POSITAL

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WHITE PAPER


# Kit Encoders: Technologies and Applications

*Closed-loop motion control systems use feedback measurements to ensure the precise positioning of mechanical components. Self-contained position sensors, such as rotary encoders, can do a good job of providing this feedback. In some cases though, it is technically and economically preferable to build the sensors into the machinery being controlled, avoiding the cost and complexity of external measurement devices. This is the domain of kit (or modular) encoders – position sensor elements designed to be installed inside motor housings or other types of equipment to measure drive shaft rotation directly. This paper describes some of the technologies used for kit encoders and outlines their relative advantages and limitations.*

**What are Kit Encoders?**

Kit encoders are component-level devices, designed to be built into motors or other types of equipment to provide real-time measurement of rotary position or rotational speed. They are an essential component in servomotors and can be used effectively in other kinds of machinery, including robots.

Compared to conventional self-contained encoders, kit encoders typically lack sealed housings, bearings or separate shafts. Instead, they are intended to fit inside the host machine's casing, with rotating components connected directly to the machine's shaft. This approach can reduce space requirements, lower costs and lessen mechanical complexity. However, the environment inside motor or machine housings can be challenging, with high temperatures, strong magnetic fields and vaporized lubricants. Choosing the right measurement technology is important to the overall success of a design.

**Resolvers**

Resolvers are relatively simple devices that measure the angular displacement by monitoring changes in the inductive coupling between windings on their rotor and stator components. They are physically robust, reasonably inexpensive and work reliably over a wide range of operating temperatures. However, they also have limitations. Resolvers are analog devices which require an A/D converter in the controller interface. Most resolvers are also relatively low accuracy devices without multi-turn capabilities. Multipole resolvers can deliver higher levels of accuracy but are more expensive.

**Optical Kit Encoders**

The key components of an optical kit encoder are a "code disk", installed on the rotating shaft, an LED light source and an array of photoreceptors. The disk is made of transparent material and carries a concentric pattern of transparent and opaque areas. The disk sits between the light source and the photoreceptors, so that the pattern of light falling on the photoreceptors will depend on the rotational angle of the disk. Signals from the photoreceptors can be integrated to provide an accurate measure of the rate of rotation and/or the rotation angle of the shaft

Kit encoders based on optical measurement technologies are available in a range of configurations and performance levels. At the high end, precision absolute optical measurement systems can have accuracies of +/- 0.02 degree or better and very good dynamic response. These are suitable for advanced servomotors and precision position control applications. At the other end of the price/performance scale, some manufacturers offer low-cost incremental encoders based on optical measurement technology. While these have lower precision, they can be useful for providing closed-loop feedback control for inexpensive stepper motors. By providing clear confirmation as to whether the motor was able to complete a step motion as instructed, this arrangement significantly improves the reliability of low-cost stepper motors for position control applications.

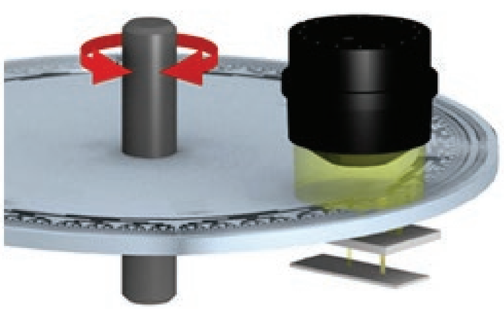

*Figure 1: Optical Encoder: Light Source, Code Disk and Photoreceptor Array*

While optical encoders can offer excellent performance, code disks and photoreceptors can be sensitive to contamination by dust, humidity and condensation. As well, to achieve maximum accuracy, code disks and photoreceptor arrays must be aligned very precisely. This can involve special assembly procedures carried out under near clean-room conditions. Optical code disks must also have relatively large diameters – up to 50mm – in order to achieve high resolutions. This means that high accuracy versions of these instruments will be relatively large.

*Figure 2: Magnetic Kit Encoder*

**Magnetic Kit Encoders**

Magnetic kit encoders use an array of Hall-effect sensors to measure the rotary position of the magnetic field created by a small permanent magnet fastened to the host machine's shaft. A microprocessor is required to interpret the signals from the Hall-effect sensors and calculate the rotational angle of the permanent magnet (and hence the shaft). Because of the mechanical simplicity of this measuring system, magnetic kit encoders can be significantly smaller and more rugged than their optical counterparts. Leading magnetic kit encoders offer 17-bit resolution and accuracy of at least +/- 0.1 degree. Latency is in the order of a few microseconds.

