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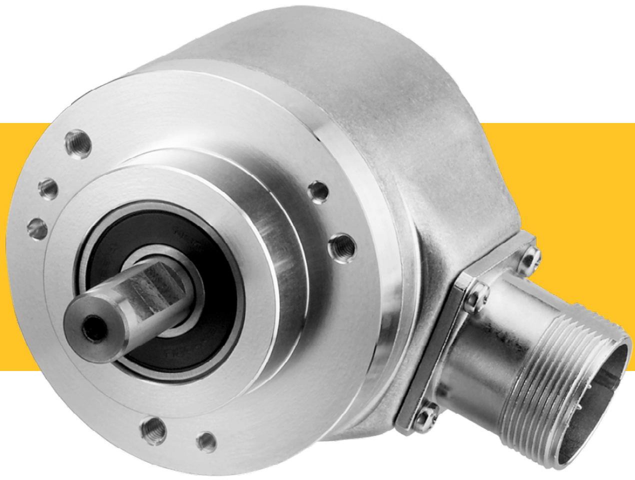
Incremental & Absolute Encoders:
What's the Best Solution for Your Application?

There are many factors you need to take into account when selecting the right encoder for your application. How do you choose between Incremental and Absolute encoders?



Absolute Encoder

VS.

Incremental Encoder

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Encoders provide feedback for a wide range of motion tasks from positioning a patient in an MRI machine to bottling beverages at 300 units per minute. When it comes to specifying an encoder, users must make decisions about a number of key characteristics. Are they tracking linear or rotary motion? Should they use optical or magnetic technology? And, perhaps most essential to the success of the application, should they choose an incremental or an absolute encoder? Even when incremental and absolute encoders are based on the same sensing mechanism, the two deliver very different performance. Building a successful system requires understanding the trade-offs involved and making the right choice between the two.

As the name suggests, an absolute encoder maintains a record of its position within some absolute coordinate system, whereas an incremental encoder outputs incremental changes from a pre-defined home position. As a result, an incremental encoder requires additional electronics (typically a PLC, counter, or drive) to count pulses and convert the data into speed or motion, while an absolute encoder produces digital words identifying absolute location. Not surprisingly, incremental encoders are typically better suited to simpler, lower performance applications, while absolute encoders are most often used in more complex, mission-critical applications with higher speed and position control requirements. The correct choice of output type depends on the application.

Incremental encoders

When an incremental encoder moves, it generates a stream of binary pulses proportional to the rotation of the shaft (rotary encoder) or distance traveled (linear encoder). In the case of an optical design, a patterned disc or linear strip passing between an LED and a photosensor alternately passes or blocks the beam, producing an analog signal; additional circuitry, often in the form of an onboard ASIC, converts this signal to a square wave. Magnetic encoder designs can be based on any one of a variety of mechanisms but typically involve rotating a magnetic field to generate a voltage pulse or a change in resistance that can be converted into a pulse.

Single-channel incremental encoders feature a single stream of output pulses. As a result, they can only provide limited information.

Based on the resolution of the encoder—i.e., the number of pulses per revolution in a rotary design or millimeters/inches of travel in a linear design—the external electronics can count pulses to calculate speed, or track offset relative to some reference coordinate (home), which can be used to determine position. Single-channel designs provide good solutions for applications like single-direction conveyor systems.

Although they are simple, robust, and economical, single-channel incremental encoders have an important limitation—they cannot be used to determine direction of motion. That task requires more input, typically from a dual-channel design that generates output over two distinct channels ("A" and "B"), which are 90° out of phase with each other. These dual-channel designs are sometimes called quadrature encoders due to the four rise and fall points of their signal output. The direction of travel determines which channel goes high first, allowing the processor to easily monitor direction of motion (see figure 1). Resolution can be increased by as much as a factor of four by triggering on the leading and/or trailing edge of the pulses for one or both channels.

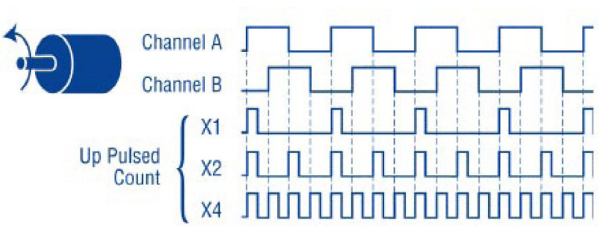

Figure 1: A quadrature encoder generates two pulse streams that are 90° out of phase with one another. As a result, the system can determine directionality by monitoring which channel leads in phase. Triggering off of the leading and or trailing edges of the pulses can increase resolution by up to four times.

Quadrature encoders provide robust solutions for challenging applications. In a high-vibration environment, for example, a single-channel encoder might misinterpret the pulse stream generated by an axis dithering about a set point as a real displacement. A quadrature encoder would be able to recognize the changes in direction and ignore the pulse stream or filter it out as noise.

Incremental encoders can also include an additional channel known as the index, or Z channel. This track causes the encoder to generate a pulse once per revolution for a rotary encoder or at a specific position for a linear encoder (see figure 2). The Z channel can be used as a tool to identify a specific location at startup. For high-speed applications, it can be an easy way to indicate a single revolution, which can be processed with time to yield RPMs.

