Encoders & Resolver Based Encoder Technology

Covering the basics of choosing the right position feedback option for your application

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INTRODUCTION

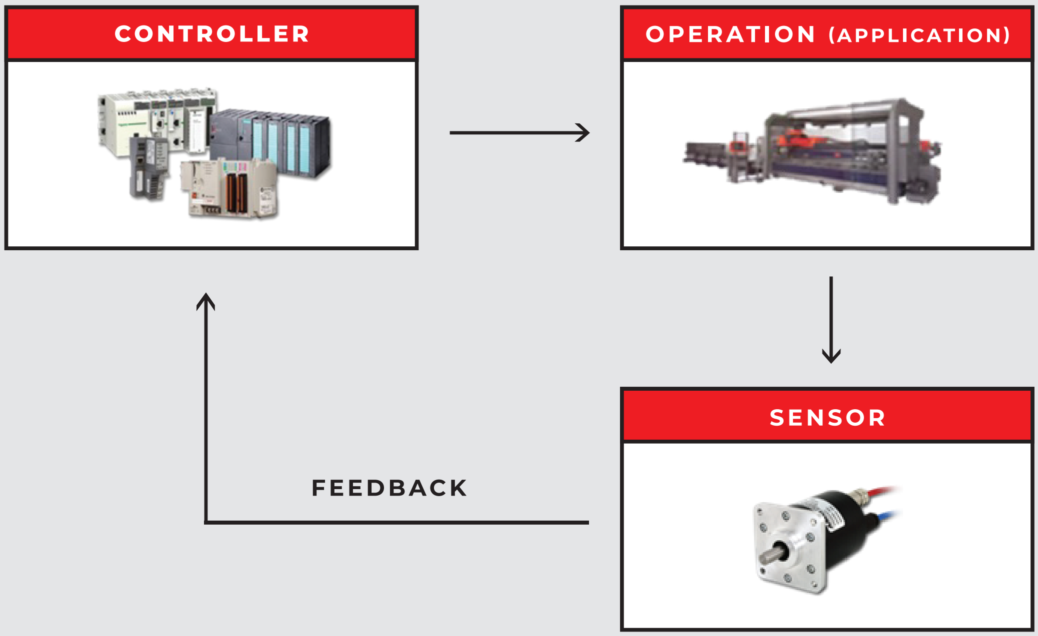
A modern control system is fundamentally a feedback control system. For example, a push button which executes an operation eventually starts a motor. That push produces an output that rotates a shaft. A feedback loop feeds information back to the controller to verify the operation and make the necessary corrections. That feedback can be, but is not limited to, limit switches, temperature sensors, or in some cases, position feedback. Position feedback can be used to monitor or make adjustments to the motor.

There are multiple ways to get position feedback but the most common types are rotary sensors, encoders, resolvers, or even potentiometers. For linear applications, magneto restrictive sensors or LVTs are commonly used. And for non-contact applications lasers are often used to provide position feedback for linear measurement.

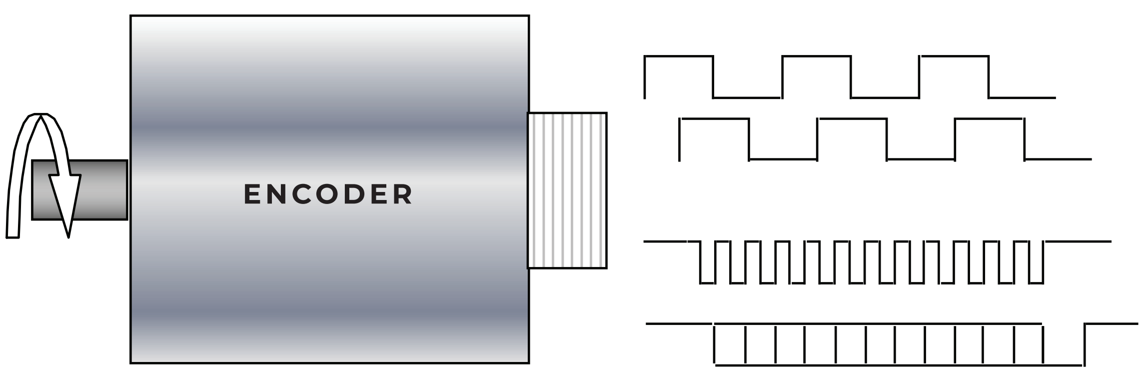
The spectrum of rotary position and feedback devices is increasing on a daily basis. The options can be overwhelming. Absolute vs. Incremental? Magnetic or Optical? What environment am I working with? Does it require bulletproof technology? The best way to find out what you need for your application is to know what you are looking for.

This white paper will break down the different types of encoders and highlight why the combination of rugged resolver technology with sophisticated signal conversion provides a long-lasting reliable performance for the most challenging environments.

WHAT IS AN ENCODER?

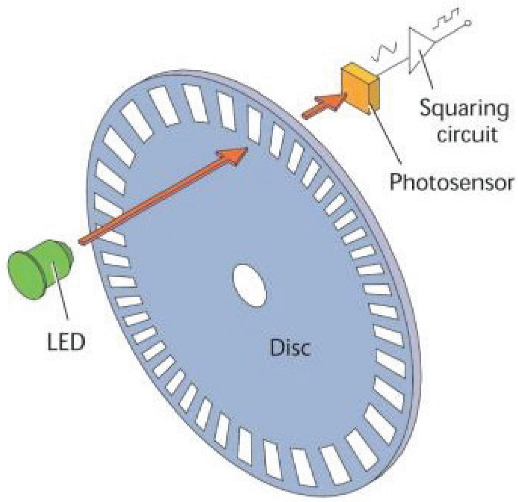


Encoders are critical elements in a motion system because they provide position and/or velocity feedback to the controller. Simply put, an encoder is a sensor which converts mechanical movement into an electrical signal and relays that data to other devices.



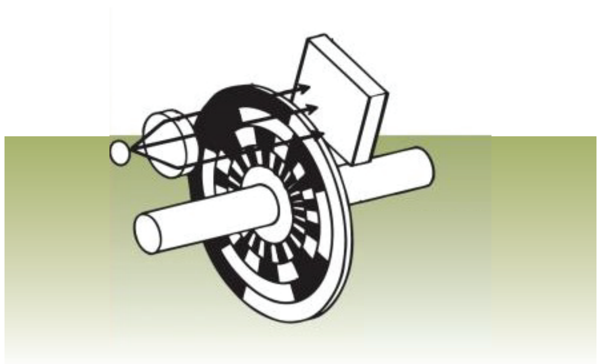
The most common method is optical position decoding. This consists of a coded disc or linear slide, an LED, and a light sensing circuit. As the coded disc rotates, the light is shuttered from the LED and is received and transmitted by the sensing circuit as a square wave.

