Feedback Choices for Servo Applications

Feedback Sensors Keep Servomotors on Target

It pays to understand all the feedback devices that are currently available for fine-tuning your servomotors, as well as your motion control decisions.

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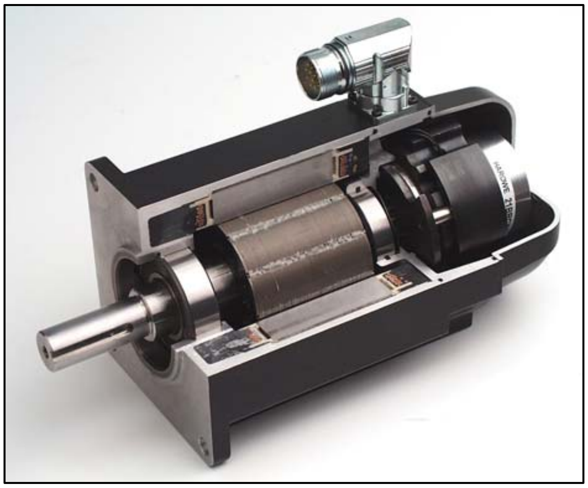
Servomotor-powered motion control systems are expected to be fast and accurate, and when correctly specified, they are. However there are numerous factors that can cause them to miss the target.

Fundamentally a servo system can perform no more accurately than the accuracy of the feedback device controlling it. In addition, errors in speed or position can be introduced into the system by the less than perfect mechanisms that transfer the motor power to the load. Environmental factors like electrical noise or temperature may also introduce positioning errors. Sometimes the errors are acceptable. More frequently, however, they are not. After all, servomotors can be expensive, and the expectation is that they will be the most reliable and accurate of all positioning devices.



Most servomotor manufacturers now integrate the feedback device directly into the motor housing. Kollmorgen's AKM™ servomotor, for example, accommodates most types of feedback devices without requiring extensive modifications, either in the housing or on the feedback device.

When it comes to high-performance servo applications, feedback devices fall into several different categories. Each offers unique advantages and disadvantages, both electrical and mechanical, that make one better suited for a particular application than another.

Feedback Device Location

The optimum location of a feedback device is at the load, where the controlled motion is required. This arrangement eliminates errors introduced by less-than-perfect transmissions that transfer the motor's motion to the load. This sometimes means adding a feedback device to the system in addition to the device that is typically mounted inside the motor. Brushless motors require that position feedback be incorporated into the motor to provide immediate rotor position data for electronic commutation (see Sidebar). When using a motor-mounted feedback device it is important to determine the cyclical and cumulative error associated with the transmission and feedback device to determine if the error is acceptable.

Direct drive servomotors have the advantage that its internal feedback device is effectively connected directly to the load thereby eliminating compliance and backlash. This in addition to the reduction of components and maintenance makes direct drive motors an ideal solution for applications requiring precision motion and high bandwidth.

Absolute or incremental

Feedback sensors report either absolute or relative incremental position. The former has the capability to report its position within one electrical cycle when the system is powered up. By contrast, the incremental position sensor typically provides output pulses for each increment of motion, but without reference to the particular location within the device's range of motion. This data, in combination with periodic marker pulses, a machine home switch and a counter, allow load position to be known. However, should the electronic feedback circuits lose power the system loses track of its location. For some critical applications using incremental encoders, the controller can connect to an uninterruptible power supply to maintain position information. Alternatively, a multi-turn absolute encoder will provide the same function without the need to keep power applied.

A second consideration is the type of technology used in the device. Some sensors are extremely rugged and are targeted at the industrial, machine-control industry. Others are relatively fragile, and are intended more for precision laboratory equipment. And, of course, there are applications where the requirements overlap, such as in semiconductor manufacturing, where conditions call for high accuracy in a particularly clean environment, with high-speed throughput, to meet high production schedules.

A third consideration is geometry. Motion systems are either linear, rotational, or a combination of the two. Feedback sensors are specifically designed for each case. They may have different mounting features and motion directions, but the basic principle of feedback device operation typically applies to either configuration. For linear systems, such as those found in X-Y-Z axes positioning, position data also indicates the exact locations of all axes simultaneously, which can be crucial in some applications. In an E-stop (emergency-stop) situation, being able to restart the motion components at the point they stopped can prevent machine jams and reduce waste.

