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A Novel Temperature Compensated Magnetic Field Sensor Based on the Magnetoelectric Effect

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Summary:
This contribution presents a novel approach for a temperature compensated DC magnetic field sensor, based on the magnetoelectric effect. In utilizing two vibration modes of a rectangular cuboid magnetoelectric sample, we can determine the samples' temperature in addition to the magnetic flux density the sample is exposed to.

Keywords: Magnetoelectric, resonant magnetic field sensor, temperature compensation, delta-E effect, electromechanical vibration modes

Introduction

Magnetic field sensors, based on the magnetoelectric (ME) effect, are considered to become promising alternatives for conventional magnetic field sensors such as Hall probes and giant magnetoresistive devices [1]. Due to the direct ME effect, i.e., an electric polarization caused by a magnetic field, each ME device is in general capable of sensing magnetic fields [2]. However, only composite-based devices (mechanically coupled magnetostrictive and piezoelectric layers) are useful in practice, since they exhibit a significantly larger ME effect compared to single-phase materials [3]. These composite-based devices have made great progress in the detection of AC magnetic fields in recent years, but the detection of DC fields remains challenging [4,5]. Detecting low-frequency and DC magnetic fields in ME resonators is usually performed by evaluating the sensitivity of the Young's modulus to magnetic fields (delta-E effect) [6]. Our novel approach, utilizing the delta-E effect as well, is capable of sensing the ambient temperature in addition to the detection of DC magnetic fields. This enables a direct temperature compensation.

The resonance frequency of a resonator is determined by its geometry and material properties (such as Young's modulus and density) [7]. When a magnetostrictive material is exposed to an external magnetic field, its magnetic domains will align along the magnetic field, causing mechanical strain and a change in the Young's modulus of the material (delta-E effect) [1,2,6]. Thus, an external magnetic field causes a shift in the resonance frequency of a magnetoelectric device. Our novel approach

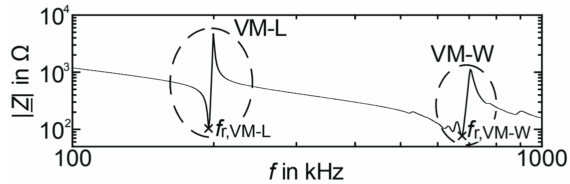

Fig. 1. Measured electric impedance spectrum $|\underline{Z}|$ of a magnetoelectric composite sample. The vibration modes in length (VM-L) and width (VM-W) direction are indicated by dashed ellipses. Their corresponding resonance frequencies ($f_{r,VM-L}$, $f_{r,VM-W}$) are marked by a cross (X).

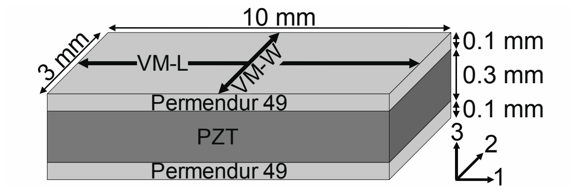

Fig. 2. Basic structure of the magnetoelectric composite samples.

utilizes two vibration modes (VM) instead of one only: (i) The VM along the length (VM-L, about 200 kHz in Fig. 1) and (ii) the VM along the width (VM-W, about 700 kHz in Fig. 1). Therefore, our sensor geometry features a rectangular cuboid shape (see Fig. 2).

Sample Preparation

The basic structure of the proposed sensor consists of three layers (cf. Fig. 2). A piezoelectric plate (PZT – PI Ceramic PIC 255, poled in 3-direction) is mechanically coupled with two magnetostrictive foils (Permendur 49). The mechanical coupling is realized by an adhesive. Two different types of adhesives were examined: We used cyanoacrylate for sample 1 and a 2-component epoxy adhesive for sample 2. A small area in the center of the contact surface is not covered with adhesive,

