POSITAL

FRABA

WHITE PAPER

Kit Encoders: New Technologies for a Dynamically Changing Market

Closed-loop motion control systems use feedback 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. However, in some cases 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.

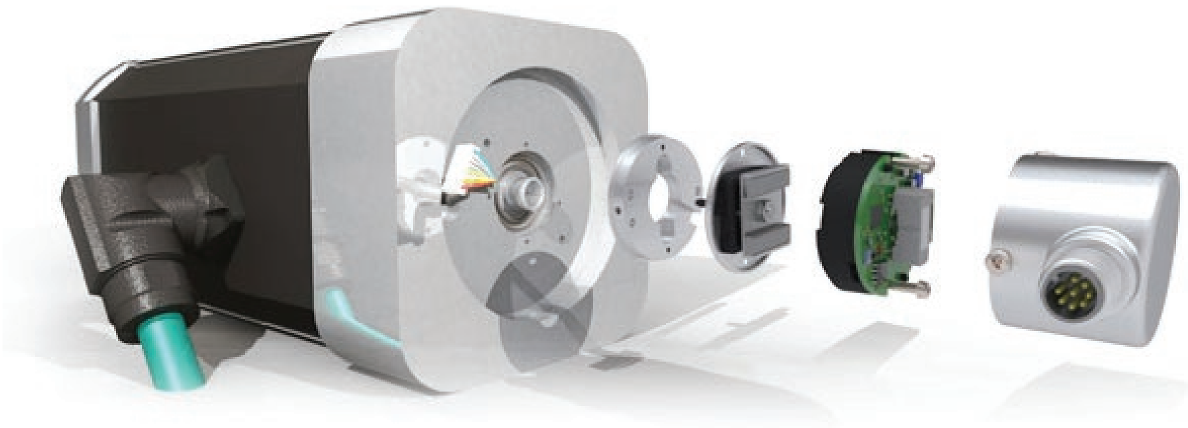

Figure 1: Kit Encoder Installation

What are Kit Encoders?

Kit (or modular) 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 usually 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 a relatively simple devices that measure rotation angles by monitoring changes in the inductive coupling between windings on their rotor and stator components. They are physically robust, iinexpensive and work reliably over a wide range of operating temperatures. However, they 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

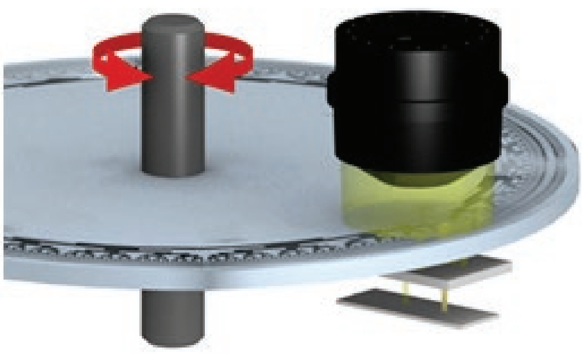

Figure 2: Optical Encoder: Light Source, Code Disk and Photoreceptor Array

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.

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 cleanroom conditions. Optical code disks must also have relatively large diameters – up to 50mm – in order to achieve high resolutions. High accuracy versions of these instruments are relatively large.

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.

Incremental or Absolute Measurements

Incremental encoders send a stream of signal pulses to the controller as the device's shaft rotates. The pulse rate is equal to the rotational speed times the device's resolution, expressed as the number of pulses per rotation (PPR). Most incremental encoders also report the direction of rotation.

Incremental encoders are ideal for speed control since they provide a real-time reading of the rate of rotation. Incremental encoders can also be used for positioning tasks, with the control system tracking the absolute position by counting the number of pulses received from the encoder. However, for positioning systems built around incremental encoders, this position count could be lost or corrupted during a power failure or system shutdown. In this case, it may be necessary to return the machinery to a known reference position and re-start the position count before operations can resume.

Absolute encoders provide a snapshot reading of the shaft's angle of rotation, usually as a multi-byte digital 'word', in response to a request from the system's controller. For multi-turn absolute encoders, the output combines the angle of rotation with a count of the number of complete rotations that the encoder shaft has experienced. Absolute encoders are ideal for positioning tasks, since most can report their complete absolute rotational position (including the number of complete turns) immediately on startup. This eliminates the position-reset problem encountered with incremental encoders.

Figure 3: Magnetic Kit Encoder

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 measures 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 significantly 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.

Miniature Kit Encoders

POSITAL has demonstrated a new generation of miniaturized magnetic kit encoders that are 22 mm in diameter and 23 mm deep, while retaining the accuracy and functionality of their larger predecessors, including a multi-turn measurement capability. These units are especially well suited for use with smaller servo or stepper motors.

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. With these devices, designers of servomotors or feedback-controlled stepper motors can install position sensors at either end of a motor's shaft.

