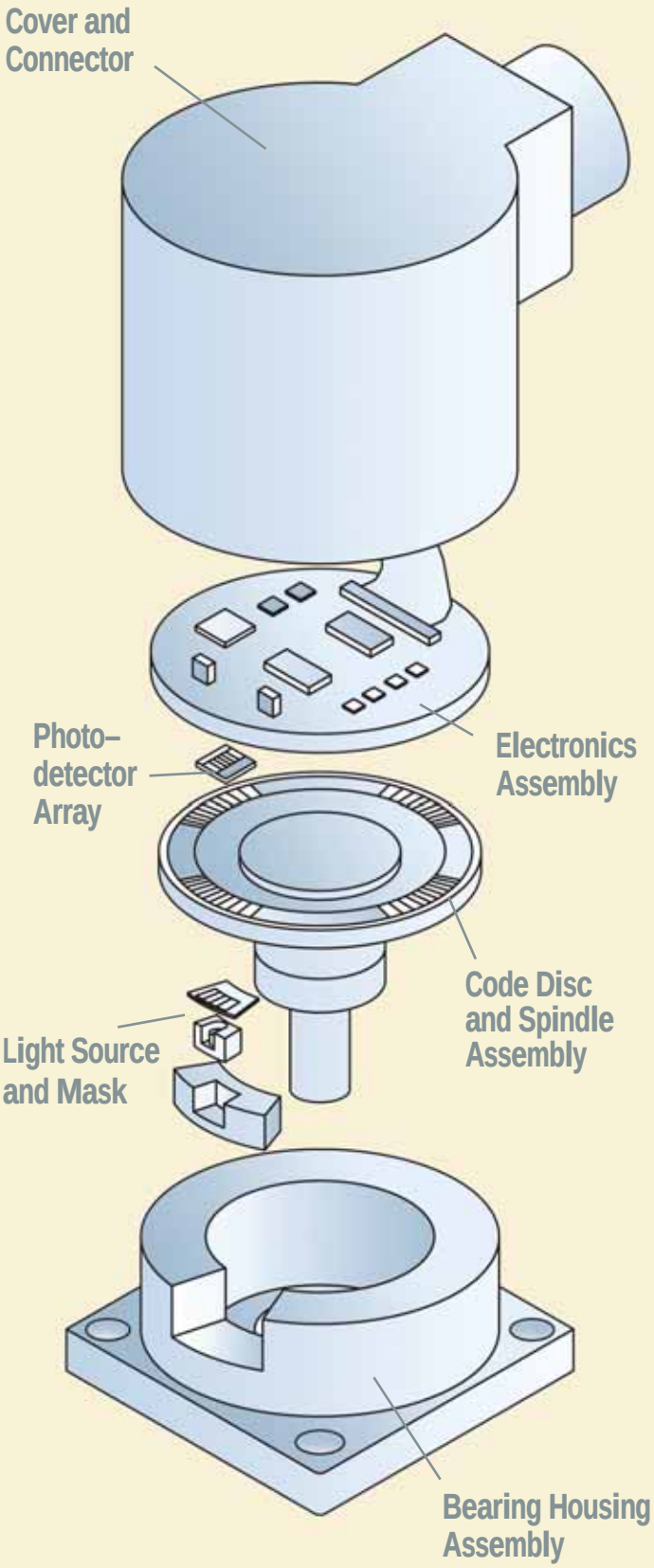
BEI Optical Encoder Design and Operation



Incremental Encoders

An incremental encoder produces a series of square waves as it rotates. The number of square wave cycles produced per one turn of the shaft is called the encoder resolution. Incremental encoders work by rotating a code disc in the path of a light source (see figure at left); with the code disc acting like a shutter to alternately shut off or transmit the light to a photodetector. Thus, the resolution of the encoder is the same as the number of lines on the code disc. A resolution of 360 means that the encoder code disc will have 360 lines on it and one turn of the encoder shaft will produce 360 complete square wave cycles, each cycle indicating one degree of shaft rotation.

Since the resolution is "hard coded" on the code disc, optical encoders are inherently very repeatable and, when well constructed, very accurate. They also have no error accumulation as you might experience with analog sensors,

and the square wave output is inherently easy for digital signal processing techniques to handle.

