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FOR MACHINE BUILDERS

Encoders

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TABLE OF CONTENTS

AD INDEX

Key positions on encoders

Understand the specifications, but don't miss any of the signals by being too slow and not willing to communicate

By Dave Perkon, technical editor

A common discussion about encoders revolves around specifications. How may pulses per revolution? What type of output? Incremental or absolute? These questions must be answered; however, there are often many considerations when deciding to use them on a machine. These devices must work to get better control of a machine position, but they must also work well in the control system.

An encoder's purpose is to report the position of linear or rotary motion as a digital signal to a controller, which then uses it for monitoring and control purposes in a variety of machine tools, multi-axis positioning systems and robotics. With a little math programming or built-in controller functionality, this digitally translated position can be used to monitor velocity, distance, angle, acceleration, deceleration and direction.

If the control system needs more information than "motor on" or other open-loop status information, a sensor of some type is required. A motor gearbox output shaft can be monitored with a high-speed proximity switch or Hall-effect sensor. This is typically a tachometer configuration where one pulse per motor revolution or teeth of a gear is converted to rpm, but this speed information is very coarse. Some drives can also monitor the motor current or pulse-width modulation (PWM) output and assume rotation causing torque in the motor, but signal errors and noise can cause inaccuracies. For a more accurate and reliable closed-loop feedback signal, encoders are a best practice.

There are many reasons to use incremental or absolute encoders, and quadrature or nonquadrature outputs. In its basic form, an incremental encoder provides digital pulse signals suitable for use with high-speed PLC inputs or counter modules.

Incremental encoders require a special PLC input to properly capture the signal. In addition to an encoder's mechanical speed limit and the type of output the encoder produces, a key specification is the encoder's response frequency—the maximum frequency the encoder signals can change and still provide an accurate output. This defines both maximum encoder electrical speed and the PLC input module's required maximum switching frequency. A standard PLC input module likely will not work.

For example, an encoder with 2,048 pulses per revolution (ppr) spinning at 5,000 rpm creates a signal frequency of more than 170 kHz (2,048 ppr x 5,000 rpm / 60 sec/min). Many encoders' response frequencies and high-speed PLC inputs are below this frequency, which, depending on the device, can be between 100 kHz and 250 kHz. While most applications run at slower speeds, be sure to check the frequency required.

A simple absolute encoder can provide parallel, discrete output signals, often in a Gray code format, that can be monitored by a PLC's standard dc inputs. No homing routine is required for the encoder to know position. With 10-digital input bits, Gray code provides a resolution of 1,024 pulses per revolution; that is plenty of information for a controller to use to monitor and control position in many applications.

However, the response frequency of the encoder still applies, but the PLC scan time must be considered, as well. With a PLC running at a 10 ms/scan rate, the digital inputs are only updated (read) about 100 times a second. That sounds fast unless an absolute encoder with 1,024 pulses per revolution is updating input signals. Rotating at just 6 rpm, the encoder changes states more than 102 times a second. Do you need all the data, or can some be lost?

If data cannot be lost, adding motion controllers or connecting encoders directly to drives is the next step for higher resolution and higher frequency applications.

With the advent of the Industrial Internet of Things (IIoT) and related smart devices, encoders are moving beyond the basic incremental encoder pulse and direction and parallel absolute position encoders. They are connecting to serial, fieldbus and Ethernet networks; and some are becoming programmable.

The synchronous serial interface (SSI), based on the RS-422 standard, has been around for quite a while and can connect directly to a PLC with the proper digital interface module. Moving to a fieldbus, such as Profibus, CANopen and DeviceNet, the bus topology is easy to integrate into automation, especially if there are many devices.

