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Selecting the Right Rotary Position Sensor for Your Application

Control Product Line

Whitepaper

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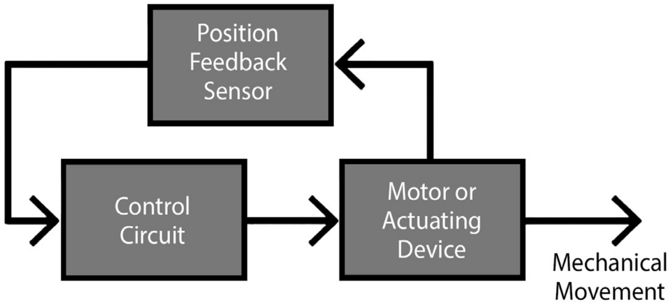

Figure 1: Rotary Position Sensor Block Diagram

Rotary position sensors are good solutions for applications that require electromechanical feedback from a change in position, change in direction, or speed of rotation. Most applications that require position feedback employ either a rotary position sensor to translate a change in angular mechanical position to an electrical signal, or a linear position sensor to translate change in distance to an electrical signal. Figure 1 provides a simple block diagram showing a rotary position sensor in a feedback function within a system.

A rotary position sensor provides an analog or digital signal to a microcontroller that is preprogrammed to execute a function based on the transmitted signal. The application requirements should be allowed to drive the proper rotary position sensor selection. Newer and more advanced rotary position sensors with IO Link compatibility provide additional data and diagnostics to maintain a more efficient operation in factory automation.

Engineering designers should consider several characteristics when selecting a rotary position sensor for an application based on environmental, mechanical and system requirements. All factors considered, the application requirements and the environment where it will operate should drive the final selection of the rotary position sensor. Application designers have many factors to consider when selecting a rotary position sensor for their specific application.

Among the primary characteristics to consider are the following:

Technology
- Contacting or non-contacting sensor technology
- Single-turn or multi-turn capability
- Analog or digital output
- Type of communication protocol required

Additional secondary characteristics to be considered are:

Performance
- Durability/rotational life
- Position sensing accuracy

Environment of the application
- Operating temperature range required
- Sensitivity to shock and vibration
- Required seal from dust and moisture

Designing rotary position sensors into a new system, or retrofitting an existing system, can be a challenging and technical process that may necessitate experienced field application engineering and product line support to ensure that the optimum sensor is selected. This white paper will provide a highlevel guide to assist application developers in selection of the right rotary position sensor for applications in general.

Evaluating Technology Options

Contacting or Non-Contacting Sensor Technology Contacting sensor technology employs a wiper or contactor, and a resistive element that provide a variable resistance at the output. When a voltage is applied to the rotary position sensor, the output provided is a variable voltage. This technology comprises three primary types of elements (i.e. wirewound elements, comolded resistive elements and resistance printed elements) used in combination with a wiper or contactor.

Wipers or contactors used in rotary position sensors are typically fabricated from metal such as beryllium copper or nickel silver at the low end of the spectrum, and precious metal such as palladium at the high end of the spectrum. Precious metal contactors have lower contact resistance and outperform other metals for rotational life and durability, but also carry a higher price tag over wipers fabricated from other metals.

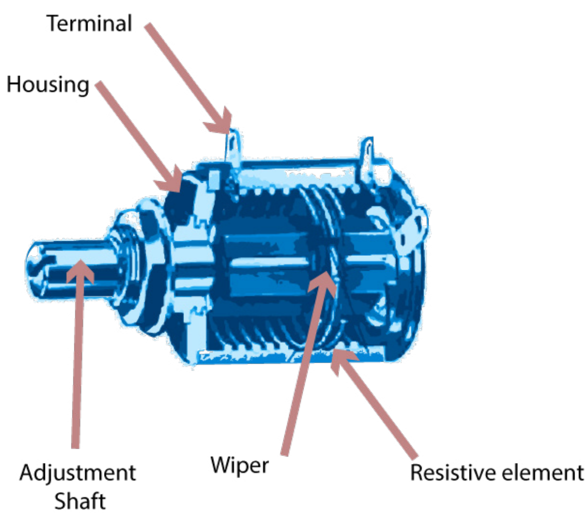

Figure 2: Wirewound Rotary Position Sensor

A wirewound potentiometer is basically considered a rotary position sensor. A variable resistance output is generated when the wiper or contactor rotates around the helical coil of wire. A variable voltage output is generated when power is applied to the unit. Figure 2 shows a cut-a-way view of a wirewound rotary position sensor.

