Technical Article

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Inductive Versus Magnetic Position Sensors

Both inductive and magnetic sensors are the design engineer's preferred choice for measuring position in harsh environments. Both offer the advantages of non-contact sensing over the traditional potentiometer. This paper describes the fundamental physics behind each technique and outlines the consequent strengths and weaknesses of each approach.

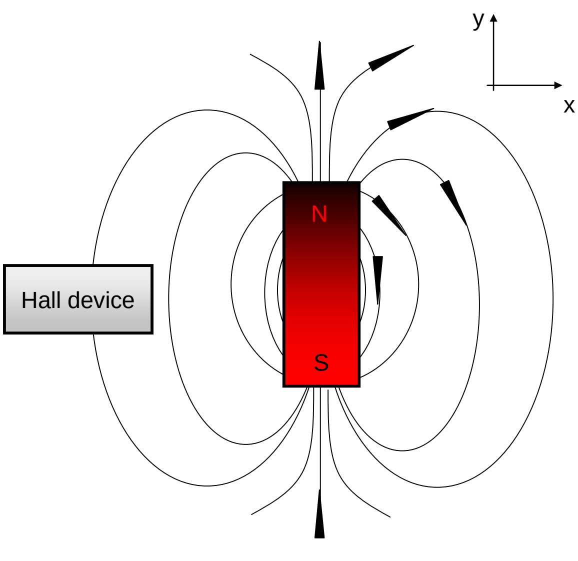
Operating Principles – Magnetic Sensors

The term 'magnetic sensor' can be somewhat confusing since this term covers a range of techniques including Hall effect, magnetoresistive and magnetostrictive.

Hall effect sensors are, by far, the most common magnetic sensor and are widely used in high volume applications in automotive and domestic appliance sectors. A typical example is in brushless DC motors for power commutation.

The Hall effect is the production of a voltage difference (the Hall voltage) across an electrical conductor, transverse to an electric current in the conductor and a magnetic field perpendicular to the current. It was discovered by Edwin Hall in 1879. In simple terms, a Hall effect sensor measures the strength of a magnetic field. This effect can be used to measure position since field strength is proportional to the distance between the Hall sensor and the magnet.

If we consider a simple bar magnet – as shown here on the right – we can see that the lines of magnetic flux extend from and to its poles. The density of the flux lines decreases with distance away from the magnet. You might recall seeing this effect from the experiment with the iron filings and a salt shaker in your school days. As the magnet moves closer to the Hall device the Hall effect increases – thus providing a basis for position measurement.



Tens of millions of Hall effect devices are made each year and for a high volume application in domestic appliances or automotive, a Hall chip for $1 is achievable. With around 10UScents for a magnet, it is possible to engineer a really low cost sensor.

So far, so good. Snag is, the magnetic field experienced by the Hall device also varies in proportion to a bunch of other factors too. These factors include variation in the position of the magnet in y & z axes; magnetic hysteresis; extraneous DC/AC fields; distorting effects of nearby magnetically permeable materials (e.g. steel); variations in temperature and differences in field strength between one magnet and the next.

All these ‘other factors’ means that Hall sensors are only suitable for those position sensing applications where:-

- only modest measurement performance is required (typically >1% linearity)
- the mechanical tolerances for the relative motion of magnet & sensor are tightly controlled
- extraneous AC fields, DC fields or nearby metal objects (*notably swarf or ferromagnetic particles in oil which may build up on the magnet over time)* is either well controlled or non-existent
- temperature is well controlled or the sizeable temperature effects are not significant to the accuracy of measurement.

