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A Comparison of Inductive and Capacitive Position Sensors

TN-1515| 191013

INTRODUCTION

A key step in selecting a position sensor is understanding the requirements of sensor size, resolution, repeatability, accuracy, mounting constraints and environmental ruggedness. This paper discusses the technologies of capacitive and inductive sensors and concludes with a key feature comparison.

KEY TERMS

Incremental Sensor provides position change information only so the actual position is unknown at startup. A once-per-rev index/marker signal defines the zero position or null of the device. It is detected during a homing routine. For commutation of a brushless motor the motor typically has three magnetic Hall sensors to provide coarse absolute position information for preliminary alignment of the magnetic fields. Incremental sensors are typically small, accurate and cost-effective.

Absolute Sensor provides the actual physical position within one revolution or within the range of linear travel. The motor does not require Halls and homing is only necessary for rotary applications if the range of movement exceeds one revolution. The sensors are usually bigger and more expensive than incremental devices.

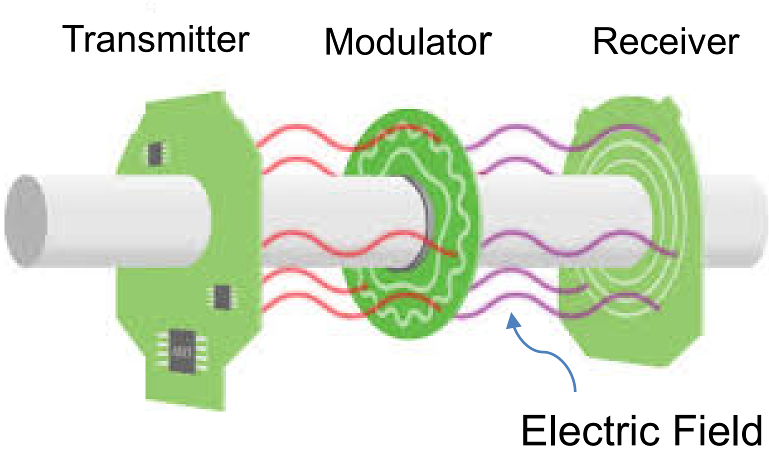
Resolution Defines the smallest position increment that can be moved or measured and is typically expressed in "counts". High resolution is required for high performance servo systems. A positioning system "dithers" between two counts so the higher the resolution the smaller the dither. Resolution also has a significant impact on velocity ripple at low speed. Since velocity is derived from position feedback, if the resolution is low there may be insufficient data in a sample to accurately derive velocity. At high speeds, high resolution devices can generate data rates beyond the tracking capability of the controller or servo drive.

Interpolation As will be seen, many sensors generate sine and cosine signals. The period of these signals is defined by the inherent "pitch" of the device. With sin/cos information it is theoretically possible to have infinite resolution by computing the ratio of the signals. This technique is known as interpolation. In practice, the fidelity of the sin/cos signals and signal to noise ratio limit the realizable resolution.

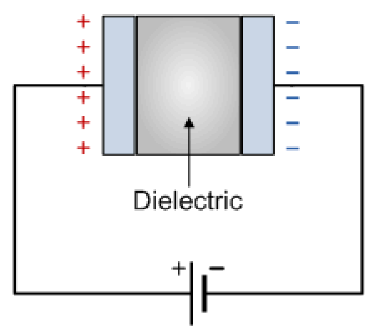
Accuracy Defines how close each measured position is to the actual physical position. Accuracy is very much a system issue and can be dominated by mechanical errors such as eccentricity, straightness and flatness. Sensor errors include non-accumulating random variations in pitch (linearity), accumulating pitch errors (slope) and variations in fidelity of internal sin/cos signals. Precision machine builders typically calibrate out errors via a lookup table of offsets. More detail can be found in TN-1005.

Repeatability Defines the range of measured positions when the system is returned to the same physical position multiple times. Repeatability can be more important than absolute accuracy. For system inaccuracies to be effectively calibrated it is important for each position reading to be consistent. Sensor hysteresis (different readings depending on direction of approach to measure position) is an important factor in repeatability.

