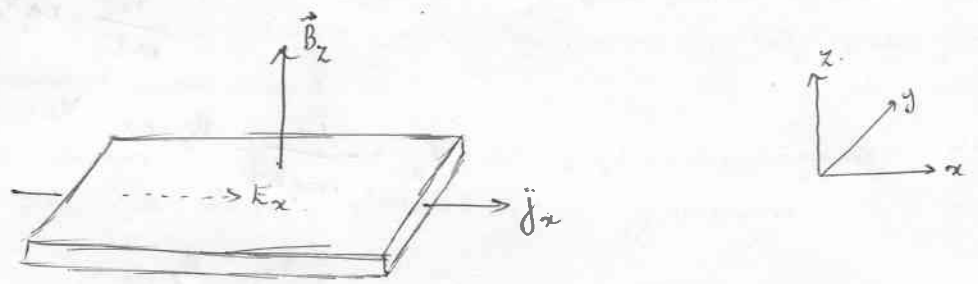
Magnetic Sensing:

Lecture Notes!   Date: 20/01/2015.   jb.

- Though less often used, magnetic sensing is a non-contact sensing mechanism with a fairly long-range.
- Most MEMS magnetic sensors are based on the Hall effect.
- Other applications include the giant magnetoresistance effect used inside the hard-disk head.

MEMS magnetic sensors:

They rely on the production of a transverse voltage across a current carrying material when a magnetic field is applied perpendicular to the direction of flow of current.



Suppose, we apply electric field E_x in the x-direction, then by Ohm's law, the current density j_x is,

$j_x = \sigma E_x$, where σ is the conductivity of the material

Now what happens, if this material is placed in a perpendicular magnetic field B_z applied in the z-direction. (out-of plane-field).

The charge carrier's experience Lorentz force given by

$$F_{lor} = q(\vec{v} \times \vec{B})$$

This force will deflect the +ve charge to -y-axis and hence an electric field E_y is build up along the y-axis. The force due to the electric field will be

$$F_e = qE_y$$

At equilibrium, $F_{el} = F_{lor}$

$$qE_y = q(\vec{v} \times \vec{B})$$

$$E_y = \vec{v} \times \vec{B}$$

$$E_y = v_x B_z$$

where E_y is the Hall-field ~~and is given by $\frac{V_H}{d}$~~

Now from the field, the Hall-voltage can be determined as

$$V_H = -\int_0^w E_y \, dy$$

$$= -E_y \cdot w$$

$$V_H = -E_y \cdot w$$

$$= -V_x \cdot B_z \cdot w$$

Now from Drude's theory $j_x = nqV_x$, $j_x = \frac{I_x}{A} = \frac{I_x}{w \cdot t}$

$$\frac{I_x}{w \cdot t} = nqV_x$$

$$V_H = -\frac{I_x}{nqwt} \cdot B_z \cdot w \qquad V_x = \frac{I_x}{nq\,wt}$$

$$= \frac{-I_x}{n \cdot q \cdot t} \cdot B_z$$

$$V_H = -\left(\frac{1}{nq}\right) \frac{I_x \cdot B_z}{t}$$

$$\boxed{V_H = -R_H \cdot \frac{I_x \cdot B_z}{t}} \qquad R_H = \text{Hall coefficient}$$

That is the Hall-voltage is directly proportional to the magnitude of the perpendicular magnetic-field. Thus a change in magnetic field would produce a change in the measured Hall-voltage. (Field detection range $1\mu T - 1T$)

The current related sensitivity is a key figure of merit of a Hall sensor and can be defined as

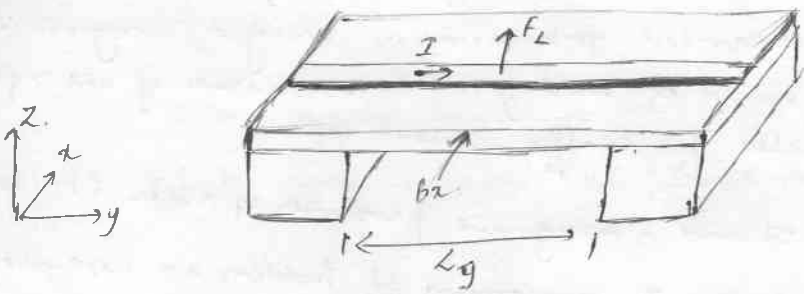
$$S_I = \left| \frac{1}{I} \frac{\partial V_H}{\partial B_z} \right| \text{, upto } 1000\,V/AT \text{ has been achieved.}$$

Since the Hall voltage is related only to the z-axis magnetic field component, Hall magnetic sensors are basically uniaxial devices.

(~~Field~~

Resonant Magnetic Sensors:

Resonant sensors exploit Lorentz force of resonating micromachined structures. These sensors can detect magnetic fields upto 1mT with a resolution down to 1nT.



A clamped-clamped beam resonant structure. Inorder to excite the device a metallic loop is placed on the clamped-clamped beam surface where an excitation current $(I) \approx \sqrt{2}\, I_{rms} \sin(2\pi f t)$ flows inside it with a frequency equal to the resonant frequency of the beam. {How to determine resonant frequency? → either by analytical models and simulation tools and it depends on the elastic modulus, density, deflection and geometric features of the resonant structure}

When this beam is exposed to an external magnetic field (B_x) in the x-direction, then a Lorentz force (F_L) is generated

$$F_L = I \cdot B_x \cdot L_y,$$

The Lorentz force acts as an excitation source on the beam, causing an amplified deflection on the mid point. The magnitude of the beam deflection depends on the Lorentz force amplitude, which is proportional to current I and field B_x.

→ How do you determine B from this method

→ So for a constant current I, the magnitude of deflection depends on B.

→ The deflection can be read out through a piezoresistive readout setup, where the change in the resistance of the piezoresistive material is proportional to the Lorentz force acting.

→ From this, the magnetic field can be determined.

Applications

→ magnetic field sensors on the micro scale with moderate sensitivity, could be used for vehicle detection and recognition.

- Vehicles moving over ground can generate a succession of impacts on the earth's magnetic field, that can be detected by means of magnetic perturbation using a magnetic sensor. Such sensors could be used for the measure of the speed and size of vehicles for traffic surveillance.

→ Environment Science - magnetic properties of rocks (1-1000 nT)

→ Military → detection & mapping of hidden or unexploded ordnance (10-1000 nT range) or submarines (1-10 nT)

~~Giant / magnetoresistance effect: Hard-disk head~~