Overview

CambridgeIC's resonant inductive sensing technology encompasses a variety of sensors for linear and rotary position sensing. Please see the white paper "Resonant Inductive Operating Principle" for a general introduction.

This white paper describes the principle of operation of CambridgeIC's end-shaft resonant inductive position sensor in greater detail, to explain why it tolerates misalignment between sensor and target.

Sensor Coil Design

The 4 PCB layers of the sensor pattern define COS, SIN and excitation (EX) coils. Figure 1 and Figure 2 show the layout of these three coils. The SIN coil is shown separately for clarity, but its centre actually coincides with the centres of the COS and EX coils.

For clarity the number of turns in each coil has been simplified: the number of turns in each coil is larger in the actual pattern, and cross connections are less pronounced.

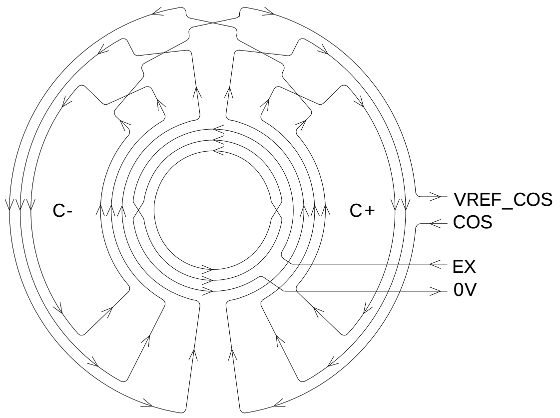

Figure 1 COS coil and EX coil, simplified

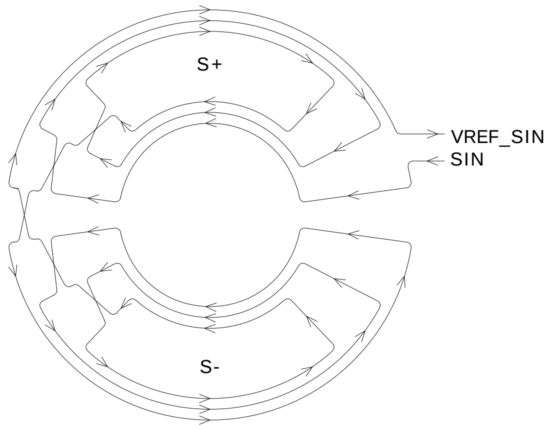

Figure 2 SIN coil, simplified

Resonator Design

Resonators comprise a coil wound around a ferrite rod, in series with a capacitor. They are packaged inside a target.

Figure 3 illustrates the resonator which it is designed to work with the sensor above, which is typically encapsulated inside a target such as part number 013-1005 illustrated in Figure 4.

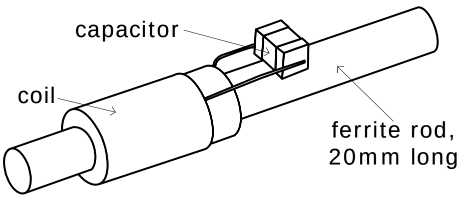

Figure 3 resonator inside Target

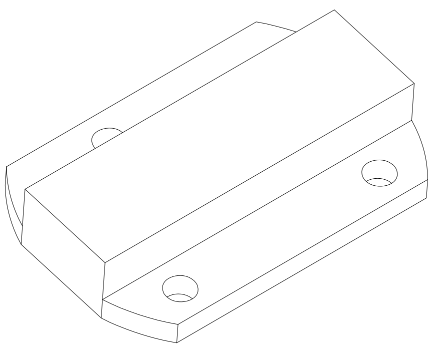

Figure 4 isometric sketch of Target

Figure 5 illustrates the resonator inside target 013-1005. Its axis of rotation is the centre of the ferrite rod, which is nominally aligned with the centre of the sensor pattern. The sensor's EX coil is located close to this axis. Since the resonator's coil is offset from its axis, there is a constant coupling between EX coil and resonator independent of resonator angle. The CTU circuit's drive output is connected to the EX coil, and is used to power the resonator to resonance.

When the resonator is at resonance, the AC field shapes approximate those of a bar magnet. Field emerges from the short end of the resonator and "flows" to the long end. Since the field is AC, it can be detected by measuring the EMF developed in coils which couple with the field. If test coils were to be placed under the short and long ends of the resonator in the plane of the sensor, they would detect equal and opposite EMFs.

In reality there are no such test coils, instead the resonator interacts with the COS and SIN coils illustrated above.