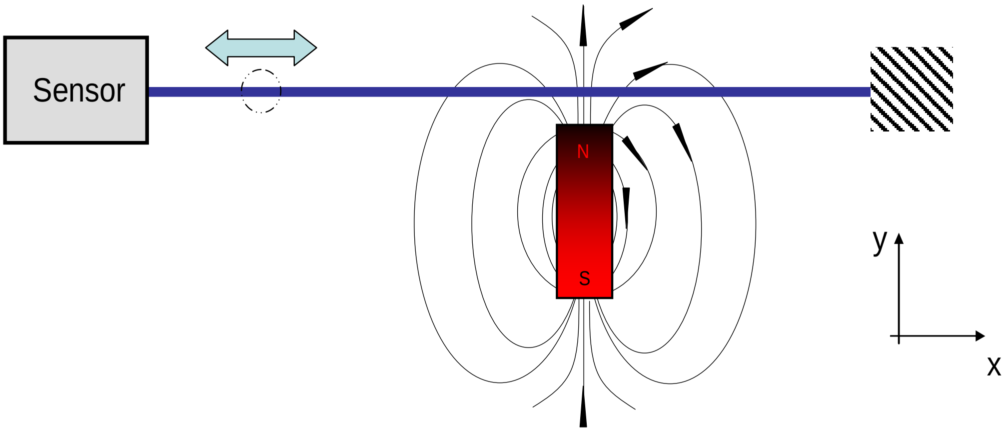
Hall devices which are capable of operation at >120Celsius are rare because measurement performance drops off rapidly at elevated temperatures.

In summary, Hall effect offers a fairly robust, cheap but low precision technique which can work well – but only if mechanical tolerancing and EMC is well controlled.

Magnetoresistive devices are similar to Hall effect devices but rather than detecting field strength, they detect field direction. In terms of position measurement, the strengths and weaknesses of the technique are also similar.

Magnetostriction is completely different to Hall effect or magnetoresistive techniques. Magnetostriction refers to an unusual property of some ferromagnetic materials which causes them to change their shape or dimensions during the process of magnetization. The variation of material's magnetization due to the applied magnetic field changes the magnetostrictive strain until reaching its saturation value. The effect was first identified in 1842 by James Joule. This phenomenon can be used to measure position by measuring the time of flight of a sound wave along a length of magnetostrictive material such as nickel.

In a magnetostrictive position sensor a length of magnetostrictive material extends between two fixed points as shown below:-

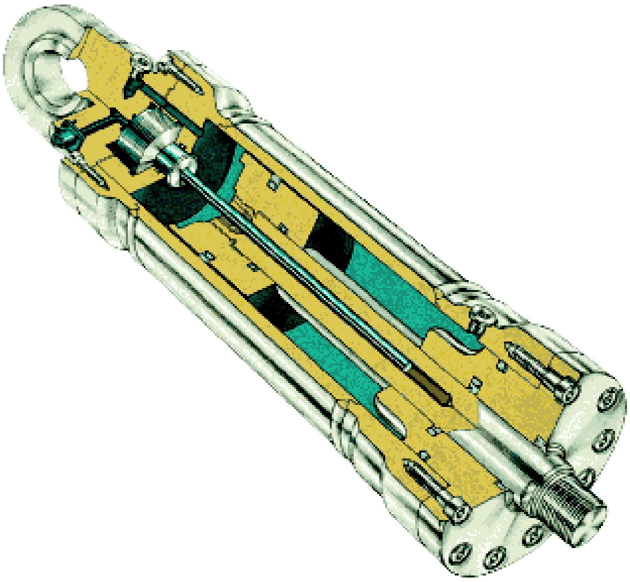


A pulse of energy sent from one end bounces back from the other end in a time t. If a magnet is brought in to close proximity with the strip, the time taken for the pulse to bounce back reduces in proportion to the distance between magnet and sensor.

Magnetostrictive sensors are most suited to measuring linear position over long lengths – most notably position sensors for hydraulic rams. This is where >90% of all magnetostrictive sensors are used.