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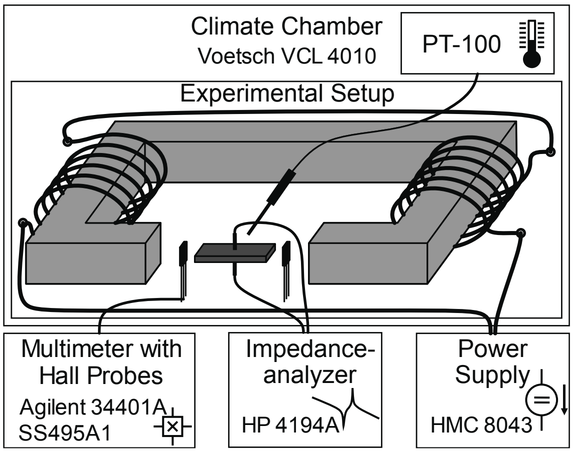

Fig. 3. Measurement setup.

but rather with silver conductive paint. This is to ensure electric conductivity between the magnetostrictive layer and the electrodes of the piezoelectric layer.

Measurement Setup

The measurement setup of Fig. 3 allowed for an evaluation of the shift in the frequencies f_r under variation of the ambient temperature and the DC magnetic flux density. The resonance frequencies ($f_{r,VM\text{-}L}$ and $f_{r,VM\text{-}W}$, respectively) of the two vibration modes (VM-L and VM-W) are determined by the measured electric impedance spectra (cf. Fig. 1). The experimental setup is placed in a climate chamber, where the ambient temperature is monitored by a PT-100 sensor placed near the sample and is stepwise increased by 5 °C from -20 °C to +25 °C. At each temperature step, the homogeneous DC magnetic flux density in the air gap of a ferrite core is reduced from +60 mT to -60 mT in 5 mT steps, while the electric impedance spectrum is measured for each set flux density. The magnetic flux density, to which the sample is exposed to, is measured by two Hall probes.

Results

The measurement results in Fig. 4 depict the sensitivities of the resonance frequencies f_r for each VM and its corresponding sample as a function of the magnetic flux density B and temperature T. Both VM show a clear decrease of the resonance frequency with an increasing temperature (Fig. 4 a-d). While the resonance frequency of VM-L is sensitive (up to 22.5 Hz/mT, Fig. 4 a, c) to the magnetic field, VM-W is almost independent from the magnetic field compared to the temperature (Fig. 4 b, d). Therefore, by utilizing $f_{r,VM\text{-}W}$, the sample's temperature can be determined by VM-W. This provides us with sufficient information on the temperature that allows us to derive the magnetic flux density from the resonance frequency of VM-L ($f_{r,VM\text{-}L}$).

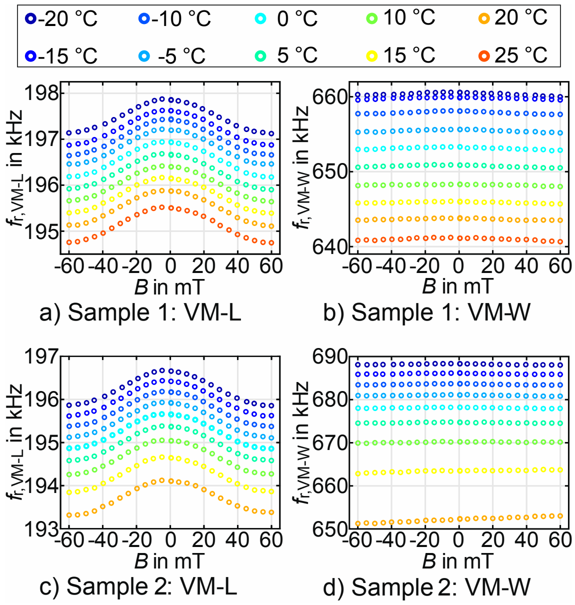

Fig. 4. Measured relationship between the resonance frequency f_r of VM-L or VM-W and the magnetic flux density B under variation of the ambient temperature T. The measurements were performed with two different samples.

Conclusion and Outlook

In this contribution we presented a novel approach for an electromagnetic sensor, which allows to measure both the magnetic field and the ambient temperature by utilizing different vibration modes. Further investigations on AC magnetic fields and sputtered layers are intended.

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