CAPACITIVE ENCODERS



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



Capacitive encoders are based on the principle that capacitance is proportional to the dielectric material between two charged plates. As shown in the illustration, an electric field is created between the capacitively coupled transmitter and receiver. The rotor sinusoidally modulates the dielectric ε causing a change in capacitance. The change in capacitance in turn modulates the potential difference between transmitter and receiver. Multiple modulating tracks are employed to define absolute position.

Capacitive encoders are compact and consume very little power. They are, however, susceptible to condensation and electrostatic build-up. Capacitance also varies with temperature, humidity, surrounding materials and foreign matter, which makes engineering a stable, high accuracy position sensor challenging. The components of the device have very small air gaps requiring careful installation.

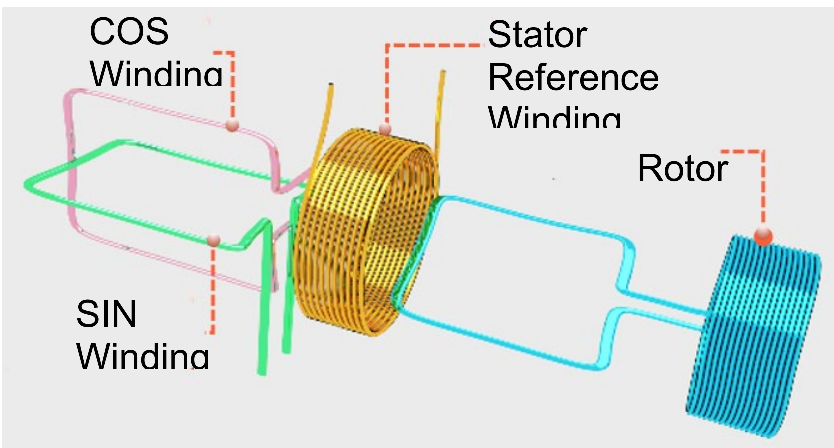
Strengths: Compact; low power.

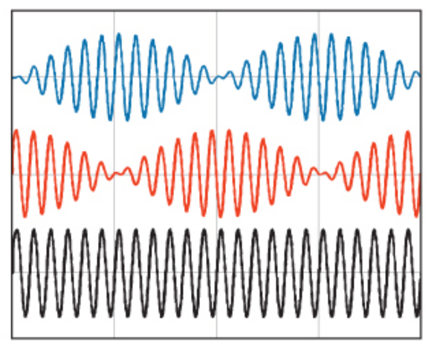
Weaknesses: Environmental ruggedness; alignment tolerances

TRADITIONAL INDUCTIVE SENSORS - RESOLVERS

Resolvers are based on the principle of electromagnetic induction – an alternating current in one conductor generates a changing magnetic field around the conductor. This magnetic field can induce an alternating current in an adjacent conductor. The magnitude of coupling from one conductor to another depends on the rate of change of magnetic field and the relative position and geometry of the conductors.

As shown below, a 5kHz (typ.) sinusoidal reference voltage in the stator induces a sinusoidal voltage in the rotor winding. A second, axial, rotor winding then induces a voltage in two axial signal windings displaced by 90º back on the stator. The amount of coupling into the stator windings is a function of the relative position of the rotor which effectively amplitude modulates the stator signals as shown.





In the illustration above the rotor is shown outside the stator for clarity. The radial windings on the stator interact with only the radial windings on the rotor. In turn, the axial windings on the rotor interact with only the axial windings on the stator. This is to avoid the stator reference winding coupling to the stator signal windings. Winding a resolver is not trivial and the end result is a heavy, bulky device. The resolver does, however, have unmatched ruggedness as there are no electronics or fragile parts in the device.