Speed information is commonly derived from position data by taking the derivative with respect to time, making these devices a "one-stop" purchase for most servo-based systems. However, for applications requiring precise speed information at low speeds, sometimes a feedback device designed for that specific purpose, such as a precision analog tachometer is preferred.

The Good News

Feedback devices often play a critical role in closed-loop control systems. Not long ago choosing the right one was a daunting task, but now selection has been greatly simplified.

Many motion control manufacturers offer complete motion-control systems where the motor, feedback device, and drive and cables are combined into an optimized package. Such packages handle more than 90% of today's motion applications. The benefit to the engineer is that he doesn't have to separately wire or mount the feedback device into the servo system, where wiring connections can be as high as 9 or 13 wires, or as few as four. In addition, some manufacturers like Kollmorgen offer "smart" feedback devices in their motors allowing plug-and-play operation by providing the drive with an electronic motor nameplate with motor parameters. These parameters configure the drive allowing motion in seconds. Smart feedback devices can be based on any of the standard feedback types with the addition of an imbedded chip containing the motor parameters.

So what does one need to know to select the optimum feedback device for their application? First are the positioning accuracy and resolution requirements. Additionally, environmental factors such as distance between the motor and drive, electrical noise, or temperature can be factors in determining the optimum feedback device.

A wide variety of devices are available to suit nearly any feedback requirement, including Hall-effect sensors, resolvers, general-purpose encoders (of a wide variety), and sine encoders. Fortunately, many servomotor suppliers offer multiple feedback options for a given motor to accommodate a wide range of performance or environmental requirements.

Among the simplest and least expensive feedback devices are Hall-effect sensors. These are digital on-off devices that detect the presence of magnetic fields. Made of semiconductor material, they are rugged, can be operated at very high frequencies (equating to tens of thousands of motor rpm), and are commonly used to provide six-step commutation of brushless motors. They are well suited for torque control or coarse speed control, and simplify the drive electronics by directly switching the motor phase power devices.

Resolvers are rotary transformers that are well suited to harsh environments, where extreme temperatures or vibration and shock are factors. They can also handle motor speeds in excess of 10,000 rpm. These are low to moderate on a cost scale, and provide moderate accuracy and resolution that is suitable for most industrial applications.

What is Commutation?

Commutation is the control of current to produce torque.

In permanent magnet motors, torque is produced when the magnetic field from the winding interacts with the field from the magnet. When current is channeled to the proper winding(s), optimal torque is produced.

When the motor is moving the position of the windings relative to the magnets changes. This means that the optimal path to channel the current changes, depending on the motor position.

In a brushed motor, this occurs automatically by means of brushes and a commutator connected to the armature windings. In a brushless motor, rotor position is fed back to the drive which then electrically switches current to the appropriate windings via transistors.

Incremental encoders come in a variety of configurations, from non-contacting optical to contacting types, in both linear and rotary versions, and with multiple line count variations. These encoders provide excellent accuracy and can be operated up to many thousands of rpm. While today's incremental encoders are more rugged than ever before, some are not suited to extremely harsh environments.

Sine encoders offer very high-level performance. Although more expensive than resolvers or incremental encoders, they are best suited to applications requiring high accuracy coupled with high resolution.

Hall-Effect Sensors

When a machine doesn't require precise speed control or high resolution from the motion system, low-cost feedback sensors such as Hall-effect devices are a suitable option. These digital on-off sensors detect the presence of magnetic fields, either by measuring the strength of an electromagnetic or permanent magnetic field. At each pass of a magnetic field they generate a pulse.

Hall-effect devices are digital On/Off sensors used to sense the presence of magnetic fields.

Hall-effect devices come in stand-alone packages that are mounted within the servomotor housing. In brushless servomotors, these sensors are sometimes embedded in the stator windings and switched by the rotor magnets. These devices report the shaft's position, which can also be converted to speed or acceleration data.

In servomotor applications, the most common function for Hall devices is six-step commutation, a type of electronic commutation requiring relatively simple drive electronics. This may not suit some industrial servo applications because it can be less efficient at producing torque, and worse, can generate high torque ripple. In this case, torque ripple results from abrupt current transitions resulting in torque fluctuations, which usually produce minute but detectable speed variations. In some cases torque ripple can seriously deteriorate the overall performance of a drive system.

