Portescap

WHITE PAPER

STERILIZABLE ENCODERS AND BLDC MOTORS

Introduction

Magnetic encoders allow for high resolution feedback, enabling precise motion control profiles. Understanding how these devices work and their advantages compared to traditional feedback methods (such as hall sensors) is important to maximize the utility of a surgical hand tool drive system. This paper will evaluate the underlying technology of magnetic encoders and illustrate the benefits and design tradeoffs to consider in a surgical hand tool or surgical robotic application.

There is an array of potential feedback devices for electric motors, particularly brushless DC (BLDC) motors. Electronic commutation is required in these types of motors, so rotor position sensors have been a critical component from the start of brushless technology. Options for sensing rotor position include hall sensor, encoder or "sensorless" (software estimation of rotor position).

Beyond commutation, if a motion system requires complex speed and acceleration motion profiles an encoder is often the best possible sensor to achieve system requirements. Magnetic encoders can provide the resolution and accuracy necessary within a small, robust package uniquely suited for an autoclave environment. The many features and variations of these products are explained below.

Technology Review

On a system level, a drive is composed of three high-level blocks. Figure 1 depicts a motion system block diagram with an encoder as the feedback sensor.

a. Motor
b. Feedback sensor (e.g., encoder)
c. Controller & Power Electronics

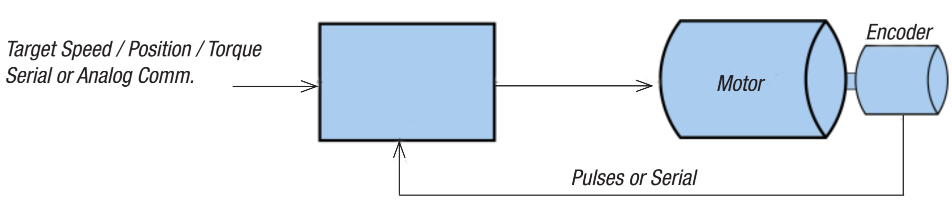

Figure 1. Motion System Block Diagram

The motor converts electrical energy into rotational mechanical energy. In a BLDC motor it is composed of a stator and rotor with an output shaft connected to a load. The feedback sensor (in broad terms) provides information to the controller of the actual state of the control variable. It allows for the calculation of error between the desired state and the present state, critical for a control system. The encoder shown in the block diagram here communicates the real-time position and velocity of the motor to the controller either through quadrature pulses or a serial communication protocol.

The controller produces the necessary voltages and currents to drive the motor. In this layout it uses the information from the encoder to commutate the motor and calculate the error in the control system. It receives the position or velocity command and can generate the required corresponding response from the motor to meet the command.

Within the encoder itself, there are more important terms. The first is the type of encoder: absolute or incremental. An absolute encoder returns the absolute angle of the rotor position, with respect to a reference point. Through power cycles and direction changes, this reference point does not change, and the reported position is always an actual angle value. In magnetic encoders, the angle value is typically communicated serially or by an analog voltage with a defined ratio compared to 0-360 degrees.

In contrast, an incremental encoder will only provide a pulse when the rotor incrementally changes position. If there are multiple pulses in quadrature (phase shifted by 90 degrees), direction can also be determined. However, at any given moment, the encoder is not reporting the position of the output shaft referenced to an index point. As a result, the feedback system loses track of the true position of the rotor when powered off, which can be critical for successful operation of a medical device.

Resolution defines the precision capability of an encoder. In an incremental encoder the resolution represents the angular value of a single pulse. Resolution is often given in terms of the number of pulses in a single mechanical rotation. This definition is nearly the same in an absolute encoder but just defines the granularity of the angular sensing capability and is not tied to a single pulse.

Accuracy in an encoder represents the capability to correctly report the actual angular position of the rotor. It allows a system designer to understand the margin of error in the reported angle and to build in an allowable margin in the drive system. This value is usually given in terms of degrees and can sometimes vary non-linearly. In magnetic encoders, the linearity curve is important to have so that any inaccuracies can be accounted for.