Wirewound elements offer good stability in humid or dry conditions, excellent linearity, relatively low noise, excellent performance in a wide temperature range, high power capability, extremely low temperature coefficient of resistance, and good operational life over a wide range of resistance values up to 500 kΩ. Utilizing the right types of lubricants, wirewound rotary position sensors have the best performance in temperature extremes. Some of the limitations associated with wirewound elements include a finite resolution caused by the wiper moving in steps from turn to turn perpendicular to the coil of the wire. Low resistance values are constructed with a large diameter resistive wire as opposed to high resistance values that use a smaller diameter resistive wire. This results in a low resolution on the lower resistance values and a better resolution at higher resistance values.

If the application is sensitive to resolution, it is critical to select a resistance value with a high enough resolution to meet the requirements. Wirewound elements also have an inherent capacitance between windings. This capacitance increases with higher resistive values due to closer proximity of the windings, and conversely decreases with lower resistive values. This element technology fares well in heavy duty industrial applications that will encounter changes in environment and temperature extremes but do not require precision position sensing. Overall, wirewound contacting technology is a costeffective solution.

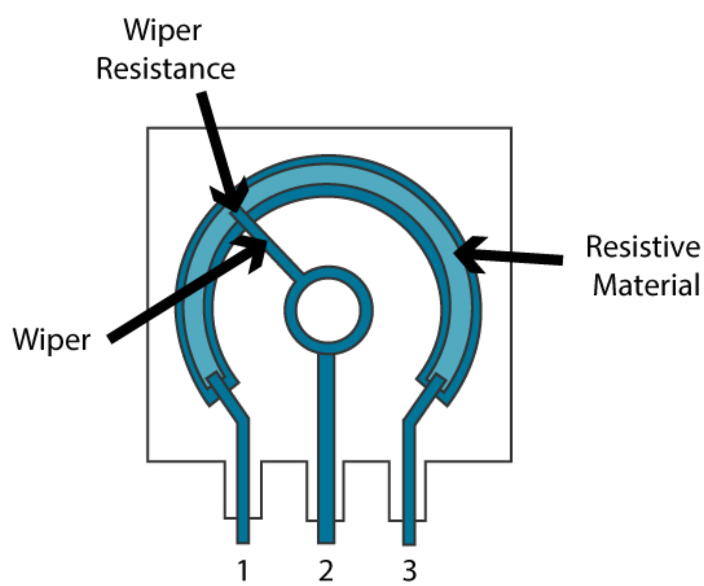

Figure 3: Thick Film Rotary Position Sensor

Single turn potentiometers are also considered rotary position sensors. As the wiper transverses the element, a variable resistance output is generated. A variable voltage is generated when power is applied to the unit. Comolded elements consist of a carbon resistive track molded onto a thermoset plastic material to create a resistive element. Similar in design, thick film printed elements have a resistive track that is printed on a ceramic, phenolic or thermoset plastic substrate to create the resistive element.

In either case, the wiper or contactor rides on the surface of the element to produce the change in resistance at the output. Figure 3 shows a diagram of a single turn rotary position sensor. These rotary position sensors are generally available in a wide range of resistance values up to 2 MegΩ. Static and dynamic noise characteristics such as contact resistance variation and output smoothness are significantly improved over wirewound elements.

Rotational life is also significantly improved, and resolution is essentially infinite producing exceptional output linearity. These types of elements do have some weaknesses. Temperature coefficient of resistance is relatively high in comparison to wirewound elements resulting in resistance shifts during temperature changes. In addition, resistive inks are typically hygroscopic and are prone to resistance shifts in changes from humid to dry conditions.

