensating field) applied to the device, significantly increases stability and linearity of the measuring system.

Key words: magnetic field sensor, giant magneto-impedance, metallic glass

1. Introduction

The occurrence of giant magneto-impedance (GMI) effect was first reported by Mohri at the RQ-8 Conference in 1993 (published in 1994 [1]), though in fact this phenomenon was observed for the first time long ago (in the 1930s, see Ref. [2]), but then it did not attract a great notice. The renewed invention of the GMI-effect created a great interest considering both, basic research and applications. The physical background of this effect is now well recognized (see e.g. Ref. [3]). In respect of its application, the GMI-effect is widely utilized in numerous sensitive sensors of the strength of magnetic field, stress or torsion (see e.g. Ref. 4]). Amorphous ribbons, micro-wires, films as well as multilayered structures of different electrically conductive magnetic materials are used as the active element in these sensors. Most technological applications are related to micro-sensors, the principle of operation of which is based on the static field dependence of the magneto-impedance. Nevertheless, a given sensor is provided with an electronic circuit, which operates in a various manner depending on a specific solution. For example, in a certain number of sensors the active magnetic element is a part of the oscillation circuit (see e.g. [5]), the frequency of which changes under the influence of the external static magnetic field due to the alterations of the magneto-impedance of this element (it should be notice that the principle of the above cited sensor, being undoubtedly grounded on the GMI-effect, was introduced long time before this phenomenon was once more identified).

The purpose of the present work was to design and construct a laboratory model of the sensitive magnetic field meter based on changes of the quality factor of an oscillation circuit containing a magnetic field sensitive element. These changes are due to alterations of the impedance of this element (in fact its real component) generated by an external static field.

The main purpose of the work was to show rather a proof of the correctness of the proposed novel idea of the principle of operation of the presented sensor than a complete design of such a device. Therefore, the sensor shown here is in the form of a laboratory model, however, the device in its final construction can be manufactured in microminiaturized and semi-integrated form.

2. Principle of Operation and Characteristics of Magnetic Field Meter

A piece (25 mm long and 25 µm thick) of "non-magnetostrictive" amorphous ribbon of its nominal composition $Co_{67}Fe_4Mo_{1.5}Si_{16.5}B_{11}$ (Vitrovac®6025) was used as the active magnetic element in the designed magnetic field meter. The meter operates exploiting the steepest parts of the dependence of the real component of the impedance, which occur in the vicinity of zero external DC-field between two maxima (see Fig.1 which shows this active part of the characteristic measured for the as-quenched ribbon in the presence of the RF- current of 30 MHz flowing along the specimen). Schematic diagram

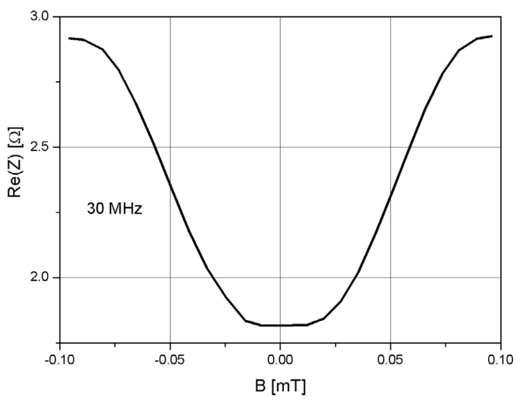

Fig.1. A part of the field dependence of real component of impedance of the as-quenched sample measured at the frequency of 30 MHz.

of this meter is shown in Fig.2, whereas, Fig.3 presents a detailed scheme of electronic circuit of the laboratory model of the system. The heart of the meter is a free-running oscillator working at RF-frequency of 30 MHz. A piece of the amorphous ribbon is incorporated into a tank circuit of the oscillator (connected in series with the resonant inductance, L_r, of this circuit). Change of the real (in-phase) part of the impedance, Re[Z] = f(H), of this element, in consequence of the alteration of an external axial magnetic DC-field (see Fig.1), influences the quality factor of the tank circuit and hence the amplitude of oscillation. Variations of the frequency due to changes of the reactance component are insignificant for the operation of the meter since it is not sensitive to these changes. In fact, the inductance of the sensing element is much smaller than L_r, and the frequency variations are smaller than 0.3 %.