BEI provides incremental resolutions up to 288,000 counts per turn through a combination of direct read on the code disc and various multiplication techniques (see quadrature detection on next page).

Generally, incremental encoders provide more resolution at a lower cost than their absolute encoder cousins. They also have a simpler interface because they have fewer output lines. Typically, an incremental encoder would have 4 lines: 2 quadrature (A & B) signals, and power and ground lines.

A 12 bit absolute encoder, by contrast, would use 12 output wires plus a power and ground line.

Questions?

Call 1-800-ENCODER and ask for “Applications Assistance”

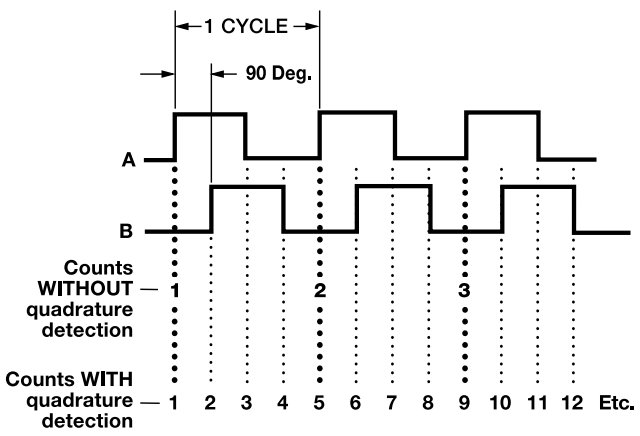
Quadrature Detection (Edge Counting)

Incremental encoders are usually supplied with two channels (A & B) that are offset from one another by 1/4 of a cycle (90 degrees). This type of signal is referred to as quadrature and allows the user to determine not only the speed of rotation but its direction as well. By examining the phase relationship between the A and B channels, one can determine if the encoder is turning clockwise (B leads A) or counterclockwise (A leads B).

Many counter and controller manufacturers include a quadrature detection circuit as part of their electronics. This allows the use of a two-channel quadrature input without further conditioning.

With quadrature detection the controller can derive 1X, 2X or 4X the basic code disc resolution. 10,000 counts per turn can be generated from a 2500 cycle, two-channel encoder by detecting the Up and Down transitions on both the A and B channels. With a quality disc and properly phased encoder, this 4X signal will be accurate to better than 1/2 count (see diagram below).

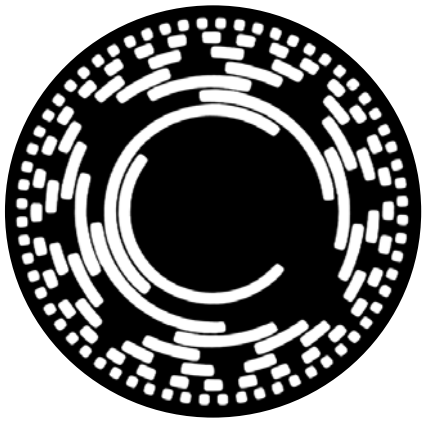
Another means of increasing resolution, interpolation, electronically subdivides the base resolution. Interpolation is achieved through the use of internal electronics acting on the raw encoder signal. This interpolated signal can be further multiplied through the quadrature detection method mentioned above. Interpolative multipliers of 2, 4, 5,10 and 20 are readily available. More detail is available on pages 32 and 33.



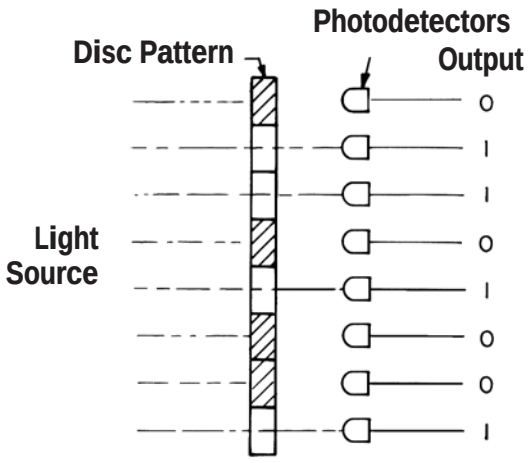
Absolute Encoders

By contrast to incremental encoders, an absolute encoder provides a “whole word” output with a unique code pattern representing each position. This code is derived from independent tracks on the encoder disc (one for each “bit” of resolution) corresponding to individual photodetectors. The output from these detectors is HI or LO depending on the code disc pattern for that particular position.