Lastly, comolded and thick film printed elements have a lower power rating over wirewound elements. This element technology fares well in applications that require precision position sensing and will not be subject to extreme environment and temperature changes, or extreme shock and prolonged vibration conditions. Overall, printed element contacting technology is a more costeffective solution over wirewound element technology.

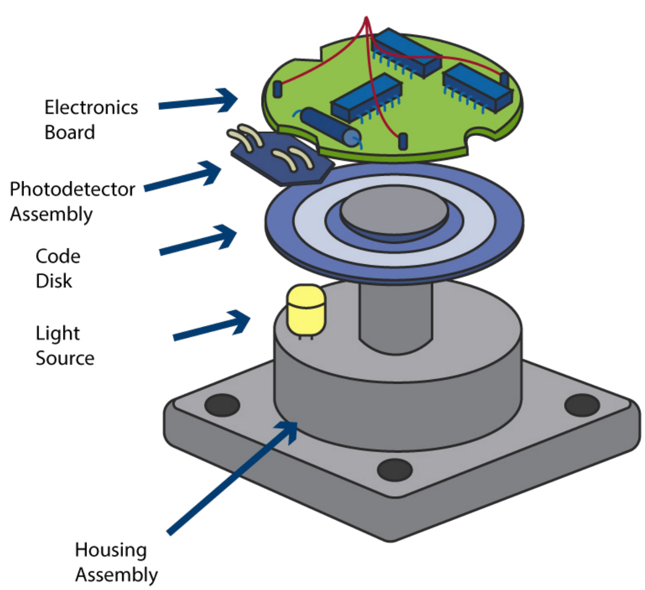

Figure 4: Optical Rotary Position Sensor

Non-contacting sensor technology provides a longer sensor life since the wear and tear associated with mechanical contact is eliminated. Optical, magnetic and inductive are all common types of non-contacting technology.

Optical technology utilizes three main components for sensing: a light source (typically an IRED or LED), a code disk, and a photodetector IC. The code disk is rotated allowing light to pass through the slots in the disk. The detector IC senses the light and generates the output code. Rotary position sensors that use these components deliver a longer field deployment over any products utilizing contacting technology. Figure 4 shows components and assembly of a typical optical rotary position sensor.

Optical technology can be used both in static and dynamic applications, and perform extremely well in controlled environments. Applications using optical rotary position sensors can expect extended rotational life 2 to 5 times better than contacting technology. 10 million to 100 million cycles are typical rotational life performance specifications. At the higher end of the spectrum, the larger and more expensive optical rotary position sensors can operate at high speeds for prolonged periods of time and are rated at higher rotational life specifications. Standard digital output codes used in most applications include incremental quadrature, absolute, and grey code. However, there are some limitations to optical technology.

Optical rotary position sensors are very sensitive to extreme temperature excursions, high humidity conditions, and conditions where mechanical shock or vibration will be encountered. Overall, the price range for optical position sensors is directly related to the required resolution and rotational life specification. Low resolution will cost a few dollars whereas ultra high resolution with extended life will cost a few hundred dollars. Magnetic technology utilizes two major components: a magnet and a sensor IC. The magnet rotates above the sensor IC that senses the magnetic pole position generating the output. Designs can use Hall-effect or magnetoresistive sensor ICs to generate the output.

Figure 5 shows the configuration and function of a typical Hall-effect rotary position sensor.

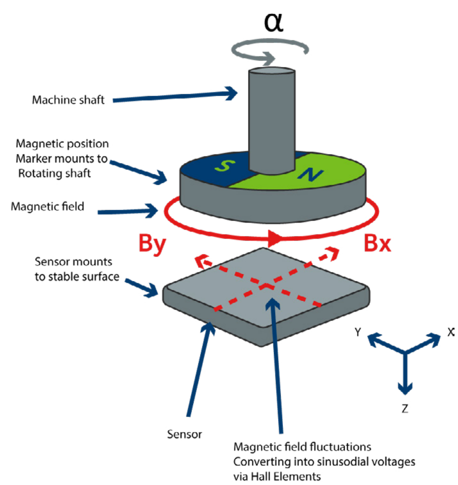

Figure 5: Magnetic Rotary Position Sensor

Rotary position sensors that utilize this technology also deliver a longer rotational life span over any products utilizing contacting technology.

