DOI 10.5162/SMSI2023/C5.2

Flexible Magnetic Sensors Enabling Novel Measuring Capabilities

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Summary:
Since several years, magnetic sensor elements are available in fully flexible architectures that often reveal identical sensing properties, compared to their rigid counterparts, while being bent severely and repeatedly. Nowadays, a variety of magnetic senor principles, including well known Hall, AMR and GMR but also more exotic PHE and AHE sensors were demonstrated on such flexible platforms. The novel properties of being thin, lightweight, shapeable, and wearable enable magnetic sensory systems to be utilized in vicinities and conditions that are inaccessible for rigid and microchip-based sensors.

Keywords: flexible electronics, flexible sensors, magnetic sensors, novel applications, in-situ sensing

Introduction

The ongoing technological development of flexible electronics is motivated by the eagerness of multifunctional electronic systems towards being thin, lightweight, compliant, wearable or even implantable and transient. This requires all components of circuitry, including passive, active and responsive (sensor) elements being reshapeable on demand after fabrication and assembly. Ideally, they fully maintain their electronic properties and mechanical integrity while being severely and repeatedly distorted. Such flexible electronic designs pave the way to novel application fields like, foldable and wearable electronics, smart textiles, soft robotics, electronic skins, as well as domestic healthcare devices and functional medical implants.

Especially for sensor devices, thin and flexible architectures allow utilizing sensing elements in narrow, non-planar or soft and volatile environments that are otherwise not accessible.

Flexible magnetic sensors

Also magnetic sensors underwent the transition from rigid and microchip-based to fully flexible and other shapeable designs.[1] This is particularly mediated by the fact, that many physical effects that are exploited in magnetic sensing are occurring in layered thin film structures, that can be arranged on flat polymeric supports in order to obtain flexible devices. The main technological obstacles in this process, which are surface roughness, temperature restrictions and limited miniaturization, are tackled by means of adapted preparation procedures.[1]

Besides Hall [2], magnetoresistance (MR) [3], giant magnetoresistance (GMR) [4,5] and tunnel magnetoresistance (TMR) [6], also more exotic magnetic sensing principles, *i.e.* planar Hall effect (PHE) [7] and anomalous Hall effect (AHE) [8], have been realized on flexible platforms, recently. Hence, a variety of flexible magnetic sensor elements, covering different target field ranges, sensitivities, sensible field components and environmental working conditions, is available nowadays.

For magnetic sensing, the added value aspect of being integratable into narrow constrictions or operating in close proximity to an arbitrarily shaped surface is particularly beneficial, since the detectable magnetic field strength is rapidly decreasing with the distance from the source to be detected.

Novel measuring capabilities

A selection of application scenarios, where the compliant mechanical properties induce specific advantages for magnetic sensing are given in Fig. 1.

Magnetic particles are widely used for diagnostic or therapeutic purposes in biology and medicine by means of fluidic systems. For the detection of these particles, which are often used to label specific biological objects having target properties, flowing through a fluidic channel, flexible magnetic sensors offer an elegant approach to enhance their sensing capabilities. As depicted in Fig. 1a, a flexible sensing element can surround the entire channel cross-section.[9] In comparison to a planar sensor, that is limited to one single face of the channel, this circumferential arrangement makes the detection of the magnetic entities less susceptible to the specific transit position inside the channel. Furthermore, magnetic sensors are often sensitive to only a single magnetic field component with respect to their orientation, which requires the magnetic objects to be aligned to the sensor upon detection. A circumferential sensor, however, gives rise to a unique isotropic sensitivity [9], omitting the need for particle alignment.

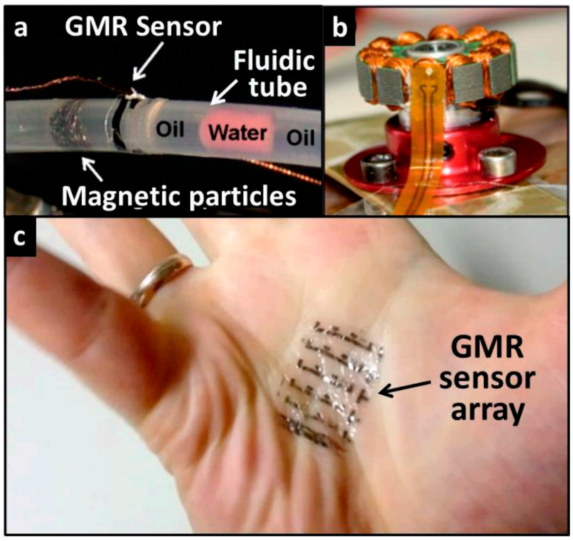

Fig. 1. Selection of novel measurement capabilities utilizing flexible magnetic sensors. (a) circumferential magnetic sensing in fluidics [9]; (b) direct flux density measurement in the air gap of electrical machines and drives [10]; (c) on-skin magnetoception [4].

Due to their thin architecture, flexible magnetic sensors can also be integrated into the narrow and curved air gaps of electrical machines and drives, *i.e.* between rotor and stator, where conventional sensors simply do not fit (see Fig. 1b). This allows measuring the strong magnetic fields directly at the position where they act to drive the machine. In particular for active magnetic bearings, this allows for direct flux-based control [10], offering more stiffness, precision and resilience in operation.

Flexible magnetic sensors can also be operated directly on the human skin.[2] Especially ultra-thin designs of only few µm total thickness are able to intimately conform to the epidermis (see Fig. 1c) and simultaneously follow their natural deformations and distortions without performance degradation. The highly compliant magnetic sensor foil is haptically not perceived by the recipient if worn on skin. This artificial magnetoception [4] gives rise to novel capabilities for touchless human-machine interaction.

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