WHAT IS AN ENCODER CONT.

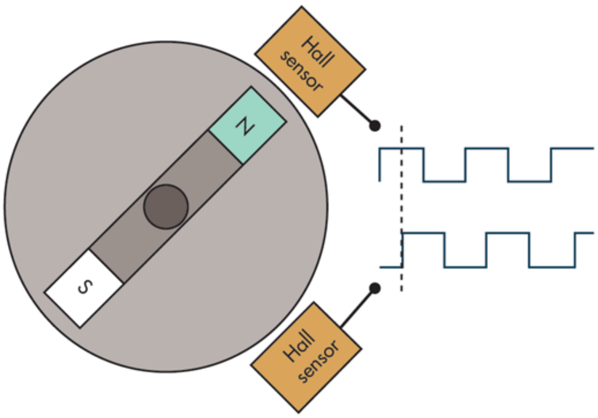


This image illustrates the basic format for generating position data. However, as you can see from the following image, by adding a sensing circuit array and varying patterns on the coded wheel, more complex position data can be derived.

Another method for generating position data is magnetic positioning. In this method a series of magnetic poles pass in front of magnetic, or hall, sensors to generate the electrical signals that ultimately provide us with the position data. This solution has less components, providing a lower cost alternative.



Absolute rotary optical encoders sport multiple patterns so that a unique output is generated for each disc position.



The number of applications that require encoders is extensive. The options available for both mechanical and electrical configurations require a solid understanding of your application in order to make the best selection.

SELECTING AN ENCODER

TYPE (ROTARY, LINEAR, INCREMENTAL, ABSOLUTE)

↓

ELECTRICAL INTERFACE

↓

MECHANICAL CONSIDERATIONS

The first step in selecting an encoder is to examine your application and identify what exactly it is that you need.

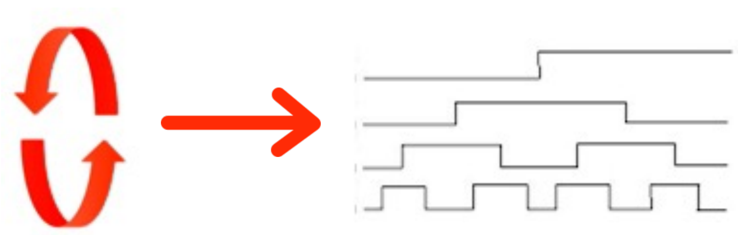
1. DO WE NEED TO MONITOR ROTARY OR LINEAR POSITION MOVEMENT?
2. WHAT TYPE OF OUTPUT SIGNAL DO I NEED?
3. IS IT INCREMENTAL OR ABSOLUTE?

COMMON TYPES OF ENCODERS

Rotary, Linear, Incremental, Absolute

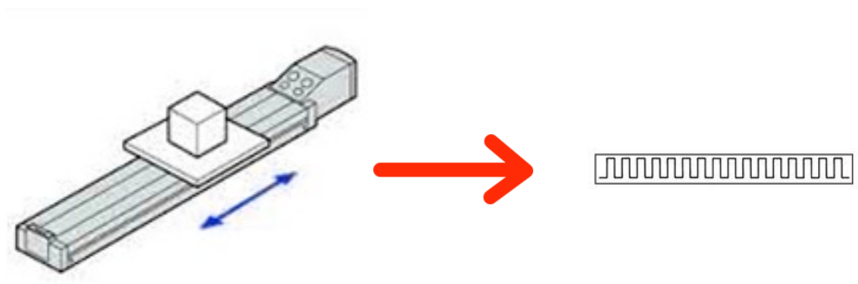
ROTARY ENCODERS:

A rotary encoder converts angular position in an analog or digital signal. A rotary encoder works best for applications where angle of the shaft, number of turns for a rotating axis, or velocity data of an axis are needed.



LINEAR ENCODERS:

Linear encoders convert linear distance movement to an electrical signal. A linear encoder is selected in order to measure distance traveled or linear position information. Linear encoders are available in a wide range of options, but here they are reduced to three basic types.



The wire draw translates pulled wired length distance to position feedback. This is simple enough. Think of an old fashioned pull toy with a spring in it.

A linear scale is a two-part device consisting of a reading head and passive scale. The passive scale contains he coated surface, similar to the rotary coated wheel.

And last, a rack and pinion arrangement convert motion of the linear gear to rotary motion.

All three methods can generate position data in either absolute or incremental data format.

MEASURING ROTARY POSITION

The classic rotary encoder is the SHAFT encoder. The shaft of the encoder is mechanically coupled to the rotating shaft that is being monitored. The HUB shaft encoder mounts onto that shaft. The lengths that the shaft of the encoder can accept is limited because the housing prevents the shaft from passing through the sensor. A THROUGH SHAFT encoder is similar to a hub shaft unit but has the benefit of an open frame, allowing the shaft to pass through the encoder. Like linear encoders, rotary encoders can provide both absolute and incremental position data.

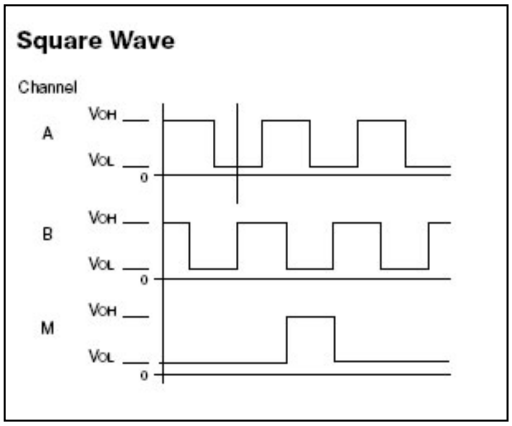
SHAFT ENCODER

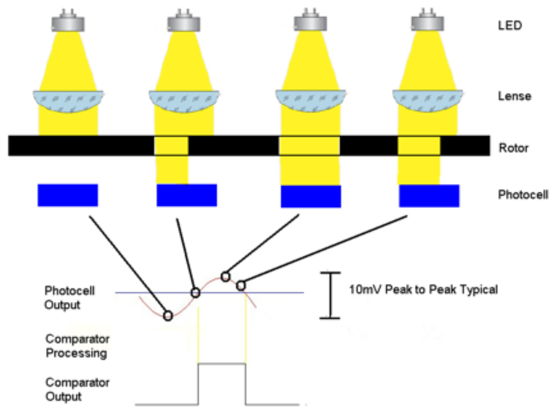
HUB SHAFT

THROUGH SHAFT

INCREMENTAL VS. ABSOLUTE ENCODERS

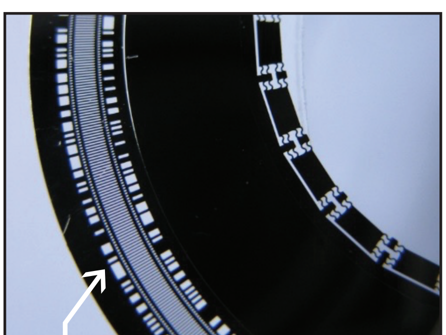
Incremental encoders produce electrical pulses, or **counts,** with a change in position. The signals are typically square wave but can be sinusoidal.