In addition, magnetic technology can reliably operate in a wide temperature range and in humid or dry conditions. Magnetic rotary position sensors are intended for use in dynamic and static applications, and perform extremely well in a wide variety of hazardous and dirty environments. Shock and vibration conditions are no problem with this technology.

Applications using magnetic rotary position sensors can expect extended rotational life 2 to 5 times better than contacting technology. At the higher end of the spectrum, the larger and more expensive magnetic rotary position sensors can operate at high speeds for prolonged periods of time. There are some limitations to this technology.

Magnetic rotary position sensors may require compensation at high temperatures and may not operate well at low temperature extremes. Magnetic rotary position sensors cannot be used near high magnetic fields without proper internal or external shielding. Many magnetic rotary sensors require some form of calibration prior to installation, or after installation. Overall, the price range for magnetic position sensors is directly related to the required accuracy and rotational life specification. Low accuracy will cost a few dollars whereas ultra high accuracy extended rotational life sensors will cost a few hundred dollars.

Inductive technology utilizes three major components: a metal target, a coil and a sensor IC. The metal target is made from copper, aluminum, brass, or other conductive type of metal. The metal target rotates around the coil that is typically etched on a printed circuit board and connected to a surface mounted sensor IC. The metal target disturbs the magnetic field produced by the coil as it rotates around the coil.

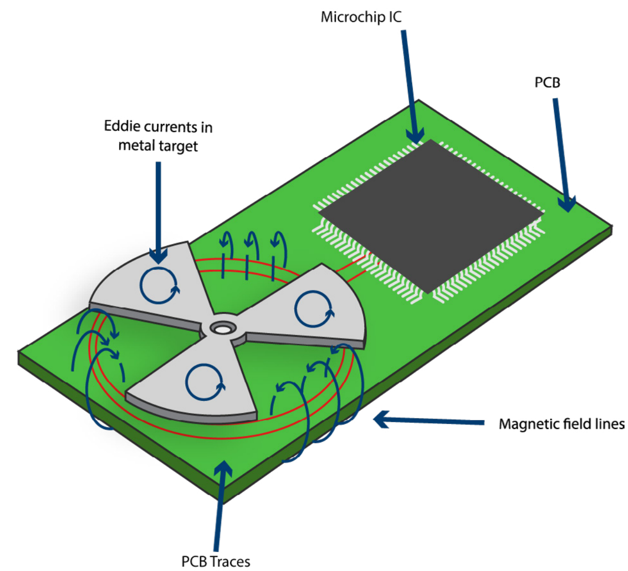

Figure 6: Inductive Rotary Position Sensor

The disturbances are sensed by the sensor IC that generates the output signal. Figure 6 shows the simple assembly of an inductive rotary position sensor. Rotary position sensors that utilize this technology deliver a longer rotational life span over any products utilizing contacting technology. In addition, inductive technology can reliably operate in high temperature and humidity conditions.

Like magnetic technology, inductive rotary position sensors are intended for use in dynamic and static applications, and perform extremely well in a wide variety of hazardous and dirty environments. Applications using inductive rotary position sensors can expect extended rotational life 2 to 5 times better than contacting technology. Resolution is scalable and position sensing is highly accurate. Stray magnetic fields are not a problem for inductive rotary position sensors since magnets are not used to produce the output. However, there are some limitations to this technology. Inductive rotary

position sensors are not plug-and-play devices. They must be calibrated prior to installation. Calibration can be done in the manufacturing facility prior to installation, or they can be shipped with custom calibration by the manufacturer. Overall, inductive rotary position sensors are a cost effective alternative to optical and magnetic rotary position sensors.

Single or Multiturn Capability

Depending on the application, either a single-turn or multiturn sensor will be required to account for the full position range, or electrical rotational angle in the application. The electrical angle can vary from a few degrees to multiple revolutions, where 360 degrees represents a full revolution. Rotary position sensors offer similar packaging, construction, and standard features, with the difference in part number accounting for the number of turns or the mounting style for which the device was designed.