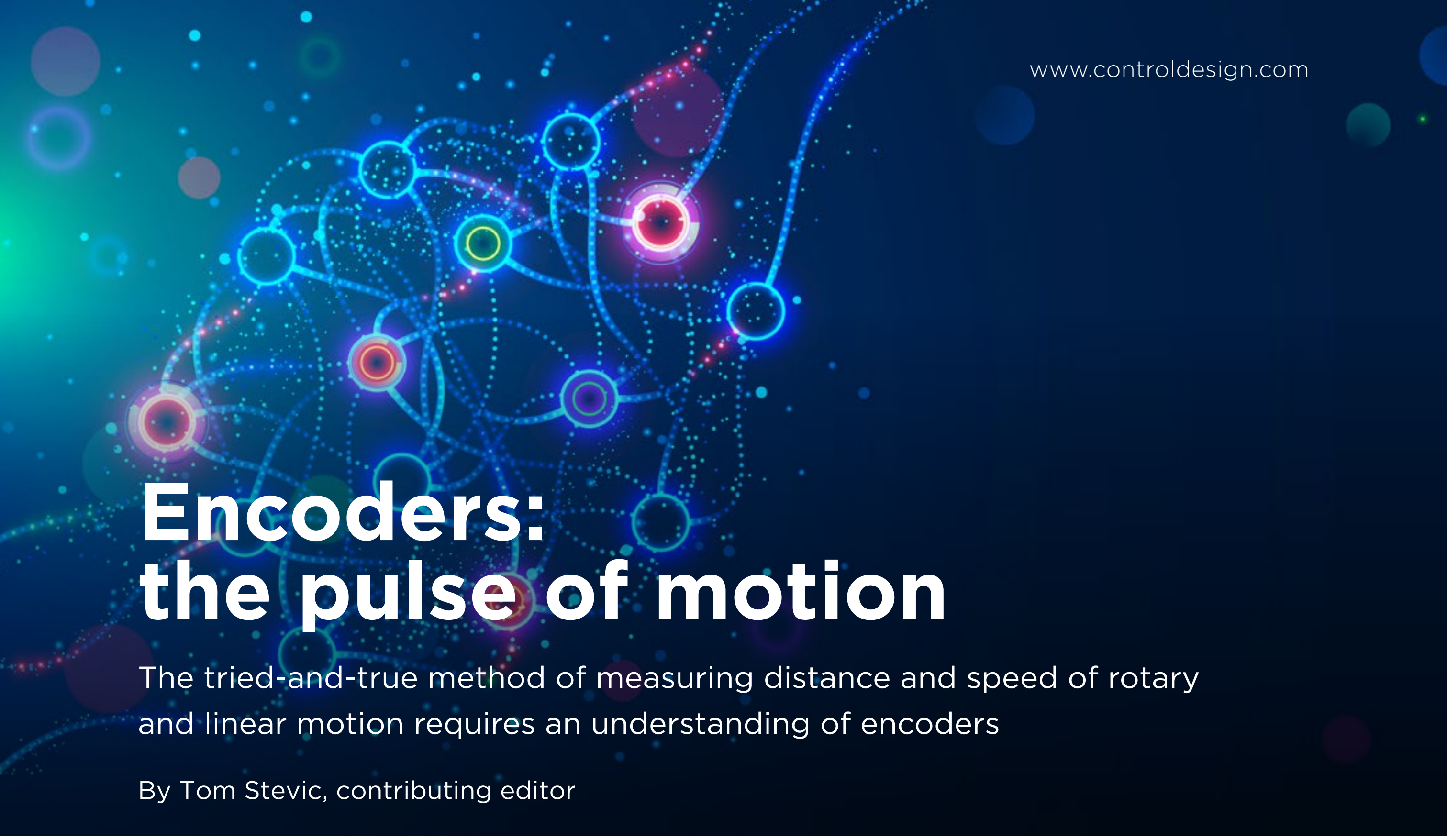
Using an Industrial Ethernet interface to encoders is also a great option, especially since many controllers are already using EtherNet/IP, Profinet, Powerlink, EtherCAT and others Ethernet protocols.

Both fieldbus and Ethernet communication interfaces provide a simple way to read position data from an encoder, but they are also smarter and provide extensive diagnostic capabilities.

With any of these communication options, be sure to understand the update rate of the encoder and the update rate required by the application. Monitoring and controlling positions of an on-the-fly cutter process has much higher speed and resolution requirements than controlling the speed of several conveyors.

For an encoder there are several parameters that must be specified. The programmable encoders are making that configurable. Once an incremental or absolute programmable encoder is selected, resolution can be programmed. Some programmable encoders may include programmable output types, index pulses, number of turns and waveforms. Some programmable absolute encoders also allow configuration of the code, such as Gray or binary, and code sequence, such as clockwise.

Be sure to understand all encoder requirements for an application, double-check some key specifications, such as frequency, and consider a variety of ways to connect it to the controller.