Figure 2: Code disc for an optical quadrature encoder shows the inner ring for the Z channel, which generates a single pulse per revolution. The outer bands correspond to the A channel and B channel; notice that they are offset by 90°.

Applications suitable for incremental encoders are generally simple, only requiring a direct connection between the encoder and the control device regardless of whether it is a counter, PLC, or drive.

What to know before you choose:

1. What is the complexity level of your application?
2. What parameters (speed, position, direction) do you need to control for?
3. Can your application afford to rehome if powered down?
4. What performance level (in pulses-per revolution) does your application require?
5. How will the encoder communicate with other electronics in the system? Does your application require communication via one of several protocols?
6. How cost sensitive is your application?

Absolute Encoders

The biggest drawback to incremental encoders is that when the system is powered down, for example during a temporary power outage, it does not track any incremental change output by the encoder. As a result, in order to provide accurate position data, an incremental encoder must be rehomed at startup. For an application like a converting machine that might be shut down every night and restarted every morning, this is not a problem. In the case of an automotive assembly robot arm that loses power while welding seat brackets inside a vehicle, rehoming could cause catastrophic damage to both product and robot arm alike. Absolute encoders provide an effective alternative suitable for high-reliability applications.

Unlike an incremental encoder, an absolute encoder does not generate output as pulses but as digital words that identify its position as a static reference point within an absolute coordinate system. As a result, even in the event of power outage, an absolute encoder maintains record of its absolute position. Upon restart, the system can resume motion immediately, without rehoming.

An absolute rotary encoder features a code disc attached to the shaft and a fixed mask that allows the system to essentially create a unique binary identifier for each point of travel (linear versions operate analogously, but for the sake of simplicity, we'll focus on rotary versions here). As the code disc rotates atop the fixed mask, the system periodically reads out the identifier, outputting it as a multi-bit digital word. The associated controller or drive polls the encoder to capture position data that it can use directly or process into velocity information.

In the case of an optical encoder, the fixed mask features alternating transparent and opaque regions. Similarly, the code disc is patterned with transparent and opaque regions to define a set of rings (tracks) and periodic radial zones on those tracks (see figure 3); each track is read out by a different LED/photosensor pair. The code disc sits atop the fixed mask, which typically sits atop a sensing ASIC that contains the detector array and associated electronics. As the code disc turns, its transparent regions periodically overlay the transparent regions on the fixed mask, allowing the optical signal to pass through to the detector to generate a pulse. Each track on the code disc corresponds to a specific bit in the output; the number of tracks n generates 2n radial positions. Many manufacturers have a base single turn resolution of 4096 (12bits) positions per rotation. More advanced devices will be able to resolve positions all the way up to 4,194,304 unique positions (22bits).

Coordinated motion applications will often utilize a multi-turn encoder that can track multiple rotations of the shaft. This can eliminate a system from having to home to limit switches such as in a CNC or similar XY stages. In a multi-turn encoder a secondary disk (or discs) are geared to the primary single turn code disc and track the number of rotations. Each time the primary disk completes a revolution, the secondary disk indexes.
This design thus assigns a unique coordinate for each shaft position corresponding to each revelation of the indexed shaft up to 4096 revolutions. This may be referred to as a 24bit encoder. Having 12bits of single turn information and 12bits of multi-turn information.

Figure 3: Code disc for an optical absolute encoder features one track for each bit of resolution. The number of bits n (2n) corresponds to 2n radial positions.

Applications that use absolute encoders are usually more complex, requiring both hardware and software implementation in order to interact with other electronics in the system (PLC, drive, etc.).

Incremental versus Absolute

There is no one right encoder type, only the type determined by the requirements of the application (see table). Incremental encoders are simple to integrate and easy to maintain. For less complex applications in which cost is a major concern, an incremental encoder might be the best choice. They are frequently used for speed or velocity monitoring, for example coordinating the line speed of conveyors in a warehouse or mail-sorting facility. Whether the appropriate incremental encoder is a single-channel or a quadrature design depends upon whether the application is direction sensitive.

Table 1: Comparison of incremental versus absolute encoders

	Incremental		Absolute
	Single-channel	Quadrature	
Complexity	Simpler		More Complex
Output	Speed, Displacement	Velocity and Direction	Velocity and Absolute Position
Needs homing on startup?	Yes		No
Resolution	Up to 10K PPR (Direct Read)		Up to 22-bit (ST) / 12-bit (MT)
Communication via protocol	No	No	Yes
Cost	Generally Lower		Generally Higher

As we discussed, absolute encoders are a good fit for safety-critical applications that cannot allow rehoming, like high performance CNC machines. They also work well for cases in which rehoming would add significant time or cost to a task. If the power fails on a DNA sequencer in the middle of a multi-day analysis, for example, the system needs to be able to reliably restart without jettisoning a carefully cultivated sample or compromising results. An absolute encoder would allow operations to be seamlessly resumed when power returns.

Because they output data as a digital word, absolute encoders are compatible with a range of communications protocols and busses, including BiSS, synchronous serial interface (SSI), DeviceNet, Profibus, Modbus, CANopen, IO-Link and a number of Ethernet-based protocols.