When it comes to the choice of encoder technology, optical and magnetic are the two main categories. Optical encoders require a light source and sensor with a wheel between the two with transparent and opaque sections, usually along multiple tracks to generate the rotational pulses. Within magnetic encoders, there are magneto-resistive and hall-effect based technologies. In autoclavable applications, with steam, fluids and potential debris, magnetic topologies offer a small and robust option.

Motion Control Challenge

What types of situations call for an encoder as part of a drive system? Examples include a) precise angular position control, b) precise velocity control, c) smooth torque control and d) increased safety through rotor position locking.

a) *Angular position control*

A position control system, which is used to precisely rotate the output shaft of a motor from one angle to another, requires tight control and knowledge of the rotor shaft position. The movement profile displayed in Figure 2 sometimes looks like a polynomial curve over time, with an acceleration, constant velocity, and deceleration section, as shown in Figure 3.

The feedback loop for this control system must provide enough resolution to command a rotation from 0 to 90 degrees without overshooting the target. In this situation, hall sensors alone, with their 60 electrical degree resolution, may not provide enough precision for smooth movement.

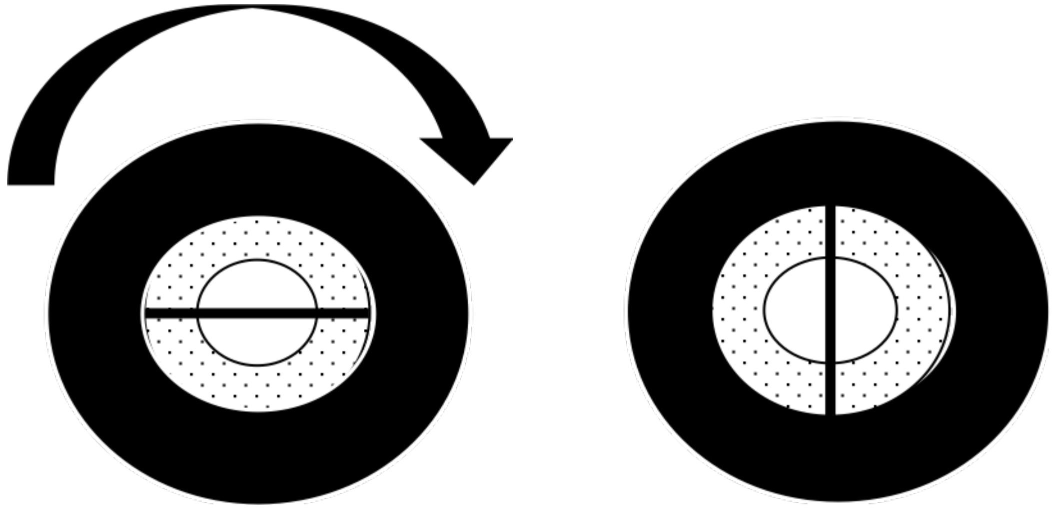

Figure 2. Rotation Example

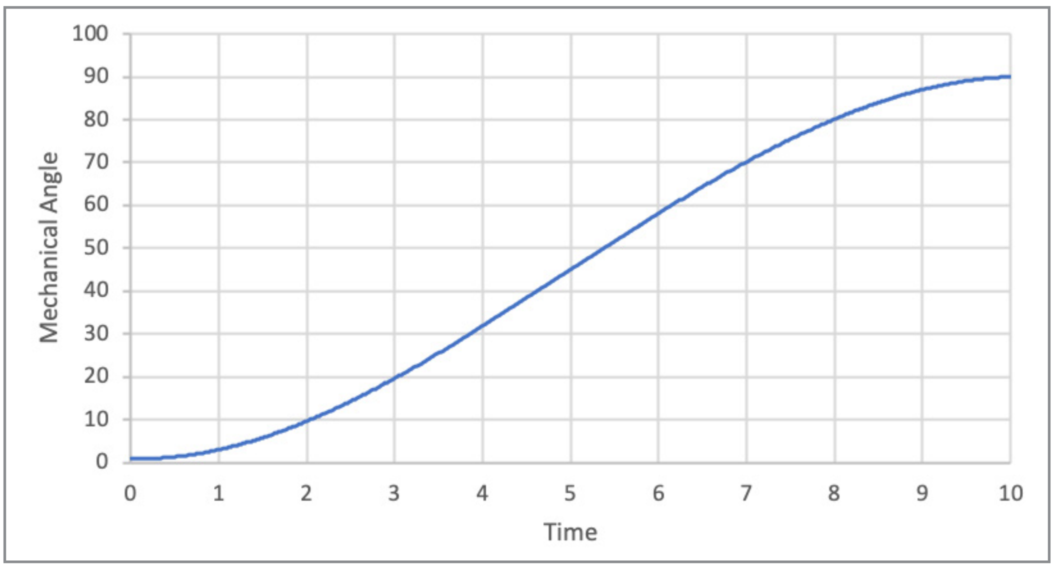

Figure 3. Position Control Motion Profile

Potential applications for this type of motion profile would be robotic actuation or fine-tuned tightening control. Incremental or absolute encoders can be used depending on the type of application and information required.

b) Velocity control

Velocity control systems can also benefit from an encoder. Beyond knowledge of the shaft position, speed and acceleration can also be determined from the encoder's feedback.

Suppose an application requires tight control over how fast the system rotates between 0 and 90 degrees and also requires the shaft to reverse rotation indefinitely. One period of the oscillation velocity profile would appear similar to the below graph.