With sinusoidal current drives, Hall sensors may be used in combination with incremental encoder feedback to provide precision sinusoidal commutation. In servo drives, Hall sensors also function as current sensors to close the current loop. In other industry applications, they sense the position of crankshafts, cams, or other mechanical devices.

Resolvers

Resolvers, along with encoders, handle the majority of closed-loop motion-control tasks. A resolver is a rotary transformer with a primary and two secondaries. The primary is fed with an AC voltage. The secondaries couple the input voltage ratiometrically according to shaft position. The resulting sinusoidal signals, Sine and Cosine, are converted into digital signals in the drive controller by resolver-to-digital converters (RDCs) or by interpolation software in the drive. A two-pole (single speed) resolver provides an absolute position signal within one revolution of the motor.

In a resolver, the position feedback signal is provided by the two sinusoidal signals, Sine and Cosine. Resolvers are durable and tolerate heat very well.

Because resolvers are basically analog devices, they provide relatively clean signals. Their high-voltage range makes them less susceptible to noise, too. The converted output resolution is generally determined in the drive, and may be up to 16 bits. However, the resolution may be limited by motor speed because of a maximum frequency limitation. Resolvers can be single speed or multi-speed, which refers to the number of electrical cycles per mechanical revolution. The counts-per-revolution increase by a factor of the resolver "speed".

Resolvers have many positive attributes: they are rugged devices that are highly resistant to EMI noise, and tolerate heat, vibration, and shock. However, they require more electronics for signal conversion than is needed for encoder based systems. Additionally, resolvers are generally less accurate than optical encoders, but some versions, known as tooth-wound units, improve on this. The manufacturing techniques for these units keep part-to-part variation to a minimum, which increases their output accuracy by about 50%. Resolvers are commonly rated at 155º C, with special models able to withstand 230º C, or even be radiation hardened. Frameless brushless types are commonly used in servomotors due to reduced maintenance needs and a large through bore that can accommodate motor modifications such as hollow shafts and additional shaft extension options.

Encoders

Encoders are characterized in three basic categories: rotary or linear, incremental or absolute, and by the method of signal generation being optical, magnetic or contacting. When optical encoders first appeared, they were praised for their ability to offer high accuracy in both low and high-speed applications.

At one point they were viewed as unreliable, but much of the problem related simply to their misapplication. They were installed on heavy industrial equipment where vibration and temperature took their toll on the fragile electronics and glass encoding disks.

Today's versions are more rugged, with better-protected electronics and optics. Even so, most manufacturers still recommend that optical encoders be selected for lighter industrial applications where they are exposed to temperatures below 90º C and vibration below 20 g's.

Encoders can be contacting or non-contacting devices, with non-contacting optical encoders the more common of the two. These use a light detection unit that reads the on-off pattern as light passes through the coded disc/shutter mechanism, which then sends that data to the drive system.

Encoder makers offer several types of discs that generate as many as two million counts per revolution and algorithms that decode them for extremely high resolution positioning. Encoders typically come with multiple channels, such as A and B, and their compliments to wash out any noise pulses that might contaminate the signal. Other signals and their compliments provide a reference position marker for homing and commutation.

Linear Encoders

Linear encoders contain a linear track and a read head, and are usually used with systems that track linear movement, such as X-Y stages, and position tables. The linear track can range in length from a few inches to several feet. It is etched with graduations that are scanned by the read head as motion components move. The read head detects multiple channels to provide position and direction data. Encoders with sinusoidal outputs use additional interpolation circuitry to electronically improve resolution.

For equipment that requires particularly high resolution, linear encoders are the best choice in their class. Resolutions to 0.1 microns are common, with some systems offering resolution to 20

nanometers. Accuracy, typically 20 microns per meter, may decrease linearly over the travel distance of the track. However, this can be compensated for with slope error correction to bring any error below 5 microns per meter. Machines operating at high speeds use linear encoders for feedback because these devices typically operate at higher speeds than other feedback devices.

The primary factor that can potentially limit speed is whether or not the electronic counting circuitry can keep pace.

Optical Rotary Encoders

Optical rotary encoders consist of a light source, rotating code disc, and a light detector. The disc has either slits or graduations that divide it into equally spaced areas of dark and light. These markings often are referred to as lines, hence the unit of measure, lines per revolution (LPR). This measurement indicates an encoder's resolution or granularity.