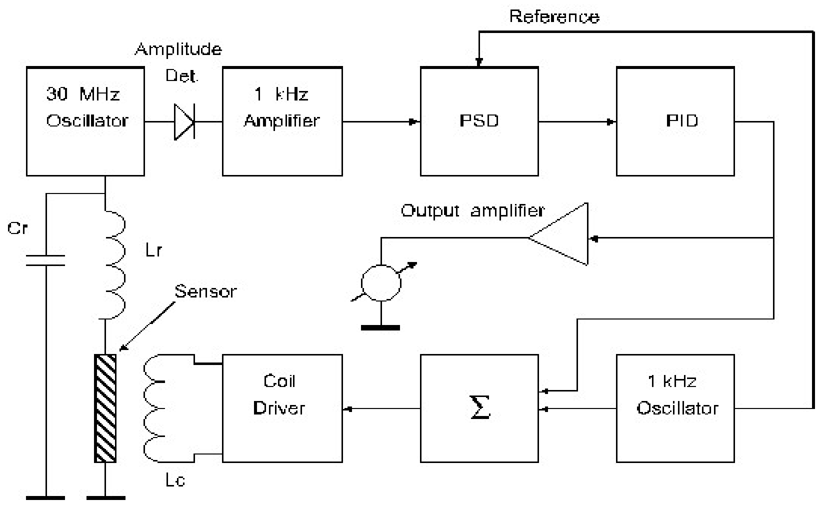

Fig.2. Block diagram of designed and constructed laboratory model of magnetic field meter.

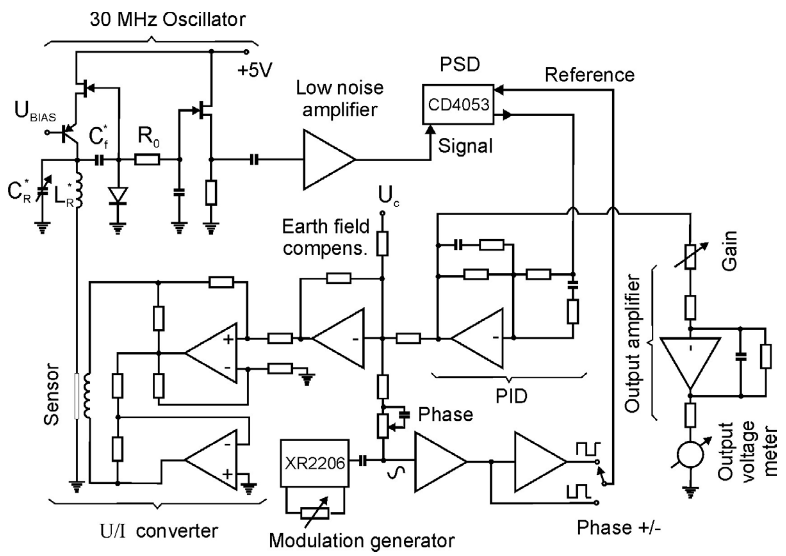

Fig.3. Detailed scheme of electronic circuitry of laboratory model of magnetic field meter.

The signal proportional to the amplitude of the RF-oscillations is present at the output of the first detector. Sinusoidal magnetic field modulation of an acoustic frequency f_m (1 kHz in the presented version) imposed on the external DC-magnetic field produces corresponding sinusoidal variation of the output. The phase of this signal depends on the current slope of the RF-oscillation amplitude dependence on magnetic field. Hence, the error signal of the corresponding sign is present at the output of the phase sensitive detector (PSD). The signal is conditioned and feed back to the coil surrounding the sensor. Since the f_m- component at the input of PSD vanishes at zero average magnetic field at the sensor, the feedback circuit compensates the external magnetic field at the sensor feeding current to the feedback coil. Thus, the value of this current is proportional to the external magnetic field. The same coil is used for magnetic modulation.