Encoders: the pulse of motion

The tried-and-true method of measuring distance and speed of rotary and linear motion requires an understanding of encoders

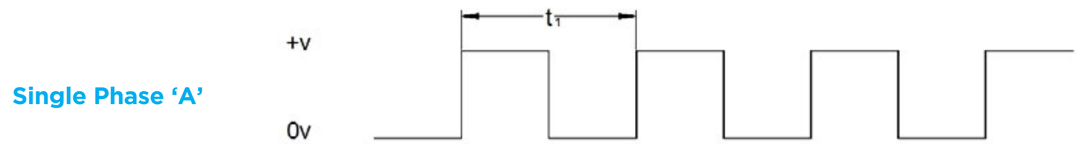
By Tom Stevic, contributing editor

Encoders are used to measure distance. Rotary encoders measure the angular distance around the circumference of a circle, often in degrees. Linear encoders measure the distance an object moves in a straight line. Measuring the number of pulses over a set period produces the property of speed. Encoders are further classified as incremental or absolute.

Most Incremental encoders generate an electrical pulse for each division of travel. The division of distance depends on the design of the encoder. If a rotary encoder is designed to produce 100 pulses per revolution (ppr), each pulse is equal to 3.6 degrees of rotation. For a linear encoder designed to produce 100 pulses per meter, each pulse would equal 10 mm of travel. The number of ppr can be as low as 10 or as high as several thousand.

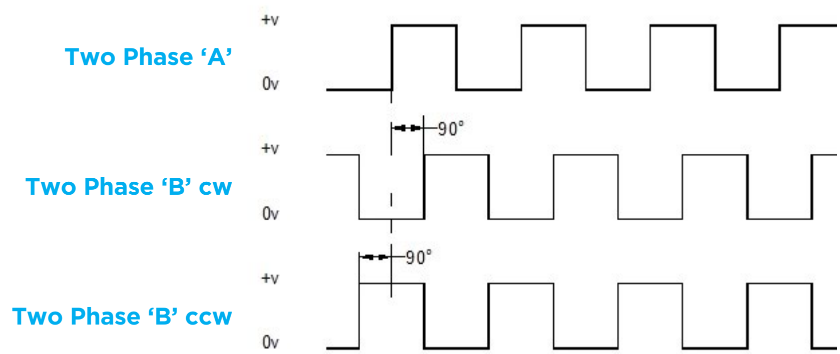
Each pulse an incremental encoder produces is identical to every other pulse. The result of this characteristic is that the mechanism needs to be moved to a known position before being used to measure distance or if the encoder loses power for any reason. Moving the mechanism to a known position is typically referred to as homing. Manufacturers may refer to this procedure by different names.

The simplest type of incremental encoder has one output pulse signal. This style of encoder is sometimes referred to as a unidirectional encoder because the counting device can de-



SINGLE PHASE ENCODER SIGNAL
Figure 1: A simple incremental encoder provides this single phase square-wave output.

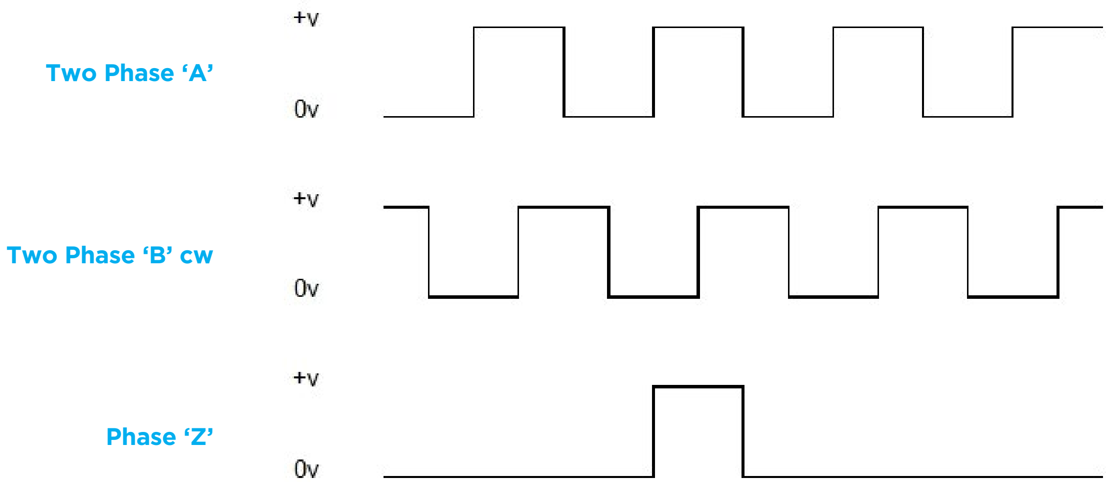
termine movement, but it cannot determine direction. In Figure 1, the time period t1 represents one full pulse. As the speed of the device being measured increases, t1 will decrease. A decrease in t1 will also occur with an increase in the number of PPR the encoder provides. To be reliable, the counting device the encoder is connected to must be fast enough to process the incoming signals.