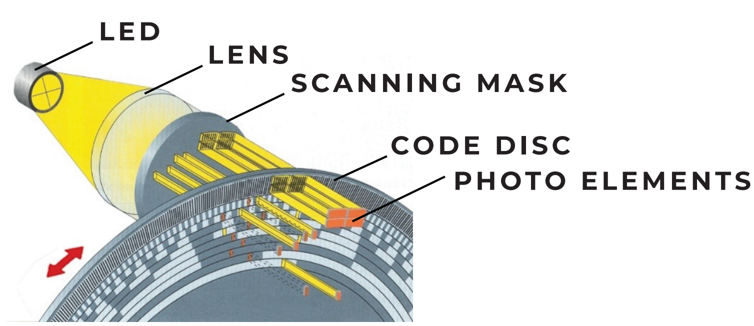


Incremental encoders **do NOT retain position** after a power failure or cycle. They can be thought of as sensors that monitor a relative change in position and not a sensor that reports the actual position. These encoders are typically used to monitor speed or applications where absolute position is not required.

Absolute encoders, on the other hand, provide a **unique position value** for every shaft or linear position. Absolute encoders **retain their positions** during a power cycle even if there is movement and the position changes. It always knows where it is. Signals are available in ever growing varieties but the most common types are SSI, Parallel, Networked, or Field Bus interfaces (Ethernet I/P, EtherCAT, Profinet, Devicenet, CANopen, Profibus, Etc.). Absolute encoders are used in applications where current position information is required.



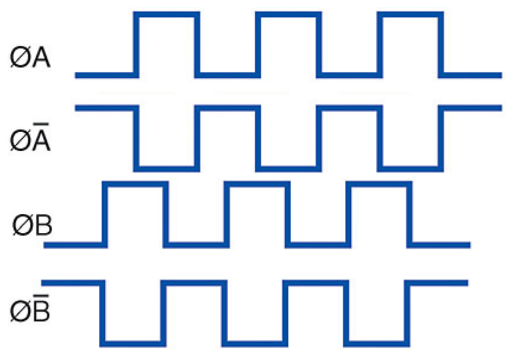
CODE DISC FOR ABSOLUTE ENCODERS

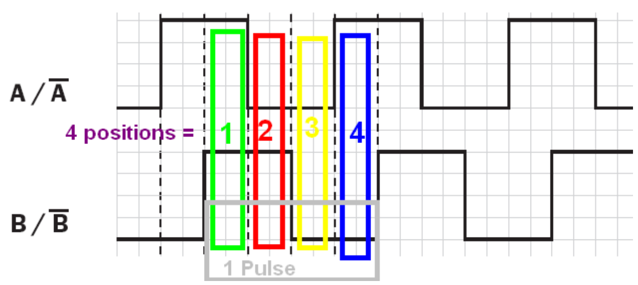


SELECTING THE CORRECT ELECTRICAL INTERFACE

ELECTRICAL OPTIONS FOR INCREMENTAL ENCODERS

To review, Incremental Encoders produce electrical pulses or increments (usually as a square wave) with linear or rotary motion of the encoder.



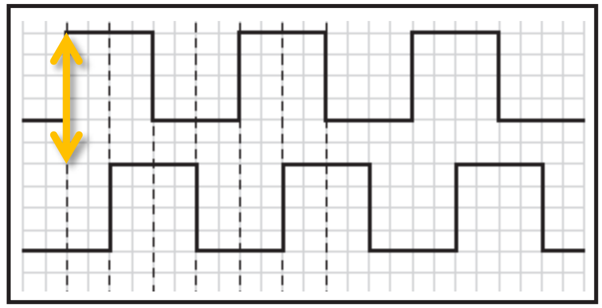


First consider the resolution or number of counts needed from the incremental encoder. The higher the number of counts, the greater precision from our sensor. The value can be referred to as **Pulses Per Revolution** or **Counts Per Turn**. Sometimes abbreviated as **PPR, CPT or CPR.** The standard convention is to output two square wave channels along with their complements. As you can see from the above figure, Channels A and B are offset by ¼ of a cycle. By using all four channels with this output, we can interpolate 4 positions within one pulse cycle. This is known as **Quadrature**. The ¼ offset also allows us to see which direction the encoder is turning based on what channel is leading. If channel A goes high first followed by channel B, we can determine the direction of rotation and vice versa.

This provides two benefits. First, it can determine direction of rotations of the shaft. Second, by counting the edges of each signal it can multiply the resolution of encoder by four, often referred to as times four decoding.

ELECTRICAL SIGNALS

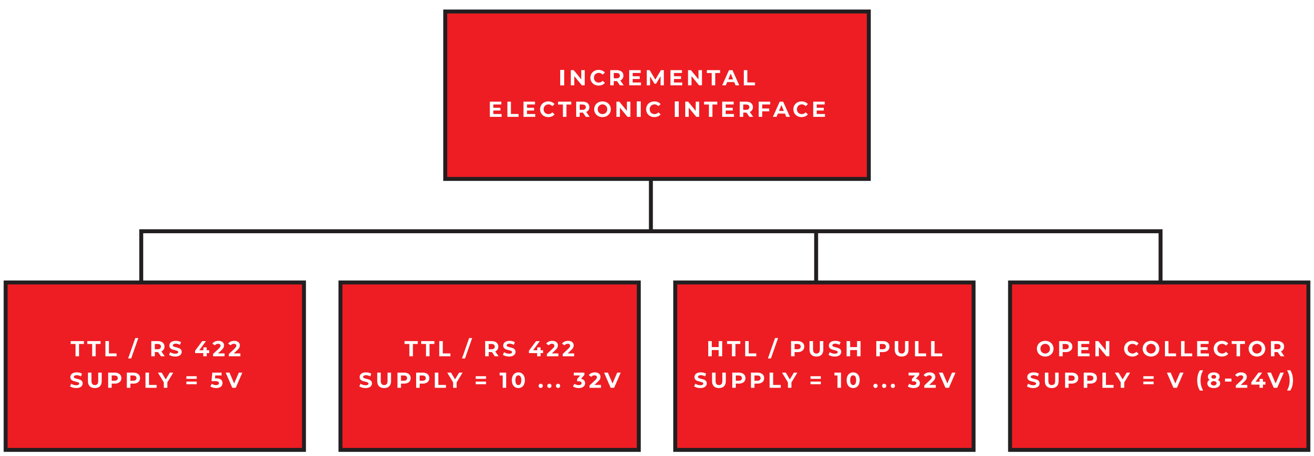
The most common output voltages are HTL, TTL, or Open Collector. These refer to the amplitude of the square wave.