Accuracy for encoders is defined as plus (+) or minus (-) so many lines or counts. It is important to note that accuracy and resolution are different attributes, although they are often related. With encoders, accuracy typically increases with resolution since accuracy is defined as +/- so many counts. As count resolution increases, so does accuracy. With resolvers, however, increasing resolution by more interpolation, 16 bits vs. 12 bits for example, does not increase the accuracy. It is quite common for resolver systems to have 100 times lesser accuracy than resolution.

As the connected components rotate, the light detector registers the on-off pattern of the light passing through the disc. The detector converts this on-off pattern into an electronic, digital signal that looks like square waves. Typically two rows of slits or markings are offset by one half of their width or one quarter of a complete cycle (90 electrical degrees), generating two electrical signals known as Channel A and Channel B. This offset lets the control determine the direction of the shaft rotation, and an important piece of information for the drive during start up, and essential for servo systems providing bi-directional motion.

Instead of using only two channels, some encoders use additional channels to track shaft position or help with noise immunity. These channels include what's referred to as the Index and Compliment channels. Another means of tracking shaft position is to add a commutation, or Hall equivalent channel. They represent alignment to the A-phase, B-phase, and C-phase back EMF of the motor.

Depending on how the encoder counts the A and B channels, resolution can increase four-fold. This will arise when the counting circuit tracks both falling and rising edges of both signals, also referred to as quadrature detection. Increasing resolution will increase system repeatability. High resolution also enables higher gain for position and velocity loops, ensuring superior system stiffness. Encoder resolutions of 50 to 5,000 lines per revolution are standard among most vendors, but line counts to 100,000 are available.

In high-accuracy applications, system accuracy is affected by errors from other sources such as lead-screw cumulative error, thermal expansion, or nut backlash. Linear encoders can overcome these challenges.

Sine Encoders

Sine encoders are at the high cost, high accuracy, and precision end of the feedback device spectrum. They are similar to incremental encoders, except that the A and B data channels are sent to the controller, typically as one-volt peak-to-peak sine waves instead of square waves. The benefit is that these devices can interpolate each complete sine wave, increasing system resolution and giving more information to the velocity controller. This reduces truncation and quantization errors, allowing higher loop gains. Sine encoders can achieve over 2 million counts per revolution, or about 0.62 arc-sec of resolution. Such capability is well suited to applications that require high precision or have high inertia loads.

Like other encoders, sine encoders also may have commutation tracks, Hall emulation tracks, or auxiliary sinusoidal channels called C and D, which provide absolute position within one revolution. The C and D channels are similar to the Sine and Cosine signals used in resolvers.

A variation of sine encoders is the multiple-turn sine encoder. Multi-turn versions are implemented using an internal mechanical gearbox. This provides absolute positioning over many revolutions of the device. These encoders can provide up to 8192 steps per revolution and up to 8192 shaft revolutions providing a total of 26 bits of absolute resolution before interpolation. Sine encoders offer high precision, resolution, and accuracy for applications ranging from high-speed registration, to film coating, and web control. Sine encoders also fit low-speed operations where smooth rotation is critical. They help motion systems achieve high gains, superior stiffness, and position accuracy in rotary tables, indexing assembly machines, and roll drives.

Quieting noise
Feedback devices can output electrical or optical signals. One advantage of using optical transmission lines for feedback signals is that they are immune to high noise or EMI/RFI environments. High noise levels interfere with clean signals and distort data sent to the drive, compromising a drive's ability to provide high-quality position, speed, and torque control. When sending signals electrically, amplifiers or signal conditioning devices may be needed to modify noisy signals. Newer feedback devices use IC chips to convert and interpolate signals to more robust waveforms that aren't corrupted by noise, and that won't diminish as they propagate through the cable to the drive.

Conclusion
More than ever before, machine designers have a wide range of servo system components available to accommodate a wide range of applications, from the simple to the complicated and demanding. This discussion is intended only as a starting point and not the final word, so consult with your motion control provider to discuss your specific application needs and to get the details about their available product offerings.

ABOUT KOLLMORGEN
Kollmorgen is a leading provider of motion systems and components for machine builders around the globe, with over 70 years of motion control design and application expertise.

Through world-class knowledge in motion, industry-leading quality and deep expertise in linking and integrating standard and custom products, Kollmorgen delivers breakthrough solutions unmatched in performance, reliability and ease-of-use, giving machine builders an irrefutable marketplace advantage.

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