Absolute encoders are used in applications where a device is inactive for long periods of time or moves at a slow rate, such as flood gate control, telescopes, cranes, valves, etc. They are also recommended in systems that must retain position information through a power outage

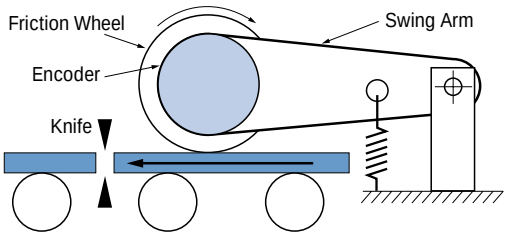


8 Bit Gray Code Absolute Disc



BEI Typical Applications of Optical Encoders

Measuring Wheel



Purpose

To measure distance travelled for a cut-to-length operation

Parameters

Speed of Travel: 25 feet per minute
Measuring Wheel Circumference: 12 inches
Desired Resolution: 0.005 inches
Uni-directional measurement only
Manufacturing plant environment, very dusty
50 foot electrical cable run to controller
Integrate to programmable controller
12V power supply available
Resolution Required = 12/0.005 = 2400 cycles per turn
Output Frequency = 25 rpm x 2400/60 = 1000Hz

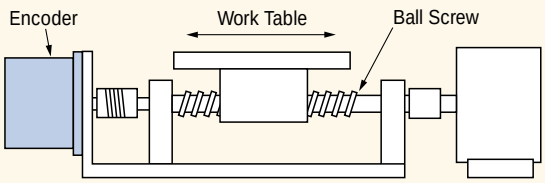
Encoder Specifications

Heavy Duty	H25
Square Flange Mount	D
Shaft Seal	SS
Cycles per Turn	2400
Channels	ABZC
Voltage/Output	Operates from 5-28 Volts
Termination	SM18 (10 pin, side exit)

BEI Model Number

H25D-SS-2400-ABZC-28V/V-SM18

Linear Position with N/C Display



Purpose

To encode the position of a work table through a ball screw

Parameters

Rotational Speed: 500 RPM
Pitch: 1/4
Total Travel: 20 inches
Desired Resolution: 0.0005 inches
20 foot cable run to counter
Oil mist environment
Overtravel protection required
5V power supply available
Resolution required = Pitch/resolution = (0.25/0.0005) = 500 cycles per turn
Output Frequency = 500 RPM X 500 / 60 = 4167 Hz

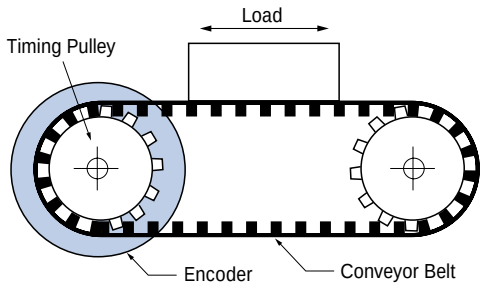
Encoder Specifications

Heavy Duty	H20
Square Flange Mount	D
Pilot (to accept seal)	B
Shaft Diameter	25 (0.25” nominal)
Shaft Seal	SS (protection from oil mist)
Cycles per Turn	500
Channels	ABZC
Note:	Z (generates home pulse with microswitch at end of travel)
Voltage/Output	Operates from 5-28 Volts
Termination	SM18 (10 pin, side exit)

BEI Model Number

H20DB-25-SS-500-ABZC-28V/V-SM18-28V

Belt or Conveyor



Purpose

To determine relative position, direction and speed of travel in a bi-directional conveyor belt

Parameters

Conveyor Speed: 100 feet per minute maximum

Desired Resolution: 0.002 inches

Diameter of Conveyor Belt Drum: 4 inches

Manufacturing Plant: Dust and dirt

100 foot cable run to controller

Programmable controller with high speed counter module requiring 12 volt differential line drivers.