HTL (High Threshold Logic) is used in electrical systems where the desired output signal is the same as the input voltage. Commonly known as “push pull”, this output voltage will be the same as the supply voltage (e.g. if the supply on the encoder is 24V, the output signal will also be 24V).

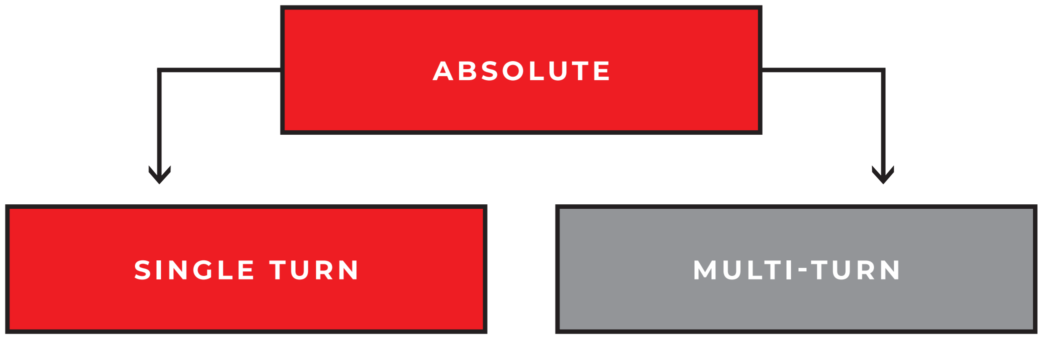
TTL (Transistor Transistor Logic) is also known as “differential line driver” or “RS422”. The output voltage will always be 5V regardless of the supply voltage on the encoder.

Open Collector is a simple transistor output that syncs current from the input device the encoder is wired to. Instead of outputting a signal of a specific voltage or current, the output signal is applied to the base of an internal NPN transistor whose collector is externalized.



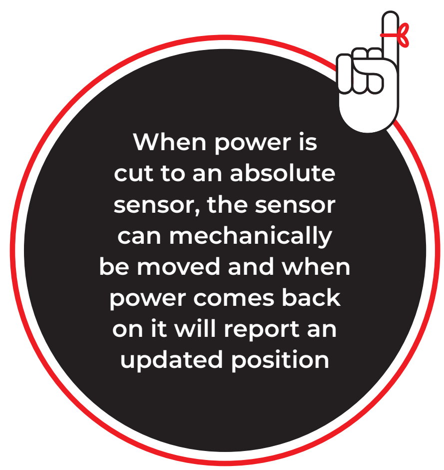
In summary, the takeaway for selecting the correct electrical interface is understanding what is the supply voltage? Is it 5 volts? 12 volts? Or 24 volts? What am I connecting the encoder to? Is it a differential input? Or a transistor type input? Is it syncing or sourcing input? All this information is necessary for selecting the correct output type of the encoder.

ABSOLUTE SINGLE TURN



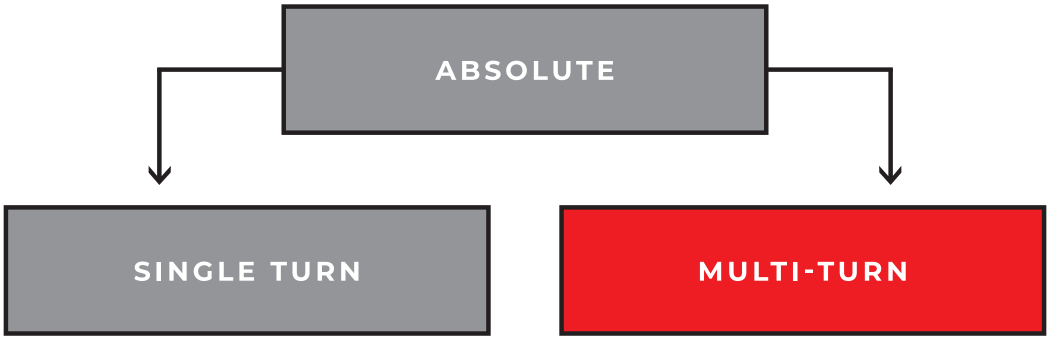
- Measures the Absolute position over one 360º revolution/turn
- Position “resets” after 1 turn

Similar to a watch with only a minute hand



Absolute rotary sensors can be either single turn or multiturn. A single turn application measures the absolute position over 360 degrees or one revolution. After that one revolution the position resets or starts over. Think of it as a watch with only a minute hand, it cannot tell how many hours have passed, only that an hour has passed. They are used to generate a signal that represents the encoder shafts actual position. It can be used to monitor rotational speed. They’re typically used for measuring angular position and with absolute position feedback sensors the angular resolution is determined by the sensor they can be at zero-to-360-degree sensor or it can provide is up to 16 bits of absolute position feedback depending upon the sensor.