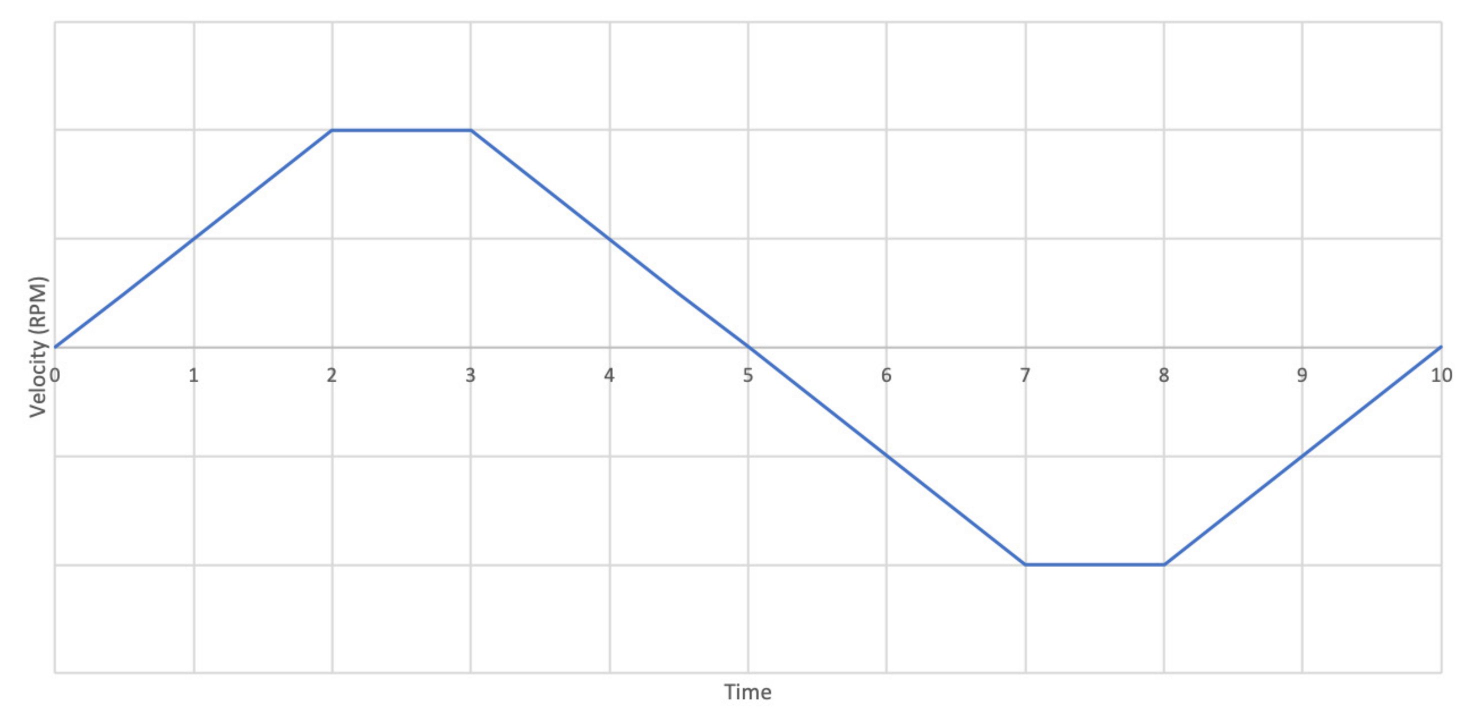

Figure 4. Velocity Control Profile

Arthroscopic shavers may require such an oscillation profile, with timed changes in velocity. Leadscrew driven linear movement assemblies are also potential applications, where the rapid movement of a load is critical. In both cases, an encoder can provide the necessary velocity feedback for tight control system realization of a target motion profile.

c) *Torque Control*

Yet another area, encoders can be used for precise motion control is smooth torque control. Usually, accurate field-oriented-control (FOC) systems are used to provide smooth torque over a wide speed range. These control systems require high fidelity position feedback and an encoder is the typical solution. Applications that can benefit from an encoder and smooth torque control include reaming and precision tightening like a screwdriver.

d) *Safety*

Tools requiring safety features for shutdown routines or to protect an operator from a blade or bit can also benefit from the absolute shaft position knowledge an encoder can provide.

If a sharp blade is required to remain within a safety shroud or unexposed to the surgeon, the absolute position information can be used to define either a keep-out region or a target "home" position to return to during specified situations.

Feedback from the encoder would allow for confident implementation of such a safety scheme without ambiguity or doubt as to the rotor's actual location.

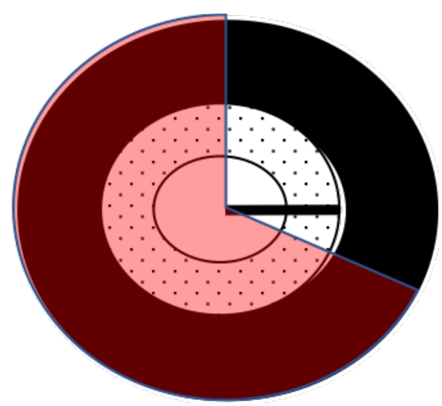

Figure 5. Safety Keep-out Region

Integration Challenges and Benefits

If design goals necessitate the use of an encoder in a drive system, integration can also pose a challenge to the tool or system designer. Encoders, typically mounted on the rear side of a BLDC motor, can require a shaft extension and add axial length as well as increased overall diameter. However, an integrated magnetic encoder can often meet the feedback requirements for a drive while remaining within the motor's maximum outer diameter, sealing all sensing components internal to the motor body, and minimizing the axial length growth.