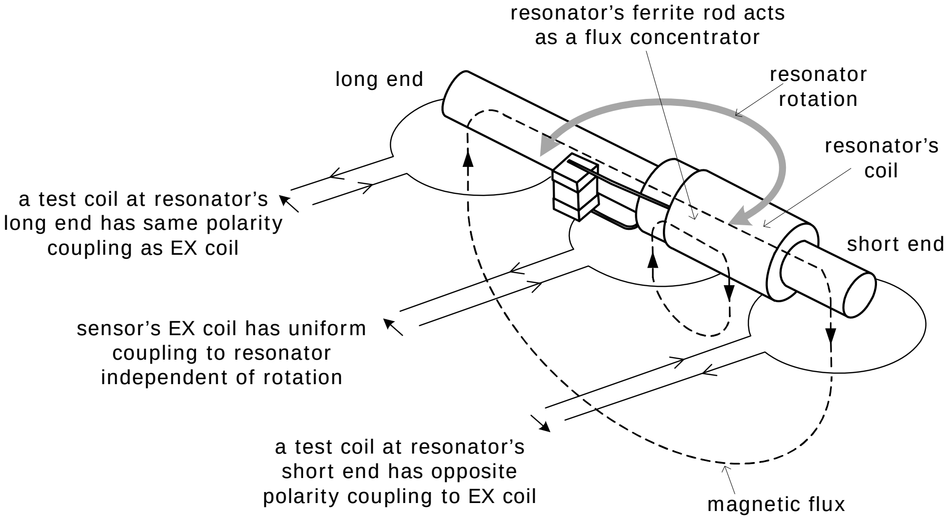

Figure 5 coupling to test coils as a function of position along resonator

Resonator to Sensor Coupling

When the resonator is aligned at 0˚ so that its short end is centered on C+ (the positive lobe of the COS coil illustrated in Figure 4) it couples in the positive direction with the COS coil. This situation is illustrated at the centre of Figure 7. At the same time, the long end of the resonator is aligned with the C lobe of the COS coil, whose winding direction is opposite to the C+ lobe. This end also couples positively with the COS coil, since the field direction at the long end of the ferrite rod is opposite to that at the short end. The net effect is a large positive coupling between resonator and COS coil (kCOS). The coupling between the resonator and SIN coil (kSIN) is zero at 0˚, because any EMF developed by the resonator in the S+ lobe is connected in series with an equal and opposite EMF developed in the S lobe.

The situation is reversed at -180˚ (which is identical to +180˚ in this case). Here the short end of the resonator and the C+ lobe of the COS coil coincide, and the long end and the C lobe. kCOS is therefore now a large negative value. kSIN remains zero.

At 90˚ the short end of the resonator coincides with S+ and the long end with S . kSIN is therefore a large positive value, and KCOS is zero.

The graph in Figure 7 illustrates the full relationship between the two sensor coil coupling factors and resonator angle. kSIN has a sinusoidal form, and kCOS its cosine counterpart. These sinusoidal shapes are key to the sensor's accuracy, and the sensor coils are carefully designed to yield accurately sinusoidal relationships.

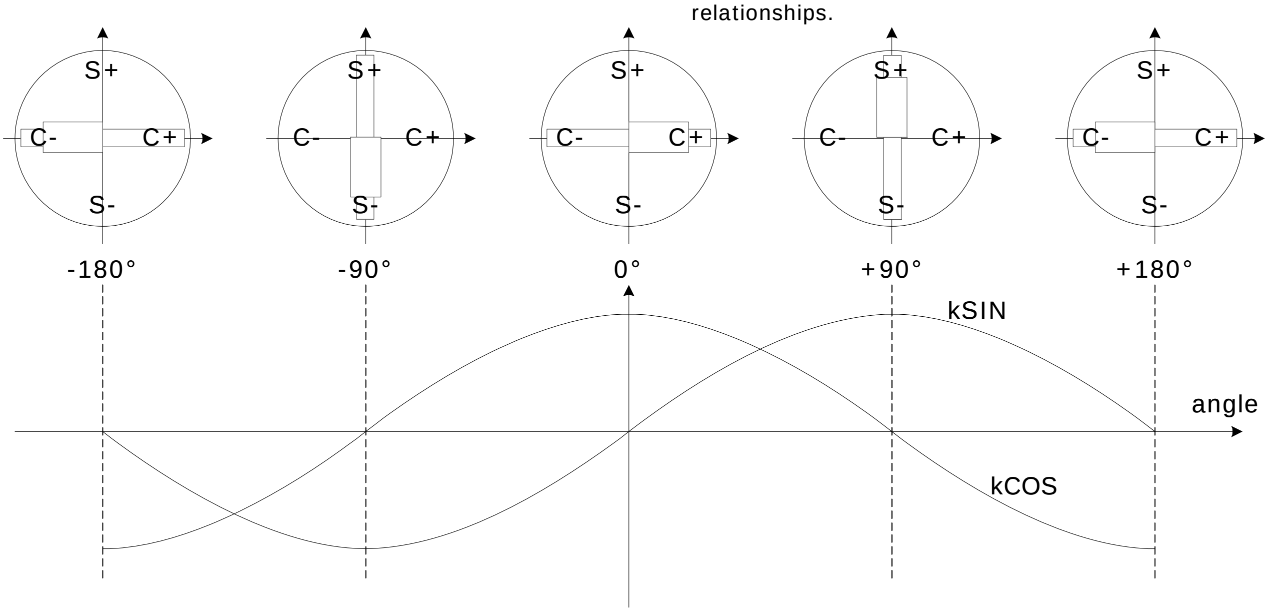

Figure 6 graph of sensor coil coupling factors as a function of resonator angle

Working out Position

The CTU circuit drives the resonator so that it generates an AC field, which is picked up in the two sensor coils. The CTU circuit detects these EMFs and uses them to establish a relative measure of the coupling factors kCOS and kSIN between the resonator and sensor coils.