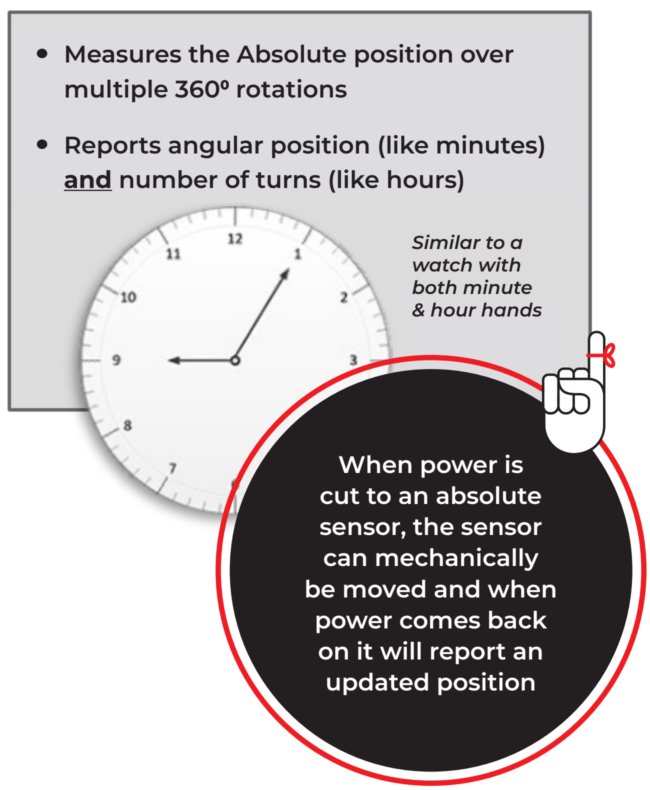
ABSOLUTE MULTI-TURN:



For multiturn rotary feedback we measure the absolute position over multiple 360-degree rotations. It reports both angular position and the number of turns that have occurred since the shaft started rotating. Similar to a watch with both a minute hand and an hour hand. These are used to measure change in position over multiple rotations. They can often be used to eliminate the need for extra sensors such as home switches or limit switches to prevent over travel. They provide precise positioning of a linear axis such as a lead screw/gantry or can provide improved control. Think of a rotating drum or cable reel.

METHOD OF TURN COUNTS

For both these certain sensors there are many ways to maintain the multiple rotation feedback and methods of turns counting. The most common are the mechanical method or using a battery. With the mechanical method, gears reduce the number of turns the internal sensor makes relative to the external shaft. There is also the option to use two sensors. When two sensors are used, a secondary sensor is used to keep track of the number of turns while the first sensor keeps track of position within that one turn. A more modern method is the use of a battery. The battery maintains power to the sensor electronics to monitor any change of position and can keep track of multiple rotations while there's no power to the sensor. There are other methods that exist but the two above are the most common.

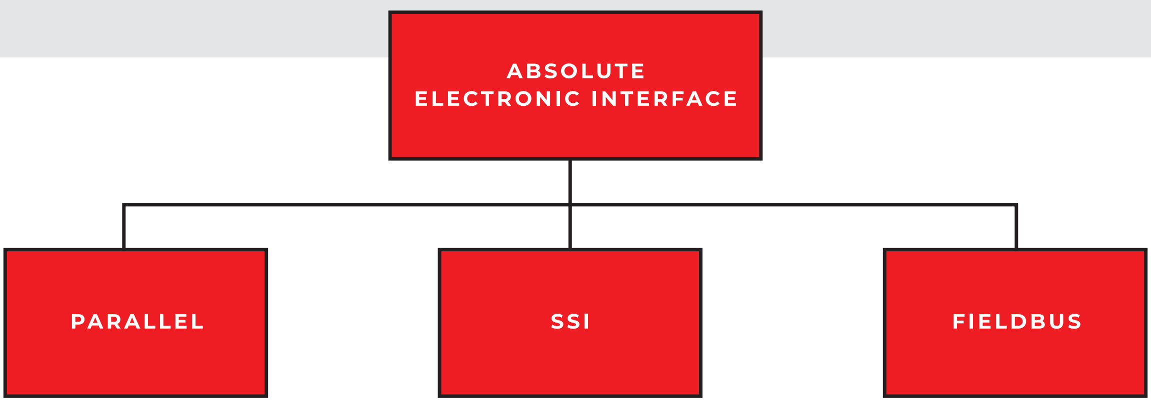


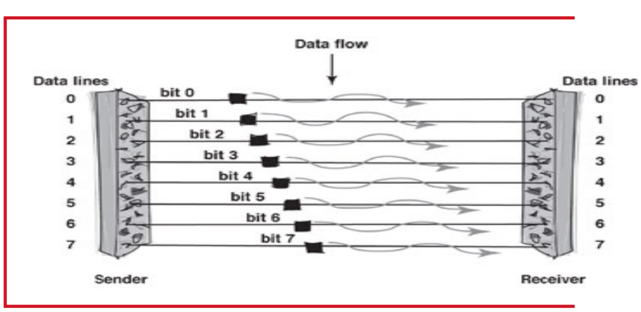
APPLICATION EXAMPLES

Satellite Antenna – Absolute encoder for satellite tracking

ELECTRICAL OPTIONS FOR ABSOLUTE ENCODERS

An absolute rotary encoder differs from an incremental encoder in that it corresponds to a specific angle of shaft position. That angle is specified to a resolution defined by a number of bits, depending on the total number of angular markings on the internal wheel. This is in contrast to the series of pulses emitted from an incremental encoder that must be counted to define a shaft's position following a homing cycle.

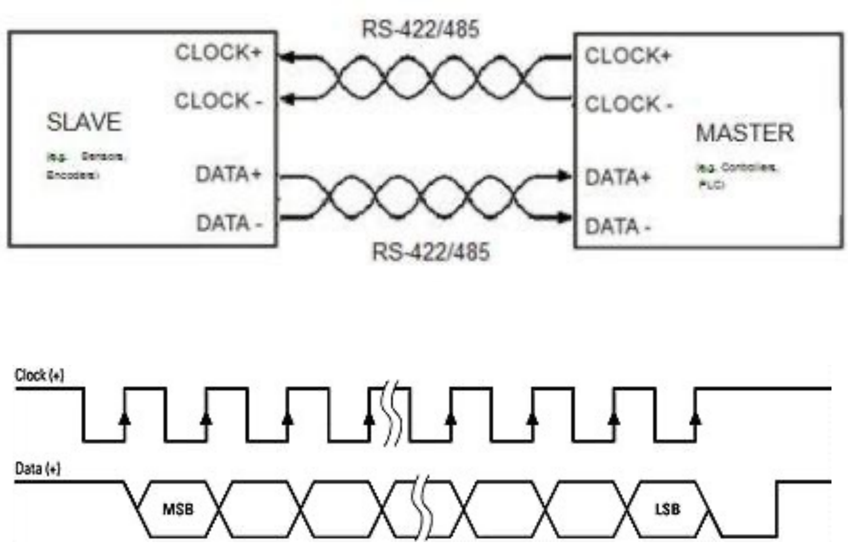




Absolute encoder outputs can take different forms depending on the encoder selected. The most common types are Parallel, SSI, or Networked (often referred to as Fieldbus outputs). You may come across other types but they are more often than not manufacturer specific.

