Technology Brief 12: EMF Sensors

An ***electromotive force*** (emf) sensor is a device that can generate an induced voltage in response to an external stimulus. Three types of emf sensors are profiled in this technical brief: the ***piezoelectric transducer***, the ***Faraday magnetic flux sensor***, and the ***thermocouple***.

Piezoelectric Transducers

▶ ***Piezoelectricity*** is the property exhibited by certain crystals, such as quartz, that become electrically polarized when the crystal is subjected to mechanical pressure, thereby inducing a voltage across it. ◀

The crystal consists of polar domains represented by equivalent dipoles (**Fig. TF12-1**). Under the absence of an external force, the polar domains are randomly oriented throughout the material, but when ***compressive*** or ***tensile*** (stretching) stress is applied to the crystal, the polar domains align themselves along one of the principal axes of the crystal, leading to a net polarization (electric charge) at the crystal surfaces. Compression and stretching generate voltages of opposite polarity. The piezoelectric effect (***piezein*** means to press or squeeze in Greek) was discovered by the ***Curie brothers***, Pierre and Paul-Jacques, in 1880, and a year later, Lippmann predicted the converse property, namely that, if subjected to an electric field, the crystal would change in shape.

▶ The piezoelectric effect is a ***reversible (bidirectional)*** electromechanical process; application of force induces a voltage across the crystal, and conversely, application of a voltage changes the shape of the crystal. ◀

Piezoelectric crystals are used in ***microphones*** to convert mechanical vibrations (of the crystal surface) caused by acoustic waves into a corresponding electrical signal, and the converse process is used in ***loudspeakers*** to convert electrical signals into sound. In addition to having stiffness values comparable to that of steel, some piezoelectric materials exhibit very high sensitivity to the force applied upon them, with excellent linearity over a wide dynamic range. They can be used to measure surface deformations as small as ***nanometers*** (10^{-9} m), making them particularly attractive as positioning sensors in ***scanning tunneling microscopes***. As ***accelerometers***, they can measure acceleration levels as low as 10^{-4} g to as high as 100 g (where g is the acceleration due to gravity). Piezoelectric crystals and ceramics are used in cigarette lighters and gas grills as spark generators, in clocks and electronic circuitry as precision oscillators, in medical ***ultrasound*** diagnostic equipment as transducers (**Fig. TF12-2**), and in numerous other applications.

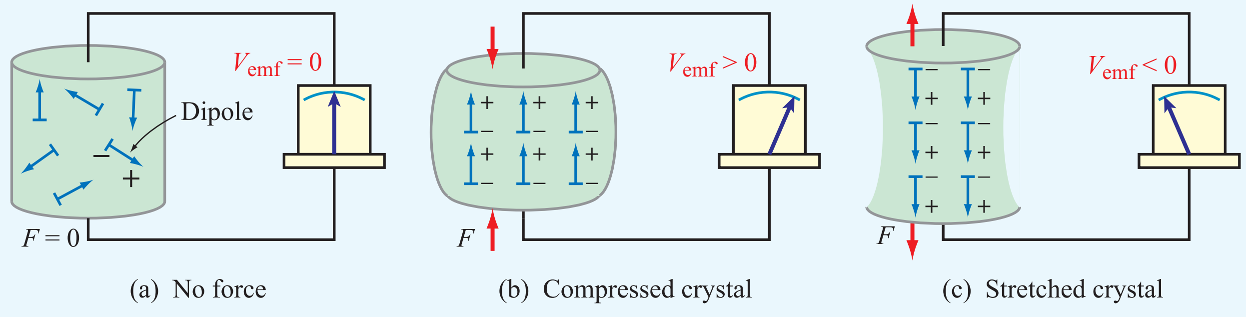

Figure TF12-1 Response of a piezoelectric crystal to an applied force.

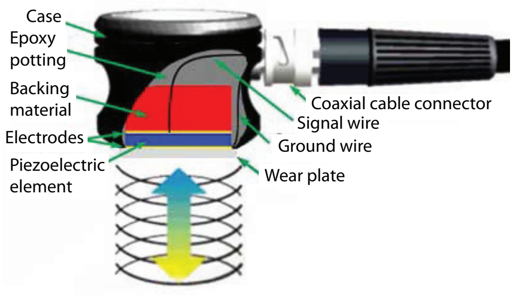

Figure TF12-2 The ultrasonic transducer uses piezoelectric crystals.

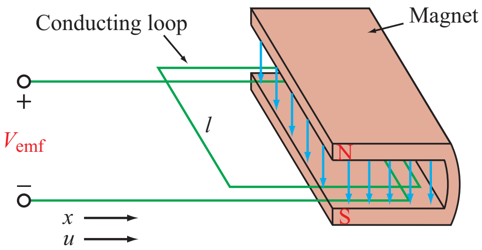

Figure TF12-3 In a Faraday accelerometer, the induced emf is directly proportional to the velocity of the loop (into and out of the magnet's cavity).

Faraday Magnetic Flux Sensor

According to Faraday's law [Eq. (6.6)], the emf voltage induced across the terminals of a conducting loop is directly proportional to the time rate of change of the magnetic flux passing through the loop. For the configuration in **Fig. TF12-3**,

$$V_{emf} = -uB_0 l,$$

where $u = dx/dt$ is the ***velocity*** of the loop (into or out of the magnet's cavity), with the direction of u defined as positive when the loop is moving inward into the cavity, B_0 is the magnetic field of the magnet, and l is the loop width. With B_0 and l being constant, the variation of $V_{emf}(t)$ with time t becomes a direct indicator of the time variation of $u(t)$. The time derivative of $u(t)$ provides the ***acceleration*** $a(t)$.

Thermocouple

In 1821, ***Thomas Seebeck*** discovered that when a junction made of two different conducting materials, such as bismuth and copper, is heated, it generates a thermally induced emf, which we now call the ***Seebeck potential*** V_S (**Fig. TF12-4**). When connected to a resistor, a current flows through the resistor, given by $I = V_S/R$.

This feature was advanced by ***A. C. Becquerel*** in 1826 as a means to measure the unknown temperature T_2 of a junction relative to a temperature T_1 of a (cold) reference junction. Today, such a generator of ***thermoelectricity*** is called a ***thermocouple***. Initially, an ice bath was used to maintain T_1 at 0°C, but in today's temperature sensor designs, an artificial cold junction is used instead. The artificial junction is an electric circuit that generates a potential equal to that expected from a reference junction at temperature T_1.

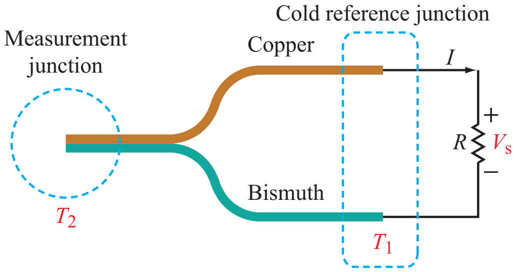

Figure TF12-4 Principle of the thermocouple.