For the laboratory model under test the amplitude of about 30% of the DC-field at which the maxima in the real component occur has been established as those providing favorable working conditions. However, the magnitude of this amplitude is not critical.

The meter has its basic range of 1 mT (10 Gs) and the two sub-ranges of 100 μT (1 Gs) and 10 μT (0.1 Gs). The characteristic of the meter measured in its 10 μT sub-range is shown in Fig.4.

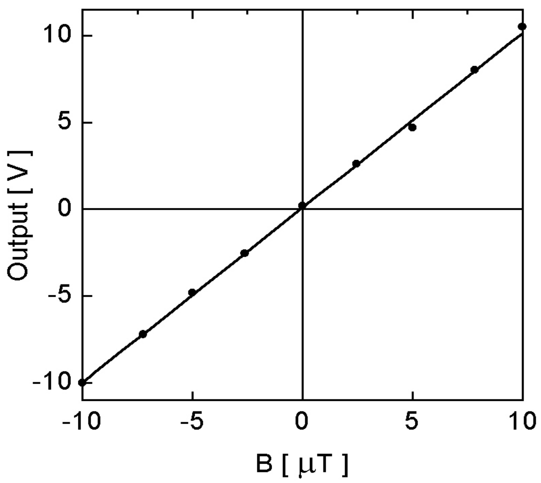

Fig.4. Characteristic of the meter in its 10 μT sub-range.

The sensitivity of the laboratory model utilizing 25 mm long piece of the as-quenched ribbon (1.0 mm wide), mainly limited by the output noise, reaches $3{\cdot}10^{-8}$ T (300 μGs). However, if a narrower (0.5 mm) piece of the same length of the ribbon annealed at 225°C for 1 hour was replaced as a sensing element, the sensitivity of the meter became threefold better, achieving 1×10^{-8} T (100 μGs). The replaced sensing element exhibited similar characteristic as that presented in Fig.1, demonstrating only more steep slopes of the inner parts of its characteristic.

The choice of the minimum of the field dependence of the real component of the impedance (see Fig.1) as a working point of the meter and the use of the feedback circuit ensure high linearity and also reduction of the temperature drift and $1/f$ noise.

The designed meter may find various applications, for example can serve for industrial measurements and automation, in electric and electronic power industry, in security devices, and in biological research. Since the sensitivity of the described laboratory model is good enough for the use as a sensor applicable in a traffic detector/classifier systems [6], detecting the disturbances in the earth magnetic field produced by the overrunning cars. Therefore, the laboratory model of the meter operates at 12 V DC-power supply (average power consumption equals around 2W - 90% of this power is consumed by the feedback coil), thus, allowing the device to be powered from the car-battery.

Additionally, the described magnetic field meter can be adapted for a contact-less measurement of the intensity of a DC-current. Then, the sensing piece of ribbon should be coiled to form a ring inside which a DC-current conductor is placed along the ring axis.

3. Conclusions

A novel magnetic field GMI-sensor/meter has been designed. Its laboratory model was constructed and tested. The principle of operation of this meter is based on changes of the quality factor of the resonance circuit due to changes of the real component of the impedance of the sensing element caused by an external DC-field. This element is in a form of a piece of the "non-magnetostrictive" amorphous ribbon. A steep part of the field dependence of this component, existing between its two maxima, is exploited in the designed meter. Magnetic field modulation of an acoustic frequency and feedback circuit (compensating field) significantly increases stability and linearity of the measuring system. The sensitivity and noise floor of the model may significantly be increased by careful choice of the sensing element and working conditions along with the optimized electronics.

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