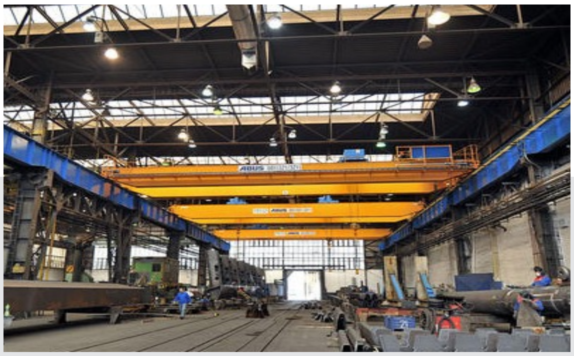
With a **parallel encoder**, the connection is point to point where each output wire represents a different data bit. So for each bit of position data from the sensor there is a corresponding connection to the interface. This means the higher the resolution or number of bits of the encoder, the more connections needed to the interface. The benefit for this type of interface is that it does not require any special interface. It provides a fast direct output to digital inputs. The drawback is that the number of connections required for high resolution encoders leads to a more complex installation and much more expensive cabling.

Synchronous Serial Interface (SSI) is a very common output type for encoders that was developed by Stegman in 1984 for absolute encoders. It provides data in a serial format, which means only four wires are needed to transmit position data, whether it is 12-bit or 30-bit. The master (PLC, microcontroller) sends a clock bit to the slave, or in this case the sensor, and the sensor sends back a data bit. After a series of clock pulses determined by the number of bits of the sensor, the master has read every data bit from that sensor it can, therefor providing us with the complete position data.



The benefits are plain to see. Simple cabling and fast communication speeds provide a lower overall cost compared to a parallel encoder. The drawback would be that you need a special interface to read the position data. The interface can be a dedicated input on the controller or a specialty interface module.

APPLICATION EXAMPLES



Overhead Crane – Multiturn SSI Encoder used to track position of crane

Fieldbus or network encoders take advantage of existing industrial networks found in most control schemes. Network encoders are quickly becoming the most popular output type. The benefits are that the sensor no longer requires direct inputs or special interfaces to provide position data to the PLC and it reduces the number of connections for multi-sensor applications. This saves money both on cabling and controller complexity, however the sensor may have a higher up front cost and require the user to have a basic understanding of network topologies.

Another feature that is prevalent today is the **programmable encoder**. This allows us to program the resolution and other features such as count direction or velocity format of the encoder. Programmable is a standard feature on networked encoders today.

In summary, when selecting the electrical interface for your encoder, you need to know what the resolution requirements are. Output supply, supply voltage and your encoder interface all need to be taken into consideration when selecting the correct incremental or absolute encoder. Delineate between single turn or multiturn position feedback. And finally, the output type should match the sensor to the available interface.

MECHANICAL CONSIDERATIONS

Manufacturers provide a wide range of mechanical options when choosing the encoder. This can often feel daunting. Understanding the basic tradeoffs in encoder design will allow you to properly select an encoder that will meet your cost and performance needs over the life of your application.

HOUSING AND CONNECTION

First ask yourself what type of housing do you need?

Do you need stainless steel because of your extreme environment?

Or will a standard housing work for your application?

Do you need a connector or will an integral cable work?

SHAFTS

Next there are shaft types that you need to consider.

Do you want a solid shaft?

And if it's a solid shaft, what diameter are you looking at?

Do you want a hub shaft?

Or a hollow shaft encoder for this application?

FLANGE

And lastly, what mounting options do you need?

Will a square flange work or would a metric servo work best?

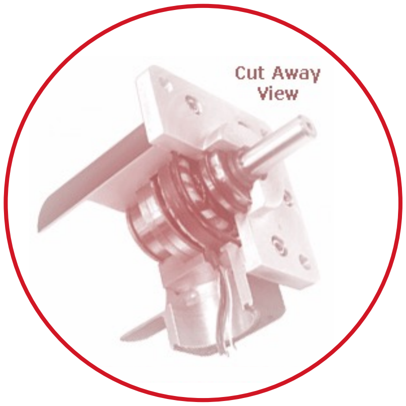
Each are very specific to the application.

RESOLVER BASED ENCODERS

RESOLVERS

When discussing **RESOLVERS**, people often interchange terms such as: encoders, rotary position sensors, motion feedback sensors, and transducer sensors. On occasion, synchros (cousin to the resolver) are also mentioned when explaining devices of this nature. Regardless of the names people choose to describe resolvers, their role in the world of automation remains unparalleled.

Referenced as an analog sensor that is absolute over a single turn, the resolver was originally developed for military applications and has benefited from more than 50 years of continuous use and development. It was not long before numerous industrial segments recognized the benefits of this rotary position sensor, engineered to withstand the punishment of a military application. Product packaging plants and stamping press lines are perfect examples of where resolver based systems are at work. In typical applications, the resolver sensor feeds rotary position data to a decoder stationed in a Programmable Logic Controller (PLC) that interprets this information and executes commands based on the machine's position.



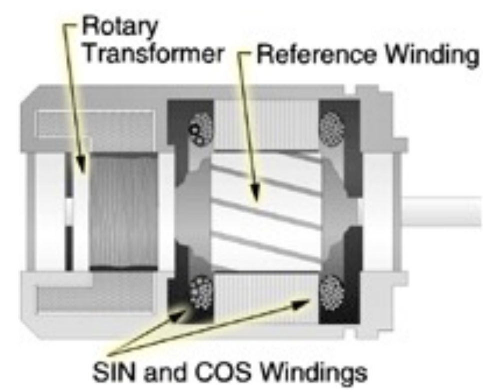
AMCI H25 AND
DURACODER DC25 RESOLVER

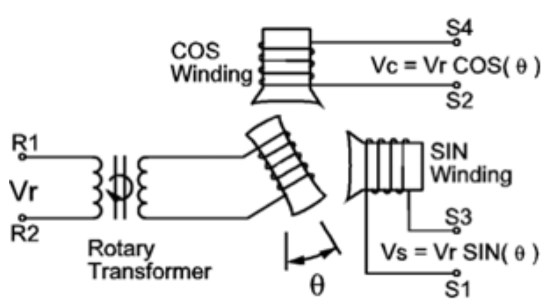
Recent advances in technology have enabled the integration of a resolver and on-board electronics in one housing as an alternative to other types of encoders. Referred to as DuraCoders, these motion sensing devices are available with the following output types; Absolute Parallel, Incremental Digital, Analog Current, Analog Voltage, and Networked. The Absolute Parallel and Incremental Digital versions can also be ordered with a field programmable option. Using simple onboard switches, technicians and engineers can easily select the unique resolution required by the application, thereby reducing the number of units that must be stocked.

