The difference between inductive proximity, displacement, and eddy-current sensors

Patrick Mannion - March 23, 2016

It seems like engineering 101, but do you actually remember the specific differences between inductive proximity, inductive displacement, and eddy-current sensors? I asked a few friends and everyone had a pretty good idea, to varying degrees, but if you aren’t immersed in the topic the nomenclature can throw you off, as they’re all reliant on eddy currents.

Eddy currents, also called Foucault current, are loops of electrical current induced within a conductor by a time-varying magnetic field in that conductor (Figure 1). This phenomenon of induction was first observed by Michael Faraday way back in 1831, and he summed up his experiments in Faraday’s Law. This of course states that the induced electrical current (electromotive force, or EMF) in a closed circuit is equal to the negative of the rate of change of the magnetic flux, or:

\[
\mathcal{E} = -\frac{d\Phi_B}{dt},
\]

where \(\mathcal{E}\) is the EMF and \(\Phi_B\) is the magnetic flux.

Figure 1 Eddy currents are generated in a conductor by a time-varying magnetic field. When induced in a nearby conductor, the induced eddy currents oppose those of the originating magnetic field. (Image courtesy of Microwave Soft.)
Heinrich Lenz contributed by adding that the direction of the induced EMF always opposes the change that induced it.

These combined phenomena of induction, eddy current generation, and opposition are the fundamental principles of proximity, inductive displacement, and eddy-current sensors. The primary differences are structure and the accompanying electronics. So let’s start with the humble proximity sensor, the most basic embodiment and application of these principles.

The basic but well-loved proximity sensor is a binary device that simply tells whether or not a metallic object (the “target”) is present – or not. It comprises a wire coiled around a ferromagnetic core and an oscillator to generate an alternating current to create the time-varying magnetic field (Figure 2).

![Inductive proximity sensor](image.png)

Figure 2 The basic proximity sensor is binary in that it uses the opposing eddy currents induced in the target metal to detect absence or presence of the target. There’s no relative or absolute position information. (Image courtesy of robotpark.com.)

When a metallic target comes close, the opposing eddy currents induced in the target cause a drop in voltage across the originating oscillator. A detector circuit (Schmitt trigger) and amplifier (comparator) are used to switch the output, which can be normally closed (NC) or normally open (NO).

Inductive displacement sensors are a big step up from proximity sensors, but mostly thanks to more electronics and processing. Instead of a binary output, the classic inductive displacement sensors provide an analog output, typically via a 4-20-mA loop, that can be processed upstream to give a good idea of the target metal’s location relative to the sensor.

More advanced iterations of the inductive displacement sensor include linear variable differential transformers (LVDTs). These look similar to transformers except that the induced current in the secondary coils from the primary are dependent on the location of the target metal, which is usually a rod (Figure 3).
The linear variable differential transformer (LVDT) is a variety of the inductive displacement sensor that detects motion in a metal rod using the relative value of current induced in the secondary coils as the rod (core) travels back and forth (or up and down, as in a toilet float position-detection application).

Proximity and inductive displacement sensors suffice for the vast majority of applications requiring detection of metal targets in harsh environments where physical contact is not possible. For detection of non-metal targets in such environments, capacitive sensors can be used.

However, where ultimate precision and accuracy is required, that’s where eddy current sensors come in. These differ from proximity and inductive displacement sensors in that they use an air-core coil instead of a ferromagnetic core. This eliminates the magnetic losses and thermal nonlinearities associated with ferromagnetic cores, and it also gives eddy-current sensors much faster response times to resolve fast-moving targets, up to the MHz range. However, the trade-off is higher cost due to more precise manufacturing, production, and calibration to the target metal before shipping.

Note, that by dispensing with the ferromagnetic core, the magnetic field in an eddy-current (air core) sensor is not as focused, so the measurement distance, or air gap, needs to be narrower.

For accurate details on relative performance specifications, best to consult the datasheets of vendors such as Bosch, Omron, Baumer Group, Sensirion, Micro-Epsilon, and Pepprl+Fuchs.

Also see:

- Sensor basics: Types, functions and applications
- Replace IR sensing with proximity detection
- Faraday discovers electromagnetic induction, August 29, 1831
- What every designer should know about magnetics in switch-mode power supplies