Single turn rotary position sensors are typically used in applications that require position sensing of less than 360° of mechanical rotation. Non-contacting single-turn position sensors allow for continuous rotation and are typically used in applications where multiple turns are required in conjunction with high speed of rotation.

These devices can be used to provide measurements such as revolutions per minute (rpm) values up to 10,000 rpm, rotation count, and direction of rotation.

In multiturn position sensors, the measurement corresponds to the position of the sensor over the full rotation angle whether it is 3-turns, 5-turns, 10-turns, 15-turns, or 20-turns. Contacting multiturn rotary position sensors typically have an upper limit to the number of rotations and typically have end stops. Multiturn position sensors are used in applications where high accuracy in measuring the rotational angle are required.

Analog or Digital

To determine the optimum sensor output, it is important to consider the sensor interface connection and the amount of board space available.

Contacting rotary position sensors and non-contacting Hall-effect rotary position sensors produce analog outputs and are designed to be use in analog systems. There is no need for output conversion when used in this configuration. Analog systems detect the change in voltage on the output of the rotary position sensor. An analog contacting rotary position sensor can be used in a digital system with the use of an analog-to-digital (A/D) converter to convert the analog output to a digital signal that is fed to a microprocessor controller.

Non-contacting optical and digital magnetic or inductive rotary position sensors are designed to interface directly with a microcontroller, digital I/O board, or programmable logic controller (PLC), thus eliminating the need for an A/D conversion process. Used in this configuration, there is a reduction of memory overhead, wiring and wiring interconnects, and greater program speed for the microprocessor unit. Less likely to be the case, a non-contacting rotary position sensor can be used in an analog system with the use of a digital-to-an-alog (D/A) convertor. This configuration is the least efficient use of non-contacting rotary position sensors and should be avoided.

The most effective and efficient use of products is to design analog rotary position sensors for use in analog systems and digital non-contacting rotary position sensors for use in digital systems.

Communication Protocol

Typically, potentiometric contacting sensors output a variable voltage, commonly known as an analog output signal. Whereas encoders produce an incremental quadrature or absolute output signals that can be directly integrated into digital systems. In today's highly computerized world, it is necessary to have flexibility with communication protocol in order to minimize circuitry and maintain maximum processing speed for a given system.

Some of the more popular communication protocols for magnetic and inductive rotary position sensors are synchronous serial interface (SSI), serial peripheral interface (SPI), controller area network (CAN), and pulse width modulation (PWM). These communication protocols are used in interrogation of the sensors to extract real time data, to activate or deactivate the units, and to perform diagnostics. Each type of communication protocol has its advantages and disadvantages, and is normally selected based on the system requirements.

Rotary position sensors being used in automated industrial process applications now require a more sophisticated form of communication. Many highend rotary position sensors are now IO-Link compatible. IO-Link is a short distance, bidirectional, digital peer-to-peer, wired (or wireless), industrial open communications networking standard (IEC 61131-9) used for connecting digital sensors and actuators to either a type of industrial fieldbus, or a type of industrial Ethernet. Its objective is to provide a technological platform that enables the development and use of sensors and actuators that can produce and consume enriched sets of data that in turn can be used for economically optimizing industrial automated processes and operations. IO-Link allows three types of data to be exchanged: process data, service data, and events.

An IO-Link system consists of an IO-Link master and one or more IO-Link devices such as rotary position sensors or actuators. An IO-Link master can have one or more IO-Link ports to which only one device can be connected. This can also be a “hub” that enables the connection of classic switching sensors and actuators. Rotary position sensors with IO-link capability have identification data such as type designation, serial number, and parameter data that can be read or written via the IO-Link protocol.

The IO-Link communications protocol consists of communication ports, communication modes, data types, and transmission speeds. There are four communication modes that can be applied to a port connected to a terminal device: IO-Link, DI, DQ and Deactivated. IO-Link mode configures the port for bidirectional communications, DI mode configures it as an input, DQ configures it as an output, and Deactivated just simply deactivates the port. There are four data types: process data, value status data, device data, and events data. The protocol can be configured to operate at three different transmission speeds: 4.8 kilobaud, 38.4 kilobaud, or 230.4 kilobaud. An engineering tool is used for configuring the master to operate as the network bridge. In summary, IO-Link capability provides a higher level of communication between rotary position sensors and operating systems improving production efficiency.

