A Review of MEMS-Based Magnetic Sensors

By
Alan Anderson
Infotek International, Inc.
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Abstract

This whitepaper reviews current micro-electrical and mechanical systems (MEMS) based magnetic sensors. The intent is to determine possible future directions for the commercial development of these sensors in magnetic flux leakage testing devices.

Disclaimer:

A REVIEW OF MEMS-BASED MAGNETIC SENSORS

INTRODUCTION

A comprehensive review of magnetic sensor technologies was done in 1990[1]. Unfortunately, micro-electrical and mechanical systems (MEMS) based designs were not included because the MEMS revolution was just beginning. Significant research has been done on MEMS-based magnetic sensors[2,3,4,5]. Three research groups have developed magnetic sensors using MEMS technology; specifically, J.W. Judy et. al. at University of California, M.G. Allen et. al. at Georgia Institute of Technology, and C. Shafai at University of Manitoba.

Judy gives an excellent description of MEMS technology and the techniques for fabrication, detection, and analysis[6]. In general, MEMS devices are miniaturized mechanical systems produced using fabrication techniques borrowed from the electronics industry. The mechanical systems cause slight electrical disturbances measured as changes to oscillating electrical signals or as Lorentz interactions. The commercial impact of MEMS devices is expected to be significant[7]. The devices are generally micrometers in size; however, accompanying electronics and packaging increase the overall size.

MAGNETIC SENSORS

SHAFAI ET. AL.

Figure 1 shows a schematic of a MEMS-based magnetic sensor developed at University of Manitoba[4]. The principal is that the Lorentz force caused by the magnetic field causes a change in the resonant frequency of the comb structures by applying a force to the crossbeam. This change in frequency is linearly related to the magnetic field. The sensitivity and range of detectable fields is controlled by the physical design of the structure.

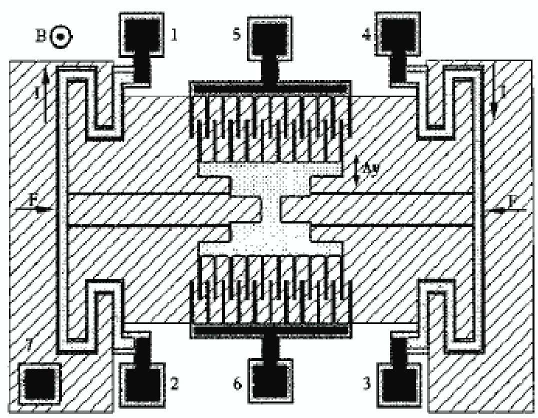

Figure 1. Schematic of a MEMS-based magnetic sensor (after Figure 2 in reference 4).

The authors report that a minimum detectable field strength of 0.5 mT is easily achievable, and they suggest better electronics will produce significantly better resolution[8]. However, they do not indicate what voltages are required or report any power consumption for the device.

Applications for this particular design are not identified; however, the authors say that the design is adjustable and can be optimized for specific applications[9].

ALLEN ET. AL.

Scientists at the Georgia Institute of Technology have developed a "magnetically excited and sensed mems-based resonant compass[2,3]." A permanent magnet is affixed to a resonant MEMS structure, and as the magnetic field changes with rotation of the device, the resonant frequency of the device changes. This relationship allows the measurement of a magnetic field, specifically the Earth's magnetic field in their work, by simply measuring the change in resonant frequency.

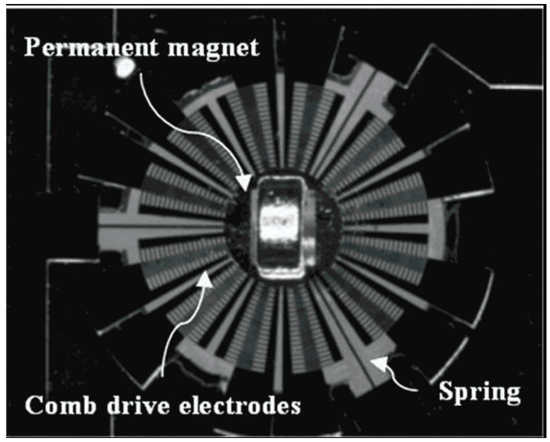

Figure 2. Fabricated device with permanent magnet affixed (after Figure 4b from Reference 3).