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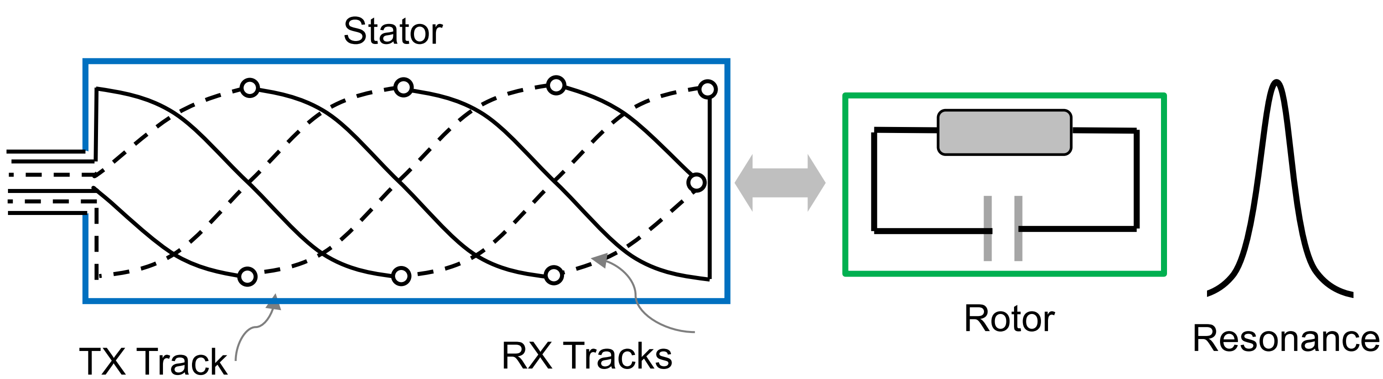
Resolvers are available in various "speeds". A single speed resolver has one electrical sinewave cycle per rev and provides absolute position information with limited resolution. A "multi-speed resolver" is wound for a higher number of electrical cycles per rev improving resolution. The higher ratio of electrical to mechanical cycles also helps minimize the effects of mechanical error sources. Multi-speed resolvers are no longer absolute and are more expensive and typically even more bulky.

Strengths: Moderate resolution and accuracy; reliable; extremely robust.

Weaknesses: Expensive; bulky; heavy.

NEXT GENERATION INDUCTIVE SENSOR - INCODER



The absolute inductive encoder is based on the same electromagnetic induction principle as the resolver but uses PCB traces rather than coil windings. The TX track on the stator is excited by specific frequency in the range 1-10MHz. This signal inductively couples into target with a resonant LC circuit. The target magnetic field induces a sinusoidal current in stator RX track. The RX track is sinusoidal in shape which effectively amplitude modulates the induced signal. A second RX track displaced by 90º carries a cosine signal. The sin/cos signals are interpolated and output as BiSS-C, SSI or in some versions AqB signals.

The RX tracks on the stator are analogous to a twisted pair wire. The balanced dipole effect cancels electric fields induced in the RX tracks from the changing magnetic field on the TX track. The RX track responds to changing magnetic field on the target only. The RX tracks also reject external electromagnetic interference. Undesirable induced stator currents are also rejected based on frequency and phase.

The main RX tracks with one sin/cos cycle per rev defines absolute position. A secondary track with multiple cycles enhances resolution. More typically the main TX track has multiple cycles (9 for example) combined with a secondary track with a number of cycles not a multiple of 3 – every position within one rev is defined by two unique readings.

The use of PCB traces versus the resolver's windings brings significant advantages including: reduced cost, size and weight; form factor flexibility including curvilinear; elimination of inaccuracies from the winding process; for safety-related applications multiple sensors can be located in the same space by using multi-layer circuit boards.

The PCB material is environmentally very stable. The option for remote electronics further increases ruggedness. The 360º sensor improves eccentricity error tolerance.

Strengths: Moderate accuracy and resolution; reliable; robust; multiple geometries; compact; lightweight.

Weaknesses: Typical minimum diameter is 37 mm.

TECHNOLOGY COMPARISON

	Capacitive	Resolver	IncOder
High Resolution	✓		✓
High Repeatability	✓	✓	✓
High Accuracy	✓	✓	✓
Resilience to Dirt, Water or Condensation		✓	✓
Resilience to electrostatic effects		✓	✓
Robust EMC Operation	✓	✓	✓
Low Thermal Drift			✓
Easy to Install		?	✓
Compact	✓		✓
Lightweight	✓		✓
Economical	?		✓

The ultimate goal is to find the most cost-effective solution that meets the requirements of precision, size and ruggedness. Resolvers and inductive encoders lead with a combination of environmental ruggedness and precision. As discussed, the inductive encoder has numerous advantages versus the resolver particularly size and weight.