Technical Article

(Ref: ZET13_v1) **9th June 2011**

Inductive Versus Capacitive Position Sensors

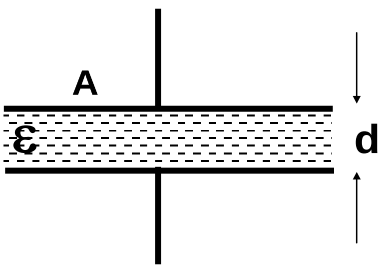
Some engineers are confused between capacitive and inductive position sensors. Both use a non-contact technique to measure position; both use AC electrical phenomena and both can be built using printed circuit boards. Nevertheless, the underlying physical principles are very different which means that each technique is suitable to particular geometries and applications. This paper describes the fundamental physics behind each technique and outlines the consequent strengths and weaknesses of each approach.

Operating Principles – Capacitive Sensors

The first capacitive sensor could be argued to have been invented by von Kleist in Germany in 1745 when he received an electric shock from a capacitor. More recently, there has been a massive increase in the number of capacitive sensors – notably in touch sensors on portable devices such as mobile phones and computers. Although such sensors are capacitive sensors, they are not strictly displacement sensors as they detect the absence or presence of a person's finger - as an alternative to a push button switch.

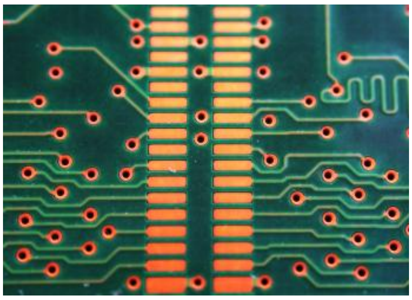
Capacitive displacement sensors work by measuring the change in capacitance of a capacitor. A capacitor is a collector of electrical charge and typically comprises two metal plates separated by a relatively small thickness of electrically insulating material or dielectric. The dielectric is sometimes air and sometimes a non-conductive material such as plastic or ceramic. Simply modelled, a capacitor may be described as follows:-

$$C = \frac{\varepsilon A}{d}$$



C= capacitance

ε = permittivity of dielectric
A = overlapping area of plates
d = distance between plates



As can be seen by the above mathematical formula, capacitance varies in proportion to distance between the plates (d) as well as the overlap of the plates (A). This phenomenon can form the basis of a capacitive displacement sensor. Displacement can be measured axially (variation in d axis) or in the planar direction of plate overlap (variation in A). Advantageously, capacitor plates can be generated using PCB techniques – as shown on the right.

For any significant effect, the separation dimension d must be small compared to the area of the plates. Dimension d is usually <<1mm. Hence such a technique is well suited to load or strain measurement. High sensitivity is possible because a small displacement (in the order of microns) represents a relatively large change to the (small) d dimension.

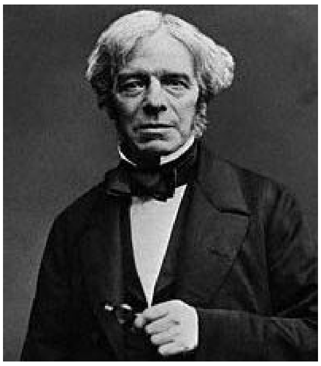
Similarly, capacitive linear or rotary sensors can be arranged so that displacement causes a variation in the effective overlap of the plates.

Unfortunately, capacitance is also sensitive to factors other than displacement. If the capacitor plates are surrounded by air then its permittivity also varies with temperature and humidity (because water has a different dielectric constant than air). As can be seen with capacitive touch sensors, the effect of a nearby object which varies the permittivity the surrounding area will also vary capacitance. With a touch sensor, it is the water in one's finger that causes a change in local permittivity – hence causing a change in capacitance, triggering a switch. *Top tip – if you struggle to get a touch sensor to work, wet the end of your finger using your tongue.*

Typically, unless the environment around a capacitive sensor can be tightly controlled (e.g. in a sealed unit with controlled conditions) they are not suited to harsh environments where there is the possibility of ingress of foreign matter or large temperature swings. Importantly, given the inherent physics, dimension d must be kept small and tightly controlled relative to the capacitor plates. This can, in turn, require careful mechanical installation for devices that measure displacement in planar axes.

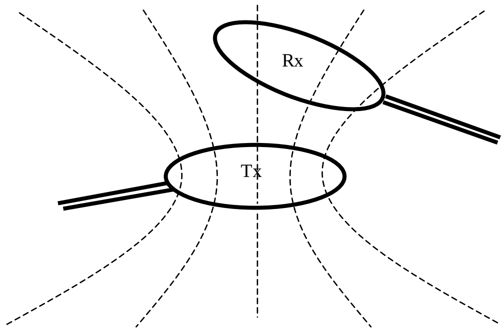
If, for example, a capacitive sensor is used to measure rotation, then the axial separation between the plates must be carefully set within tight limits. This may not be practical or economical in many applications where differential thermal expansion, vibration or mechanical tolerancing of the host system will cause the gap, d, to vary and hence distort measurement. Often, high precision mechanical installation and setting is not economically viable.