Over the last decade or so, magnetostrictive sensors have gained market share over the more traditional linear transformers (LVDTs) because they are more compact. In the last few years, the trend is reversing, with linear transformers winning back market share back because problems are now become apparent from actual practical application:

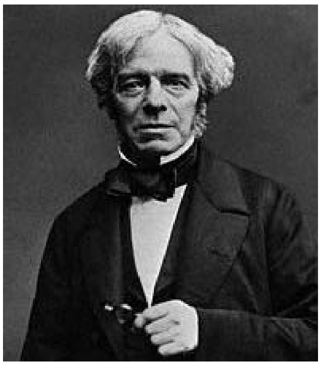
- large temperature effects *(speed of travel of energy thorough a solid is highly dependent on temperature)*
- clamping of the Magnetostrictive materials must be tightly controlled and any damage to the clamping arrangements or wave guide through shock or harsh vibration causes catastrophic failure
- low measurement performance at lengths of <150mm. The longer the measurement scale the better the accuracy (in % terms) of a Magnetostrictive device.



Magnetostrictive technique is generally not applicable to rotary position measurement. Its technical features make it particularly well suited to in-cylinder applications on long stroke lengths of >250mm, where the delicate magnetostrictive strip can be protected against shock from a substantial mechanical housing.

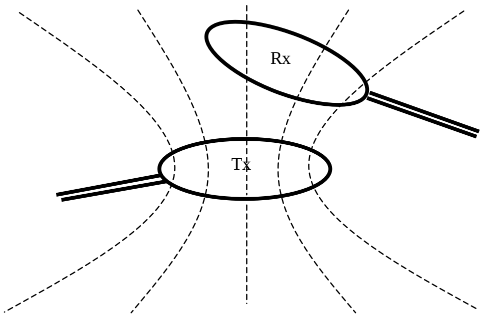
More generally, magnetostrictive devices are not more widely used because of their high cost. Whilst the sensor itself is relatively inexpensive, by the time the cost of mechanical parts for the wave guide, strip clamps etc. are counted, the basic sensor price multiples by >10 and prices are typically measured in 100s of US$.

Operating Principles – Inductive



Michael Faraday became the father of electrical induction at the Royal Society in 1835 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:-

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



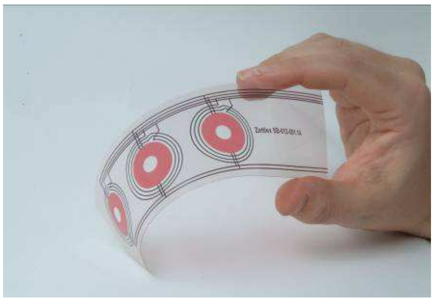
- V_{RX} is the voltage induced in the Receive coil
- K is the mutual inductance coupling factor depending on the coils' relative areas, geometry, distance, and relative number of turns.
- dI_{TX} /dt is the rate of change of current in the Transmit coil.

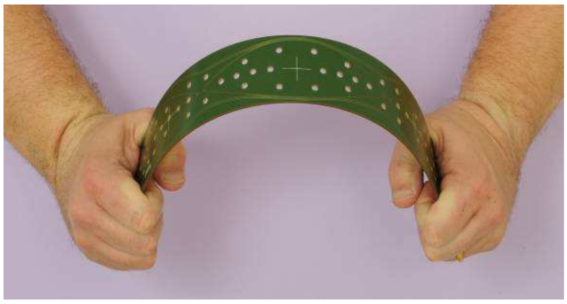
The receive signal is therefore proportional to the relative areas, geometry and displacement of the coils. But as with magnetic techniques other factors can come in to play such as temperature which changes the resistance of the coils, causing a disturbance to any position measurement. This effect is 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. 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 the coils can be produced from etched copper or printed on substrates such as polyester film, paper, epoxy laminates or ceramic. 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 maintaining the inherent stability and robustness

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:-

	Hall effect	Magnetostrictive (>250mm)	Traditional inductive	Zettlex inductive
High resolution		✓	✓	✓
High repeatability			✓	✓
High accuracy		✓	✓	✓
Resilience to foreign matter	✓	✓	✓	✓
Robust EMC operation		✓	✓	✓
Low thermal drift			✓	✓
Easy to install		✓	✓	✓
Compact	✓			✓
Lightweight	✓			✓

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