12 V power supply available

Drum speed = (12 in/ft) (100feet/min) / (PI X Diam) = (12 X 100) / (PI X 4) = 95.5 RPM

Resolution required = (4 X PI) / (0.002) = 6283 cycles per turn

Use the T5 interpolate feature:
6283/5 = 1256.6 base resolution, use 1257

Output Frequency = 6285 X 95.5 / 60 = 10,004 Hz

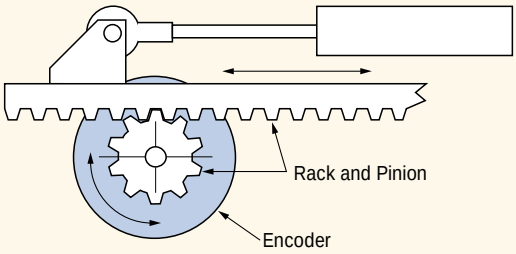
Encoder Specifications

Heavy Duty	H25
Square Flange Mount	D
Shaft Seal	SS
Cycles per Turn	6285-T5
Channels	ABZC
Voltage/Output	Operates from 5-28 Volts
Termination	SM18 (10 pin, side mount)

BEI Model Number

H25D-SS-6285-T5-ABZC-28V/V-SM18

Linear Actuator



Purpose

To encode the position and velocity of a rack and pinion

Parameters

Pinion: 40 Tooth 1/20 pitch = 2 inches per turn

Stroke: 20 inch

Maximum Linear Velocity: 10 inches per second

Desired Resolution: 0.0002 inch

Oil spray environment

10 foot cable length

24 V power supply available

Resolution required = 2 inches per turn/0.0002 inches = 10,000 cycles per turn

Use 2500 base cycles per turn with T4 interpolate for 10,000 cycles per turn

Output Frequency = 10,000 cycles per turn X 10 inches/sec X 1 turn/2inches = 50,000 Hz

Encoder Specifications

Heavy Duty	H25
Square Flange Mount	D
Shaft Seal	SS (protection from oil mist)
Cycles per Turn	10,000-T4
Channels	ABZC
Voltage/Output	Operates 5-28 Volts
Termination	SCS120 (side exit with cable seal, 120 inches long–uses shielded/ jacketed cable)

BEI Model Number

H25D-SS-10,000-T4-ABZC-28V/V-SCS120

BEI Encoders and Extreme Environments

Encoder Quality

Industrial Encoders are available for use over a wide range of environmental conditions. A large variety of designs allows the user to customize an encoder to his requirements. This also allows the specifying engineer to select only the options needed without incurring unnecessary additional costs.

There are a number of factors that must be considered to ensure reliable, consistent encoder operation in industrial applications.

In particular, the encoder must have a high degree of mechanical and electrical stability. In order to achieve this stability the encoder must have a solid foundation. The encoder disc, shaft and bearings must be of the highest quality to assure the ultimate accuracy of the device.

The encoder disc interrupts the light as the encoder shaft is rotated, and it is the code pattern etched on the disc which is primarily responsible for the accuracy of the electrical signal generated by the encoder. Should the disc pattern be inaccurate, the resulting signal will reflect that inaccuracy.

BEI has developed some of the most sophisticated, and accurate divided circle machines in the world. These machines are capable of accuracies in the sub arc second range. Originally intended for the military and aerospace industries, this quality is automatically incorporated into the industrial products.

The shaft and bearings maintain accurate rotation of the disc and help to eliminate such errors as wobble and eccentricity which would be translated into position errors. The encoder disc must be carefully mounted to avoid eccentricity as the pattern is read. Such eccentricity can cause inaccuracies in the encoder output that will not be apparent to the user during electrical testing but will cause false position information.

In order to eliminate eccentricity errors, BEI has developed electronic centering fixtures capable of centering accuracies up to 40 millionths of an inch.

When selecting an optical encoder for the industrial environment, the following areas may be considered:

Encoders intended for use in harsh or hazardous environments can be subjected to many optional tests to ensure they will perform as specified.

Heavy Loads

In applications utilizing gears or drive belts, excessive radial (side) loading on the shaft can shorten bearing life. Encoders should be specified in accordance with the anticipated side loading. Typical maximum loads for industrial encoders are 5, 40, and 100 lbs. Ultra heavy duty encoders are available to withstand heavier loads as well as shocks of up to 200 g's.

Corrosive or Washdown

Aluminum encoder housings with a chemical film coating (ex: Iridite or Alodine) finish are sufficient for most applications. However, if the encoder is intended for operation in a corrosive environment, a hard anodize finish with a dichromate seal should be considered. For food or medical grade applications where a washdown may occur, an electroless nickel coating or even stainless steel contruction may be required.