ENCODER DIRECTION
Figure 2: This two-phase encoder signal output shows how the phase angle between each phase can determine the direction of travel.

Determining direction with an encoder requires at least two pulsed outputs, this style is typically referred to as a quadrature encoder. When the pulse from the A phase leads the pulse from B phase, the encoder is either rotating in a clockwise position or, for linear encoders, traveling away from the home position. If the B phase leads the A phase, the encoder is rotating counterclockwise or toward the home position. Figure 2 shows a 90° offset between phases and a 50% duty cycle for high to low states of the encoder output pulses. There is no official standard for the lead-lag relationship, the offset or duty cycle. Refer to the manufacturer's technical literature to verify the relationship of the pulse trains for the encoder used.

Many encoders offer a third output pulse called the Z phase. For rotary encoders, the Z phase is designed to output a pulse once every revolution or, for linear encoders, once during the full travel of the encoder. If a rotary application does not require rotation of more than 360°, such as in a robot joint, the Z phase can be used as a home position. If the application requires rotation of more than 360°, the Z phase can be used as



ENCODER RESET

Figure 3: Some encoders offer a Z phase in the encoder, which provides one pulse per revolution or full-linear travel.

a check to make sure that no pulses have been lost due to signal noise or defective wiring (Figure 3).

Other types of pulse outputs include a complementary output for each pulse. The complementary outputs mirror the signals in the opposite polarity. When one phase signal is positive, the complementary output is negative.

Encoders offer several types of electrical interface styles that connect to the counting device. An open-collector interface has a transistor in the encoder electronics for each phase. The transistor pulls the voltage supplied by the counting device to ground. This allows current flow in the circuit. When the transistor turns off, the current flow is interrupted, and the counting device interprets the change in current as a pulse. Open-collector outputs can be susceptible to electrical noise if not correctly shielded. Open collector outputs are also affected by the resistive voltage drop of the connecting wires. The wires should be as short as possible.

Line-driver outputs supply differential signals and meet RS-422 communication specifications. This output style provides electrical noise suppression. If the environment is electrically noisy or the distance is such that an open collector output may lose too much signal strength due to the voltage drop across the connecting wires, line-driver output should be considered. There are other types

> To be reliable, the counting device the encoder is connected to must be fast enough to process the incoming signals.

of output signals available from different manufacturers. Always consult the manufacturer's technical information when designing a system.

Absolute encoders are similar to incremental encoders because they provide a method to measure rotational and linear distance. The difference is that absolute encoders provide an output that is directly relatable to the position of the encoder. If an incremental encoder loses power, when power is restored the counting device cannot determine the position of the encoder unless it happens to be at the home position—the home position being determined with the encoder's Z phase or an external sensor. An absolute encoder supplies its position even if it has been moved during the power outage.

One style of absolute encoder supplies a unique digital output for each position. The resolution of the encoder determines the number of separate wires required to provide its position to the counting device. An encoder with a resolution of 256 requires eight signal wires plus one signal ground. An encoder with a resolution of 4,096 requires 12 signal wires plus one signal ground. Absolute encoders use one of two digital codes to supply the position information. One code is straight binary. Most controls engineers are familiar with this. A second

Decimal	000	001	002	003	004	005	006
Binary	000	001	010	011	100	101	110
Grey Code	000	001	011	010	110	111	101

FORMATS
Table 1: Digital signals from absolute encoders provide positional information using binary or grey-code formats.

method called grey code is also available. Grey code only changes the state of one bit for each count (Table 1). Changing only one bit at a time allows for error checking by the counting device.

Absolute encoders are also built with analog outputs. All of the standard industrial signal ranges are available, 0-5, 1-5, 0-10, 1-10, 0-20 mA and 4-20 mA. The resolution for an analog encoder is dependent on the maximum count the encoder can produce or the maximum count the input device can decode. Connecting a 10-bit encoder (1,024 counts) to an 8-bit input card (256 counts) will provide a maximum resolution of 256 counts per revolution.

Synchronous serial interface (SSI) is a communication system that has been widely adopted by the motion control industry.

Optical or capacitive encoder feedback?