Selecting The Right Rotary Position Sensor For Your Application

Given the wide range of rotary position sensors available, the primary design consideration for any application should be selection of the most reliable rotary position sensor compatible with the system suited to the environment where the sensor will be located. Contacting technology can provide high precision and reliability, whereas, non-contacting technology provides a longer deployment of life under conditions such as temperature extremes, vibration, shock, and the ingress of fluids, dust and other hazardous material.

The second design consideration is to assess the required mechanical rotation so that the rotary position sensor has a large enough mechanical angle to sense the movement, direction, and/or speed of rotation. Position sensing of very small mechanical angles would typically require a multiturn rotary position sensor, whereas, measurement of larger angles with less sensitivity would be accomplished with the use of a single turn rotary position sensor.

The third design consideration is integration of the position feedback sensor into the system and the required communication protocol. Although a contacting analog output sensor may be an adequate and more simplistic approach to a design, a digital output reduces the complexity of the signal conversion in digital systems, providing direct input to a microcontroller while offering flexibility in communication protocol. The addition of IO-Link compatibility adds bidirectional communications and ability to communicate process data, value status data, device data, and event data greatly reducing equipment service down time while enhancing process automation.

Finally, the cost of the rotary position sensor should be considered for compliance to budgetary constraints. Contacting technology provides a costeffective solution, whereas, non-contacting solutions offer additional digital communication that can be advantageous for self diagnostics, enhanced communication efficiency, and production automation. These are options that can be vital in systems where the end application is in a remote area where access prohibitive.

CTS Provides A Variety Of Rotary Position Sensor Options

As the application requirements and sensor technology become more clearly defined in the selection process, the right rotary position sensor solution can be narrowed from simple to complex until the necessary features are clearly defined. Whether contacting or non-contacting, single turn or multiturn, analog or digital, the standard and optional features of CTS rotary position sensor products provide a solution for most applications.

CTS offers a wide variety of industrial grade potentiometers that can be used as single turn rotary position sensors. Available in wirewound and thick film conductive plastic printed elements, these rotary position sensors offer 1 to 3 million rotational life cycles, precision linearity, wide operating temperature range and power handling capabilities.

CTS series 285 and 286 rotary positions sensors, pictured in figures 8 and 9, are designed to fit most industrial applications. The sensors can be house in a variety of ways including flange mounted.

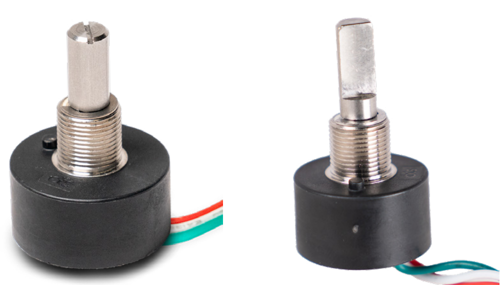

Figure 7: CTS 285 and 286 Rotary Position Sensor

Figure 8: CTS Flanged Rotary Position Sensor

Mechanical and optical encoders are available in various package sizes with incremental and absolute outputs, and a variety of resolutions. Key optical encoder performance specifications include rotational life of up to 3 million cycles, a variety of resolutions up to 64 PPR, and operating temperature of up to +85°C. CTS also offers non-contacting Hall-Effect rotary position sensors in standard bushing and flange mount styles that provide advantages over traditional contacting solutions.

Key performance specifications include 10 to 50 million rotational life cycles, precision linearity & hysteresis, operating temperature of up to +125°C, standard internal EMF shielding, and IP seal options. Modification of standard products and custom engineered solutions are also available. Can be manufactured to meet IP ratings up to IP68 for exceptional performance under the harshest environmental conditions.

About CTS

CTS (NYSE: CTS) is a leading designer and manufacturer of products that Sense, Connect, and Move. The company manufactures sensors, actuators, and electronic components in North America, Europe, and Asia. CTS provides solutions to OEMs in the aerospace, communications, defense, industrial, information technology, medical, and transportation markets.

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