Operating Principles – Inductive



Michael Faraday became the father of electrical induction principles when he found that an alternating current in one conductor could 'induce' a current to flow in an opposite direction in a second conductor. Since then, induction principles have been widely used as a basis for position & speed measurement with devices such as resolvers, synchros and linearly variable differential transformers (LVDTs). The basic theory can be seen by considering two coils - a transmit coil (T_x) and a receive (R_x) coil. The following equation applies:-

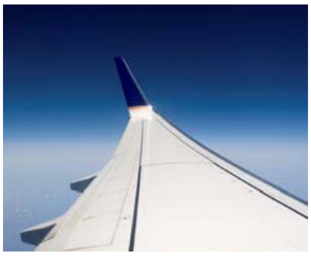
$$V_{RX} = - K \frac{dI_{TX}}{dt}$$



- V_{RX} is the voltage induced in the Receive coil
- K is the mutual inductance coupling factor depending on the coils' relative areas, geometry, distance, and relative number of turns.
- dI_{TX} /dt is the rate of change of current in the Transmit coil.

The receive signal is therefore proportional to the relative areas, geometry and displacement of the coils. But as with capacitive techniques other factors can come in to play such as temperature which changes the resistance of the coils, causing a disturbance to any position measurement. This effect is negated by the use of multiple receive coils and calculating position from the **ratio** of the received signals. Accordingly, if temperature changes, the effect is cancelled out since the ratio of the signals is unaltered for any given position. Unlike, capacitive methods, inductive techniques are much less affected by foreign matter such was water or dirt. Since the coils can be a relatively large distance apart, the mechanical installation is much less onerous. Again, this is assisted by the basic ratiometric technique.

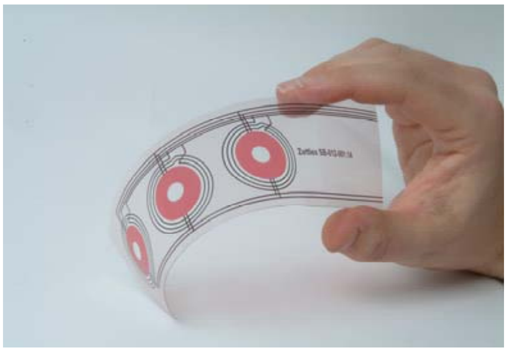
This robust, reliable and stable approach has meant that inductive sensors are the preferred choice in areas where harsh conditions are common – such as defence, aerospace, industrial, oil & gas sectors.

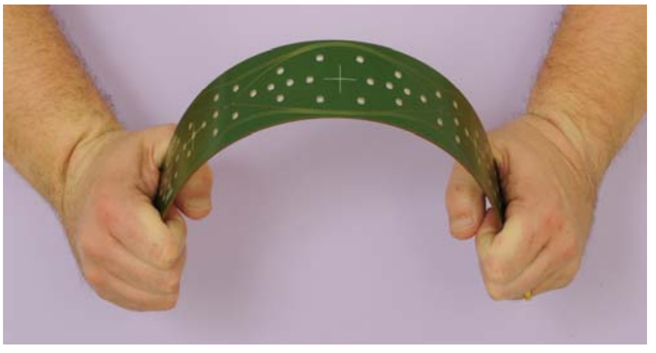


So why aren't inductive sensors used more widely if they are so robust and reliable?

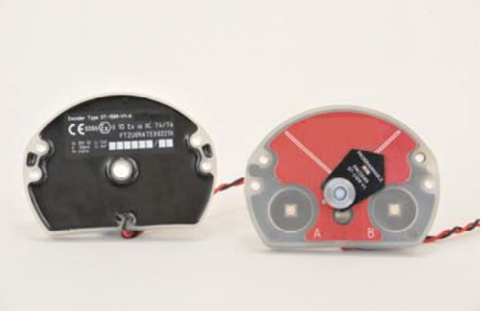
The answer is simple. Traditional inductive sensors use a series of wound conductors or spools. The spools must be wound accurately to achieve accurate position measurement. Further, in order to achieve strong electrical signals, lots of wires are needed. This makes traditional inductive position sensors bulky, heavy and expensive.

Zettlex technology uses the same inductive principles but printed, laminar constructions are used rather than wound spools. This means that the coils can be produced from etched copper or printing on a wide variety of substrates such as polyester film, paper, epoxy laminates and even ceramics. Such printed constructions can be made more accurately than windings. Hence a far greater measurement performance is attainable at less cost, bulk and weight - whilst still maintaining the inherent stability and robustness of the inductive technique.





Since inductive techniques work at greater separation distances than capacitive techniques, this allows the principle components of inductive position sensors to be installed with relatively relaxed tolerances.



Not only does this help to minimize costs of both sensor and host equipment, it also enables the principle components to be encapsulated. This enables the sensors to withstand very harsh local environments such as long term immersion, extreme shock, vibration or the effects of explosive gaseous or dust laden environments.

Electromagnetic noise susceptibility is often cited as a concern by engineers considering inductive position sensors. The concern is misplaced given that resolvers have been used for many years within the harsh electromagnetic environments of motor enclosures for commutation, speed and position control.

A summary of the benefits of each of the techniques is shown below:-

	Capacitive	Traditional Inductive	Zettlex Inductive
High sensitivity	✓	✓	✓
High resolution	✓	✓	✓
High repeatability	✓	✓	✓
High accuracy	✓	✓	✓
Resilience to foreign matter		✓	✓
Robust EMC operation	✓	✓	✓
Low thermal drift			✓
Easy to install		✓	✓
Compact	✓		✓
Lightweight	✓		✓
Economical			✓

MACCON GmbH, Aschauer Str. 21, D-81549 Munich; sales@maccon.de; www.maccon.de