Through the evolution of machine development, builders and system integrators alike, agree that the resolver transducer is unsurpassed in its ability to reliably supply rotary position data in the harshest industrial environments.

RESOLVER CONTROL TRANSMITTER

A **resolver** is a rotary transformer where the magnitude of the energy through the resolver windings varies sinusoidally as the shaft rotates. A resolver control transmitter has one primary winding, the Reference Winding, and two secondary windings, the SIN and COS Windings. The Reference Winding is located in the rotor of the resolver, the SIN and COS Windings in the stator. The SIN and COS Windings are mechanically displaced 90 degrees from each other. In a brushless resolver, energy is supplied to the Reference Winding (rotor) through a rotary transformer. This eliminates brushes and slip rings in the resolver and the reliability problems associated with them.





In general, in a control transmitter, the Reference Winding is excited by an AC voltage called the Reference Voltage (Vr). The induced voltages in the SIN and COS Windings are equal to the value of the Reference Voltage multiplied by the SIN or COS of the angle of the input shaft from a fixed zero point. Thus, the resolver provides two voltages whose ratio represents the absolute position of the input shaft. (SIN θ / COS θ = TAN θ, where θ = shaft angle.) Because the ratio of the SIN and COS voltages is considered, any changes in the resolvers' characteristics, such as those caused by aging or a change in temperature, are ignored. An additional advantage of this SIN / COS ratio is that the shaft angle is absolute. Even if the shaft is rotated with power removed, the resolver will report its new position value when power is restored.

RESOLVER CONTROL TRANSFORMER

A **resolver** control transformer has two input stator windings, the SIN and COS windings and one rotor output winding. (See **figure 1.3**) The rotor output is proportional to the sine of the angular difference between the electrical input angle of the inputs and the mechanical angular position of its shaft...in other words, the voltage induced into the rotor is proportional to Sin(Φ–θ), where θ is measured from some reference shaft position called zero.

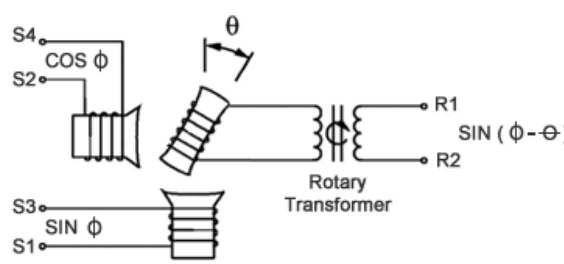
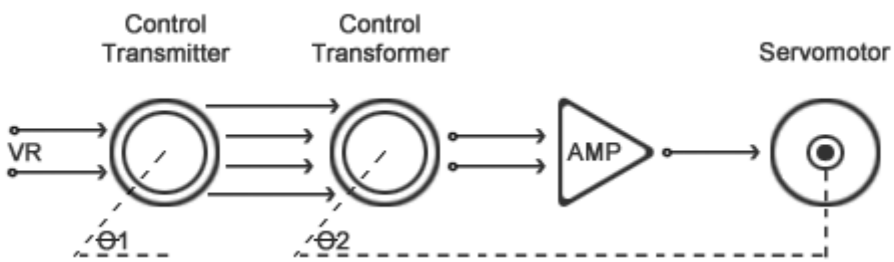


figure 1.3

The drawing shows what might be called the “classic” resolver mechanical follow-up servomechanism. The command angle is established by the shaft position of the control transmitter. When the servomotor has reached the commanded position, θ1=θ2 the control transformers output is zero and the motor stops. Although the above description is oversimplified, it is useful in describing a control transformer.

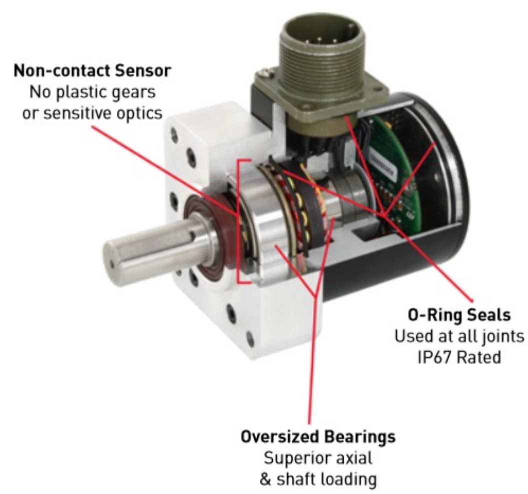


Both control transmitters and control transformers are unidirectional devices i.e. Control transmitters manufacturers specifications are only valid when the electrical input is the rotor, and control transformers specifications are only valid when the electrical inputs are the stator. Although both can be used “backwards”, performance cannot be guaranteed.

Why Choose a Resolver based Encoder (Duracoder)?

Resolver-based Rotary Shaft Encoders provide:

- Cost saving durability
- Resolver based reliability
- Field programmable output resolution
- Wide range of applications



Duracoders have earned a “bulletproof” reputation among established machine builders and successful system integrators. When an encoder application exists in a hot, humid, dusty, oily, or mechanically demanding environment, the resolver-based system is the preferred choice. Ultra reliability, coupled with proven performance support the bulletproof reputation this rotary position sensing device has earned.

COMMUNICATING TO THE PLC

PLUG-IN INTERFACES

Advantages
- Lets you expand number of encoders you can connect to a PLC
- Expanded compatibility

Disadvantage
- You need to purchase a seperate interface

DIRECT INTERFACE

Advantages
- Don’t need to buy a seperate interface

Disadvantage
- Limited by number of inputs in your PLC

After picking a sensor, the next step is figuring out how best to get that information to the controller. The most common type of control in industrial automation is the Programmable Logic Control or PLC.

The first method is using a ***plug-in interface***

The **advantage** here is that it allows you to expand the number of encoders you can connect to a PLC. Oftentimes the PLC has a limited number of I/O and that I/O is not specialized. If you have a sensor such as a resolver or an SSI encoder you need to add a plug-in module to get those sensors into the PLC. Which allows you to expand the compatibility and the different types of sensors you can use with that controller.

The main **disadvantage** of going this route is that it is necessary to purchase a separate interface for each type of sensor.

*The next method is a **direct interface***

This method takes advantage of the inputs or interfaces available to you directly on the PLC, such as analog inputs that are built into the PLC or a networked interface.
The **advantage** with this is that there is no need to buy a separate interface.

The main **disadvantage** is that you are limited by the number of inputs. Say for example you have several analog sensors that need to get back into your PLC, if you only have four analog inputs you can only bring back four sensors.