Temperature Extremes

The temperature specification of the selected encoder must be consistent with the application. Zero to 70 degrees Celsius is the standard operating temperature on BEI's industrial encoders. Extended temperature testing from -55 to +105 degrees Celsius is available, depending on the model.

Hazardous Environments

Your application may require a special certification, such as explosion proof. Testing for this certification determines that if certain flammable gases infiltrate the encoder housing and are ignited by the internal electronics, the resulting flame or explosion is not able to escape from the housing and ignite the surrounding atmosphere. Specially designed encoders are available that meet the appropriate specification. For "Intrinsically Safe" and "Explosion Proof" ratings, refer to Hazardous Area Usage on pages 47-49.

Industrial environments can really test the integrity of a mechanical design. The encoders shown here have just undergone a leak test in order to ensure that they are properly sealed against wet environments.

Wet or Dirty Environments

If your application requires operation in a liquid or dusty environment, the encoder must be selected accordingly. Adequate sealing is a "must" to ensure against contamination, particularly through the spindle assembly. Contaminants that infiltrate the shaft bearing can rapidly degrade encoder performance. In the encoder interior they can disrupt the optical components or damage the circuit board. A shaft seal is recommended in general, and must be used in applications where liquids are present. If liquid exposure is anticipated, you can specify a leak test.

Precision alignment of sensor arrays is done under high power. Close attention to critical components means robust operation for the finished product.

Electrically Noisy Environments

The increasing use of factory automation systems means industrial environments are rich in electrical signals that can create Electromagnetic Interference (EMI). Some protection can be afforded by shielded cable, especially in conjunction with the use of twisted pair conductors. When this type of cable is used with an encoder, its complements, and a differential line receiver, a significant improvement in noise immunity can be realized.

SPECIAL NOTES

INSTALLATION: Even with the appropriate package, shaft, bearings, and disc, the user must exercise care to avoid undue shock and abuse. In particular, the bearings or code disc can be damaged if the encoder is dropped or a pulley is hammered on the shaft. The typical shock and vibration specification for an industrial encoder is a 50g shock for 11 msec, as well as a vibration of 20g's from 2 to 2000 Hz.

MECHANICAL PROTECTION: To adequately protect the optical and electronic components from exposure to the environment, encoder case thickness should be consistent with the severity of expected abuse. In applications where the housing may be struck by tools or debris, a cast housing or protective shroud should be used.

Questions?

Call 1-800-ENCODER and ask for "Applications Assistance"

BEI Key Components of Optical Encoders

Shafts

Shafts transmit the rotational movement of the device to be monitored into the encoder either directly (hollow-shaft style encoders) or through a flexible coupling (shafted style of encoders)

Inside Tip: Look for corrosion resistant shafts and a low TIR (Total Indicated Runout), generally 0.001" or less.

Shaft Seals

Without a shaft seal, the bearings and optical path would be subject to contamination due to dust, dirt and moisture in the environment.

Inside Tip: A lubricated rotating lip seal provides the best overall environmental protection over the life of the encoder.

Optics & Electronics

The optics assembly, in conjunction with the electronics, generates a variable amplitude analog signal from the rotation of the code disc and translates it into a digital pulse stream for use by a controller or counter.

Inside Tip: Electronically centered discs are accurate to better than ±1/40th of a cycle.

Covers & Connectors

Covers provide mechanical protection for the internal components of the encoder and seal it against dust and moisture intrusion. Connectors carry the signal through the cover of the encoder body while maintaining environmental protection.

Inside Tip: All points of entry, including cover screw holes, should be O-ring sealed for the best environmental protection.

Bearings

Bearings, along with the shaft (or shaft tube in the case of a hollow-shaft style of encoder) combine to provide a stable rotational platform which carries the code disc.

Inside Tip: The most accurate encoders use dual preloaded bearing assemblies.

Environmental & Operational Specifications

The environmental and operational specifications establish the environment under which the manufacturer feels it is prudent to operate the encoder.

Inside Tip: Check bearing and temperature ratings carefully. There is no specification standard in the encoder community for these items. If they are critical to your application, you will want to be sure of what you are getting.