Magnetic kit encoders are compact and straightforward to integrate into motor or machine housings. The electronic module of POSITAL's magnetic kit encoders, which includes the Hall effect sensor array, the signal processing electronics and the chips supporting the communications interface is 37 mm in diameter and 24 mm deep. They are also reasonably priced, which makes them a good candidate for both servomotor or lower-cost stepper motor applications. Assembly requirements are less stringent than for optical encoders

For servo motors with magnetic brakes, a magnetic shield may be required to isolate the magnetic pickups in the measurement system from strong magnetic fields.

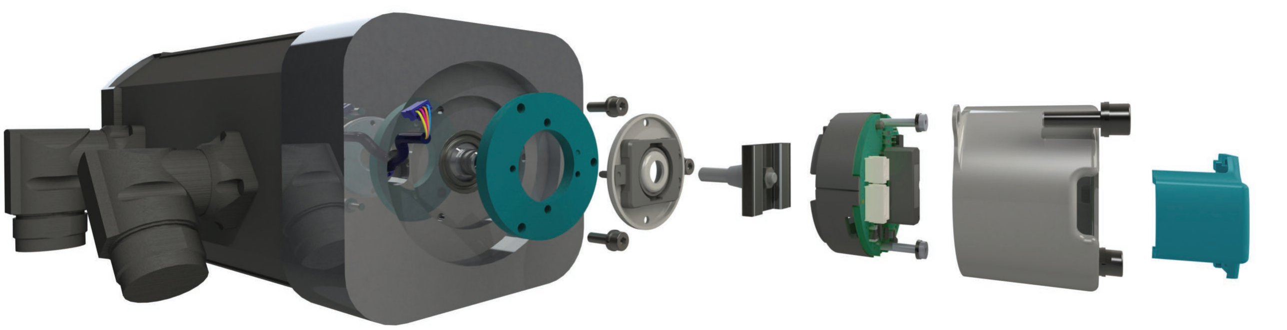

*Figure 3: Magnetic Kit Encoder Installation*

**Hollow Shaft Kit Encoders**

Most of the encoders discussed so far have position sensing elements that are positioned at the center of the device. While this is satisfactory for many applications, there are situations where designers would prefer to use measurement devices that fit around a central shaft, axle or structural element. For example:

- For servomotors, stepper motors or drives, it can be convenient to measure shaft rotation with a position sensor that fits around the drive shaft.
- Robot joints can be designed with a central hinge pin, or with electrical cables and air hoses routed through the center of the joint. Devices that measure joint angle while fitting around these structural elements can be used to create more compact joints.

Ring-shaped or hollow shaft kit encoders are designed to meet these requirements and give designers more flexibility when configuring motion control systems. With these devices, designers of servomotors or feedback-controlled stepper motors can lay out their equipment with position sensors at either end of the motor's shaft. They can also be conveniently embedded into robot joints

Hollow shaft encoders are usually based on capacitive measurement systems. Each encoder has two principle components, a stator and rotor, both with specially shaped areas of conductive material on their surfaces. These function as capacitor plates. As the rotor turns, the relative position of the conductive areas on the rotor and stator change, causing changes to capacitive coupling across the system. This is used to alter the amplitude and phase angle of a high-frequency electrical signal generated by exciter circuits in the stator and transmitted through the capacitor system. Special processors capture and decode these signal variations and determine the rotor's angular position to a high level of precision. Hollow shaft kit encoders

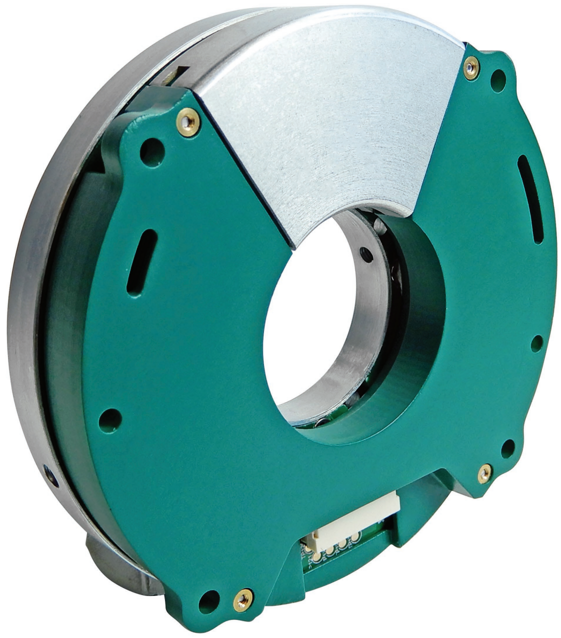

*Figure 4: Hollow Shaft Kit Encoder*

based on capacitive measurement systems can offer excellent accuracy (+/- 0.02 °) and dynamic response (up to 6000 RPM). This makes them suitable for use in critical motion control systems.