A hall effect based magnetic encoder requires a radially magnetized di-pole magnet attached to the shaft to be sensed. In a BLDC motor, this is typically the main rotor or output shaft. When positioned parallel to the magnet, an array of hall effect sensors on the encoder itself can detect the angle of this di-pole as it rotates and translate the information into either incremental or absolute position information depending on the requirements of the application.

The package and solution used by Portescap comes in a small leadless form factor allowing for integration into motors themselves. The axially in-line design, with a small, simple sensing magnet allows for motors as small as 0.5" in diameter to internally locate the encoder and sensing magnet.

As a fully contactless sensing solution, and no optical wheel to get damaged or obfuscated, the electronics can be sealed and protected against the autoclave environment. The flexibility of this design allows for both incremental and absolute operation. With resolution up to 10 bits (~0.35 degrees) and accuracy within 1 degree, the result is a highly robust and highly precise drive system that can be integrated in the motor.

Conclusion

Within surgical tools, small lightweight solutions with lots of power are important. As the capability of control systems grow, the potential use cases and motion profiles for surgical hand tools also grow. A small magnetic encoder integrated into the motor can offer highly increased position and speed data when compared to a standard six-step based hall sensor-based BLDC motor. This increased quality and quantity of data can be used to commutate the motor and/or allow for complex motion profiles in a closed loop control system. This data can also be used for operational monitoring or increased safety features.

With a proven, integrated BLDC motor and encoder, surgical hand tools can become sophisticated electrical drive systems capable of the most demanding motion control requirements and withstanding the rigors inside of an autoclave. **P**

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