How to decide which device is best for a step motor system

By Eric Rice, Applied Motion Products

Step motor systems utilize encoders to provide feedback to the motor drive or controller and improve overall performance. Typically installed to the rear shaft of the motor, encoder feedback functionality can dramatically improve system performance in regard to accuracy, smoothness, torque and positioning (Figure 1). But which encoder works best with a step motor?

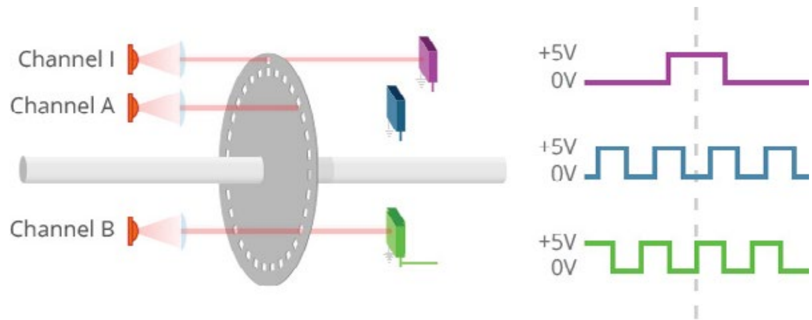
MOUNTED
Figure 1: Adding an encoder to the step motor enables greater system accuracy.
(Source: Applied Motion Products)

Optical encoders have played a role in various industrial applications for a long time. They are accurate, reliable and user-friendly. They offer a wide range of resolutions. Optical encoders operate by passing light, generated by LEDs, through a slotted disc mounted to the motor shaft to an array of optical sensors. As the shaft turns, the slots in the disc alternatively pass or block the light emitted by the LEDs. This pulsing of light as the shaft turns creates a series of digital pulses that provide position and speed information back to the motor controller (Figure 2).

While offering similar benefits, capacitive encoders utilize newer technology in providing the same position and speed information as optical encoders (Figure 3). The different operating principle of capacitive encoders lies in generating the digital feedback pulses. An ac field transmitter emits a signal that is modulated by a metal pattern on a disc attached to the motor shaft. As the shaft turns, the sinusoidal metal pattern on the disc creates a signal modulation due to varying capacitive reactance that is repetitive and predictable. A field receiver on the other side of the disc receives this modulated signal and converts it into digital pulses for use by the motor controller.

Both optical and capacitive encoders are excellent choices for the most common motion control applications. However, capacitive encoders offer benefits in harsh environments. Optical encoders are susceptible to signal degradation or loss if exposed to dust, oil or similar contaminants. Capacitive encoders are generally immune to these environmental contaminants.

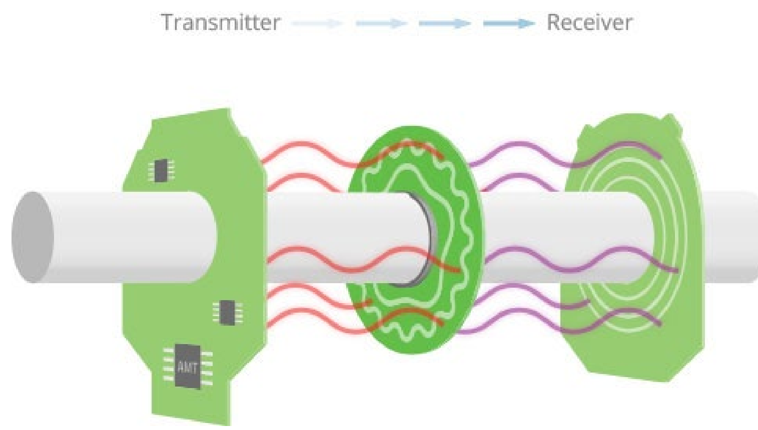
As encoders are offered in different configurations,



OPTICAL ENCODER

Figure 2: The pulsing of LED light as the shaft turns creates a series of digital pulses that provide position and speed information back to the motor controller.

(Source: CUI)



CAPACITIVE ENCODER

Figure 3: The sinusoidal metal pattern on the disc creates a signal modulation due to varying capacitive reactance that is repetitive and predictable.

(Source: CUI)

whenever possible use encoders with differential signals. Differential signals are inherently more noise immune than single-ended signals. The usage of single-ended signals should be limited to installations where ambient electrical noise is well controlled and single-ended signals are acceptable. Encoders with an index channel that creates one pulse per revolution are useful for accurate referencing of the motor axis to a home position.

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