Both stator and rotor elements are in the form of thin disks with large central openings. This makes them a good choice for space-limited situations such as servomotors, stepper motors or the joints in robotic arms, where it may be desirable to have an embedded position sensor that fits around a central shaft, structural element or cable cluster.

In summary, the hollow center configuration provides designers with extra flexibility when laying out machinery. Accuracy is very high, with 19-bit resolution (one part in 524 288). Since capacitance measurements are taken around the full circumference of the rotor/stator disks, these systems can be relatively tolerant of minor alignment errors between the stator and rotor. As a result, these encoders can be installed in servomotor housings or other machines under reasonably clean factory conditions. (By contrast, optical encoders require very precise internal alignment and are typically assembled under laboratory-like conditions.)

Capacitive measurement systems are relatively tolerant of dust and moisture, both during assembly and in operation. They are largely immune to magnetic fields, including the strong fields from motor brakes. They can, however, be sensitive to strong electrical fields, so that shielding is generally recommended.

**Multiturn Measurements**

For servomotors or drives, multi-turn measurement capabilities can be useful for monitoring the position of mechanical components when, for example a motor drives a screw shaft, a cable drum or a reduction gear system.

Resolvers are single-turn devices and are not available with multiturn measurement ranges.

For most optical encoders, multiturn measurements are enabled by adding a series of secondary code disks, geared together so that each successive disk in the train rotates at a fraction of the rate of the disk driving it. While this system has been used successfully, it is costly and mechanically complex.

Multiturn magnetic encoders typically use some form of electronic rotation counter. This retains the mechanical simplicity that is a key characteristic of magnetic measurement technology. However, for electronic counters, it is important to ensure that they can maintain an accurate count of the number of complete revolutions that the device has experienced, even if these rotations occur when instrument power is not available. (If a rotation counter fails to record every mechanical revolution, positional accuracy is lost. In this case, it may be necessary to "re-home" the system by returning the entire machine to a known reference state and re-initiating the rotation count.) To ensure accurate position counts under all operating conditions, some encoder manufacturers include a backup battery to keep the rotation counter energized when instrument power is unavailable.

Encoder manufacturer POSITAL has an innovative approach to powering the electronic rotation counters on its magnetic and capacitive kit encoders. The rotation counting system is self-powered. With each shaft rotation, pulses of electricity created by a "Wiegand wire" system mounted on the encoder generates a pulse of electrical current that provides enough energy to activate the rotation counter. This system operates independently of any external power source and doesn't require a backup battery.  Eliminating the need for batteries reduces downtime, lowers maintenance costs and avoids the need to dispose of spent batteries.

| | Resolver | Optical Kit Encoder | Magnetic Kit Encoder | Hollow Shaft Encoder (Capacitive Technology) |
|---|---|---|---|---|
| Singleturn Measurement Technology | Magnetically induced current between rotating and static coils | Rotating code disk and opto-electric sensor array | Hall-effect sensors measure field from rotating magnet | Capacitive coupling between stator and rotor elements modulates high-frequency signal |
| Multiturn Measurement Technology | N/A | Typically geared code wheels or electronic counter with backup battery | Self-powered electronic counter available | Self-powered electronic counter available |
| Cost | $ | $$ | $$ | $$$ |
| Size | | Typically >48 mm ø | 36 mm ø., 24.2 mm deep | Available 30 or 50 mm central opening |
| Accuracy | Low: +/- 0.2° | +/- 0.02° | Higher: +/- 0.1° | +/- 0.02° |
| Ruggedness | High | Code disk and sensors can be damaged by shock and vibration | High | Mid to High |
| Sensitivity to Moisture, Dust | Low | Requires clear optical path across code disk | Low | Low |
| Output Signal | Analog – A/D conversion required for digital controllers | Digital | Digital | Digital |
| Maintenance Free? | Yes | Cheaper versions require a backup battery that needs to be replaced every 2 years | Yes, although cheaper versions require a backup battery that needs to be replaced every 2 years | Yes |