Figure 2 shows the resonant MEMS structure with the permanent magnet already affixed. The comb drive electrodes are driven with an oscillating voltage and the combs attached to the permanent magnet cause the resonant frequency to change by inducing interactions between the comb teeth. The authors conclude that for a 10 V operating voltage, power consumption is 20 nW, and the direction of the magnetic field can be detected for fields as low as 0.3 mT.

This device is specifically intended for use as a compass, and the low-power, low-voltage needs allow it to be used in everyday applications, e.g. wristwatch, cell phone, PDA, etc. It is the application of the permanent magnet that allows the device to be used in this manner.

EYRE ET. AL.

In 1998, a resonant microcoil design was suggested by scientists at University of California[10]. The microcoil design is produced in standard CMOS by creating a floating plate of SiO2 attached to the substrate by "L" shaped beams. A metallic coil is placed on top to produce an interaction with the magnetic field via Lorentz force. One side of the floating plate is connected with piezoresistors arranged in a Wheatstone bridge When an alternating current is applied to the coil, the magnetic field induces a force that produces a strain in the piezoresistors thereby producing a voltage.

Figure 3 shows a schematic of the resonant microcoil design. The authors applied a 1 V bridge excitation and a 10 mA (peak to peak) alternating current in the microcoil to produce a sensitivity of 250 uG per root Hertz. The frequency of the AC current was set to the resonant frequency of the plate-beams system.

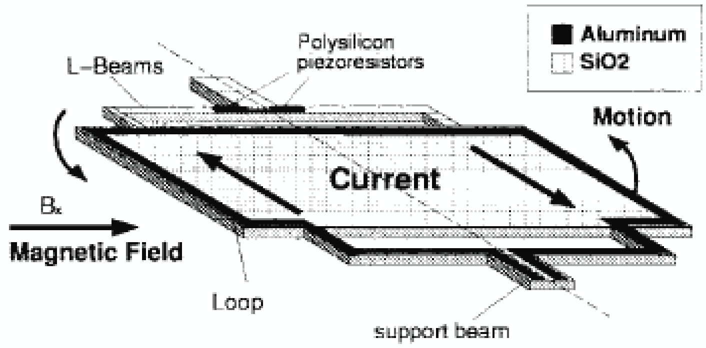

Figure 3. Schematic of a resonant microcoil sensor design (after Figure 2 of Reference 10).

SCHWINDT ET. AL.

A completely different approach developed by scientists at NIST measures spin precession frequency of alkali atoms because it has a direct relationship to the absolute magnetic flux density[11]. Their approach is to miniaturize an optical magnetometer. Figure 4 shows a schematic of their system along with a photograph of the actual device. The components are: (1) vertical-cavity surface-emitting laser (VCSEL); (2) optics package including (from bottom to top) a glass spacer, a neutral-density filter, a refractive microlens surrounded by an SU-8 spacer, a quartz l/4 waveplate, and a neutral-density filter; (3) 87Rb vapor cell with transparent ITO heaters above and below it; and (4) photodiode assembly.

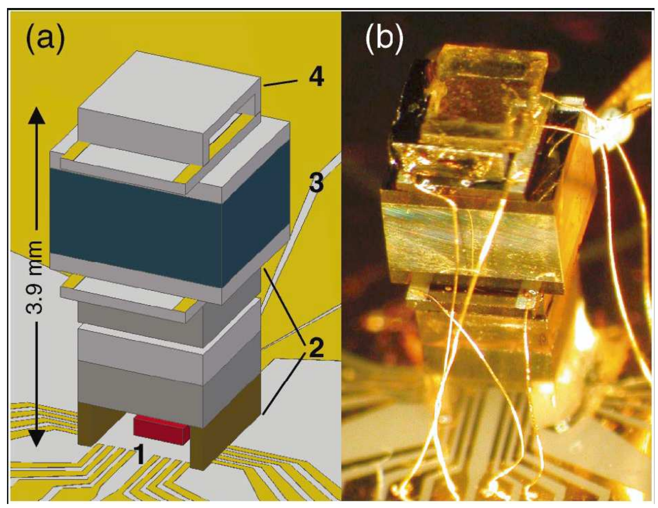

Figure 4. Schematic and photograph of miniaturized optical magnetometer (after Figure 2 of Reference).

The authors claim a 50 pT per Hertz sensitivity while requiring 195 mW of power for this first generation device.

CONCLUSION

The future of magnetic sensors is changing quickly. MEMS-based devices will provide small, customized magnetic sensors for use in a multitude of applications.

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