NETWORKED ENCODERS

*These types of encoders offer **built-in network interface** for a variety of networks.*

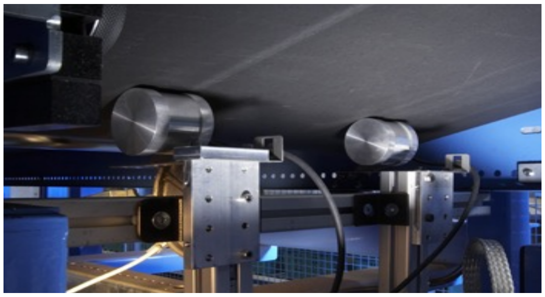
The **advantage** is the ease of set-up and trouble free performance. They are programmed using the PLC/PAC resident software, which ensures hassle free integration with your application. They also offer a vareity of programmable features such as selectable resolution, selectable count direction, selectable velocity format, and programmable presets for homing.

The **disadvantage** is that individual components cost more than standalone products (albeit there is an overall potential system savings) and that the network topologies are generally more complex.

FIELDS OF APPLICATION AND EXAMPLES

There are many applications, markets and industries where encoders can be used. Here are just a few.

- **PACKAGING:**
  Often used on labeling equipment or for machine timing.
- **PRINT & PAPER:**
  Often used for things such as registration control or even location of printing heads and rollers.
- **WOOD INDUSTRY:**
  Multi turn encoders would be used for positioning saw blades or similar for making accurate cuts.
- **METAL FORMING:**
  We often see encoders and resolvers with rotary feedback being used for measuring things like shut height control or crankshaft position.
- **PORTS & CRANES:**
  Multi turn encoders are often used for positioning cranes to facilitate unloading and loading equipment safely and efficiently
- **MATERIAL HANDLING:**
  Here XY position is a must.



Conveyors – Incremental Encoder used to track speed of conveyor

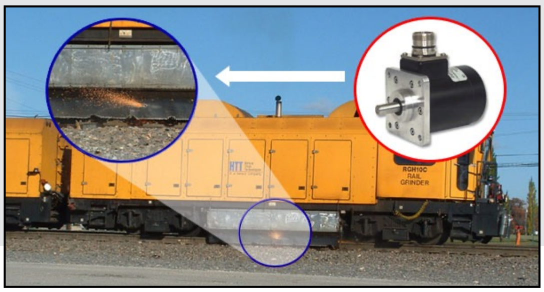
Process Control – Analog Encoder for valve position feedback

CASE STUDIES

CASE STUDY #1:

CHALLENGE: Unlike most industrial applications, railway track grinding machines operate across an incredible range of conditions and temperatures, requiring an equally rugged encoder.

These machines remove surface irregularities and restore the profile of the rail to extend track life, reduce wear on rolling stock and track components, and cut fuel consumption. These rail track grinders use independently adjustable grinding heads to efficiently grind critical track sections such as switches, turnouts, and road crossings. These grinding heads run along railway tracks and manage their position using rotary encoders.



The operating environment for these rotary position sensors is extremely heavy-duty and their engineering team needed a "bullet-proof" solution.

AMCI Duracoders meet IP 67 Ratings, enabling these sensors to reliably perform in applications that would render conventional encoders useless. By combining the time tested reliability of a resolver with advanced electronics, the duracoder enables accurate rotary position feedback in virtually any application.

CASE STUDY #2:

CHALLENGE: AGV control requires a reliable and seamless feedback system to the network in a challenging environment.

PLC's, or programmable logic controllers, have become an essential component in the automotive industry. Among other applications, they are used to control the movement of parts and components along the assembly line, ensuring that each step in the manufacturing process is completed accurately and efficiently. They can also be used to monitor the performance of machines and equipment, detecting any malfunctions or errors. AGVs have recently come to play a key role throughout this process. Moving components from station to station, warehousing, and tooling adjustment are just a few of their many uses.

CASE STUDIES CONT.

In a recent application, the AGV design used a slew drive to rotate a lift. The drive was controlled by a PLC but had no feedback for closing the position loop. It needed a method to get the rotating lift position back to the PLC. Because of its seamless integration into the PLC Network, the NR60E2 was chosen as the solution for position feedback. EtherNet/IP provided an easy-to-use interface to the PLC through the built-in network. A custom EDS and Add on instructions made adding the NR60E2 to the program a breeze.

AMCI's NR60E2 EtherNet/IP Resolver provides direct position feedback to your Rockwell Automation PLC in applications ranging from slew drives to rotational position to screw jacks for tooling or rack height.

ABOUT AMCI

AMCI is a leading US based manufacturer whose expertise with PLC networked products provides the best PLC integration available on the market today. AMCI offers a wide selection of position sensing and motion control solutions that simplify automation and add reliability to the manufacturing process.

Visit **www.amci.com** for more information
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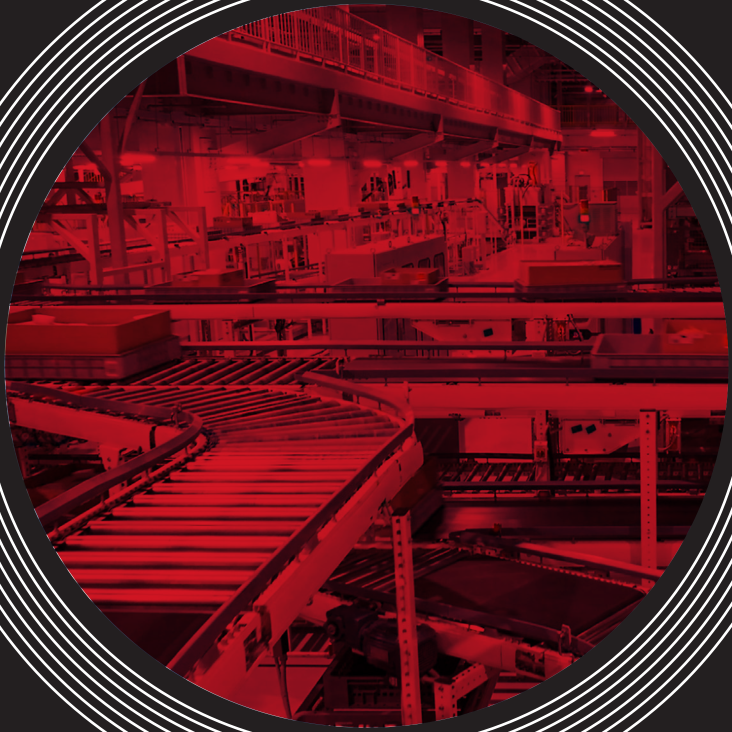

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