The calculation of reported position (Pr) from kCOS and kSIN is a 4-quadrant inverse tangent, whose operation is illustrated in Figure 8. Pr is the angle formed between the origin and the vector (kCOS,kSIN). kCS, the length of the vector, is also of interest since it depends on the gap between the resonator and sensor.

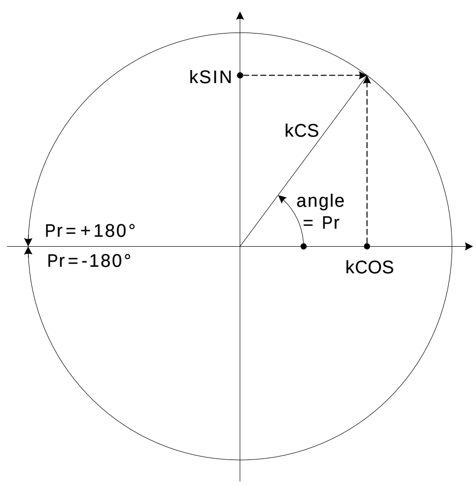

Figure 7 position calculation

Immunity to Misalignment

Used with the recommended resonator, the sensor has substantial immunity to misalignment of the target.

In traditional rotary position sensors such as optical encoders or potentiometers an offset between target (e.g. code disc or rotor) yields an error in reported angle as illustrated in Figure 9. The error arises from the sensor's unbalanced nature: the sensing takes place at a single point around the sensor's circumference. The peak magnitude of the error across target angle is given by…

$$Ae_{pk} = \frac{rm}{rr} \times \frac{360°}{2\pi}$$

Equation 1 error, unbalanced

For example, a sensor having a rotor radius of 12mm will yield a peak angle error of 5˚ when misaligned by 1mm.

Similarly, if the rotor/code disc were to vibrate relative to the sensor then there will be a significant amount of angle noise in the reported position. For example ±20µm of vibration at a radius of 12mm will induce ±0.1˚ of angle noise, rendering a 12-bit resolution encoder unusable.

As a result of this source of error and noise, optical encoders and potentiometers usually incorporate bearings and are carefully aligned to eliminate this source of error.

Figure 10 illustrates the situation with the sensor described here. The sensor's outputs are a combination of signals from the resonator's short and long ends. When the resonator is misaligned the individual components from long and short ends represent significant angle errors as before. However these errors are largely equal and opposite, so that the combined "average" reported position is a much more accurate representation of resonator angle.

This feature means that the sensor can tolerate considerably more misalignment and vibration, and need not incorporate its own bearings. It is therefore truly non-contacting.

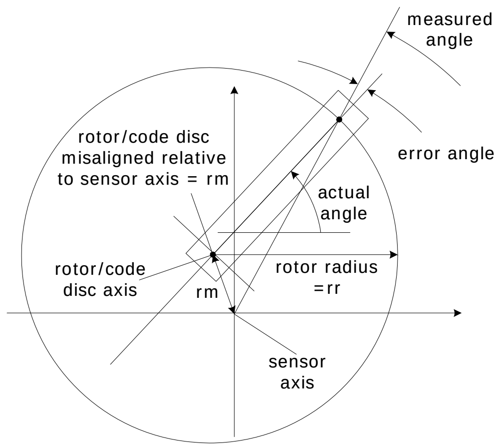

Figure 8 misalignment, unbalanced

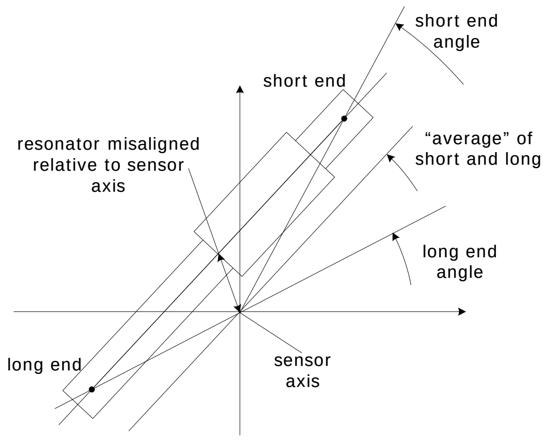

Figure 9 misalignment, balanced

Benefits

CambridgeIC's rotary end-shaft resonant inductive position sensors tolerate misalignment between the sensor and target due to their inherently balanced nature. This means:

- The sensor and target can be mounted on separate parts.
- The sensor system does not usually need its own bearings.
- There is considerable margin for tolerance stack-up (typically up to ±1mm).
- The system is suited to environments with vibration.

Document History

Revision	Date	Description
A	2008	First draft
0001	26 January 200	Updated logo and style

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