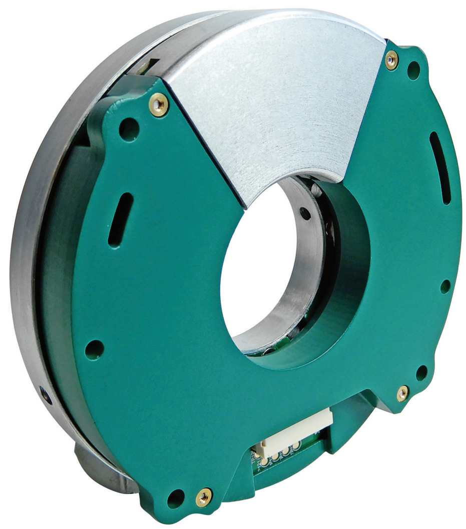

Figure 4: Hollow Shaft Kit Encoder

Figure 5: Hollow Shaft Installation

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 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 open centers. This makes them a good choice for space-limited situations such as servomotors, stepper motors or in 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 developed 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.

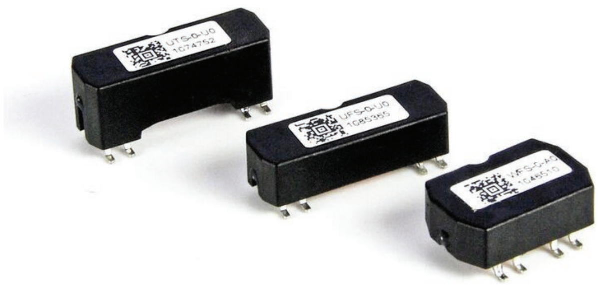

Figure 6: Wiegand Energy Harvesting Assemblies

Stepper Motors with Position Feedback –
A Low Cost Alternative

While servomotors are a popular choice for precision motion control in industrial machinery, the improved performance of stepper motors is making these lower-cost devices an increasingly attractive alternative for many applications. The key to these performance gains is the addition of rotary position measuring encoders.

Stepper motors are brushless DC motors that turn their shaft by a small fixed amount (step) in response to a control signal. In its basic form, this is an open loop control system: if the motor fails to complete a step (e.g. due to unexpected mechanical resistance) positional accuracy is degraded. This can be overcome by adding a simple incremental encoder that can confirm that step motions have occurred. Absolute encoders take this a step further by providing absolute position feedback.

Absolute kit encoders from POSITAL are available with multi-turn measurement ranges, which can be very useful when a motor is connected to a screw shaft, cable drum or gear reduction system. The multi-turn rotation counter is self-powered, using POSITAL's Wiegand energy harvesting technology. The rotation count is always up-to-date, even if the machine has moved while control system power was out. No backup batteries are required!

Kit encoders for stepper motors are designed to be easily integrated into a motor housing, measuring the rotary position directly from the drive shaft. Kit packages are available with the same mounting form factor as popular incremental encoders for NEMA-standard stepper motors, making these encoders convenient drop-in replacements for less advanced incremental encoders. The magnetic measurement module is compact and highly resistant to dust, moisture and shock/vibration loading. Shields are available to protect the measurement module from external magnetic fields. SSI and the more advanced "BiSS C" communication interfaces have been implemented. Both are open-source interfaces that are compatible with a wide range of PLC's and computers.

Stepper motors with built-in position sensors are an attractive solution for positioning tasks in manufacturing equipment, packaging machinery, robots and other applications where a reliable, cost-efficient drive mechanism is needed.

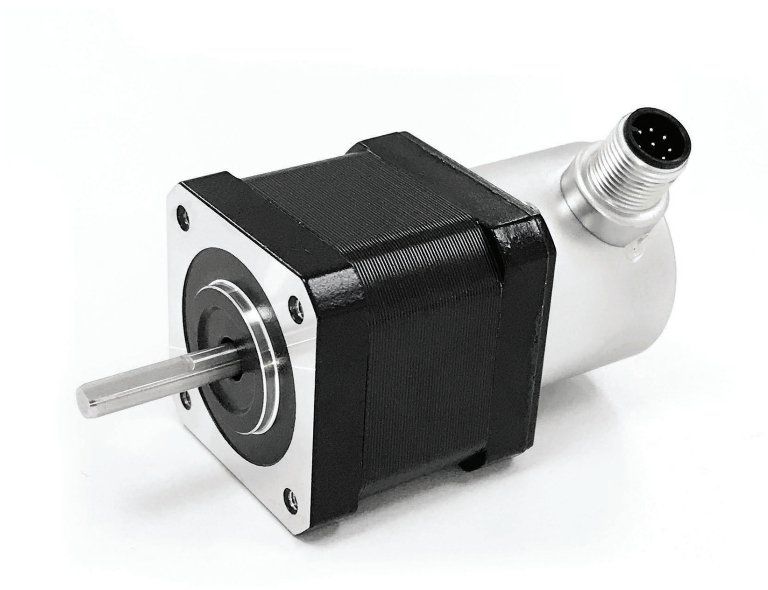

Figure 6: Stepper Motor with Encoder for Position Feedback

	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