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WHITE PAPER

Which Servo Position Feedback Device Is Right for Your Application?

The precision and responsiveness of a closed-loop servo system depend on the quality of the position feedback device. Some devices also have features that can significantly improve machine productivity and safety. Understand the available technologies, so you can make the right choice for your needs.

What is a position feedback device?

A position feedback device measures the position of a motor's mechanical output relative to the stationary part. For a standard rotary motor, the device measures the position of the shaft/rotor relative to the motor housing/stator. For a linear motor, it measures the position of the moving coil relative to the stationary magnet structure. The speed of motion and even acceleration can be calculated via position measurements over time.

There are many types of position feedback devices, based on various types of analog sensors. The most common sensing types are:

- Optical, for example Kollmorgen's multi-turn absolute Smart Feedback Device SFD-M
- Inductive, for example resolvers or Heidenhain's EQI series devices
- Capacitive, for example SICK's EEM37 series devices

Each sensing type has its own pros and cons based on cost, size, performance, ruggedness and operating temperature.

For standard rotary servo motors, position feedback devices are usually mounted inside the rear of the motor as shown in Figure 1, an exploded view of a Kollmorgen AKM2G servo motor equipped with an SFD-M feedback device.

Why does a servo motor need a position feedback device?

Some motors work without position feedback devices, for example, AC line operated motors, variable speed induction motors and stepper motors. But for applications that require precise motion control, running motors in an open loop mode without position feedback devices can compromise quality of motion through:

- Inability to hold a constant mechanical position
- Poor speed regulation when constant speed is required
- Slow changing of speed
- Slow move time from position to position
- Poor smoothness of motion
- Getting "lost," for example, settling to a very wrong position
- Poor thermal efficiency or the need to specify a larger motor size.

A position feedback device in a closed-loop system allows for the most **precise motion control.**

All of these issues can be eliminated by tracking measured motor position in a servo control loop.

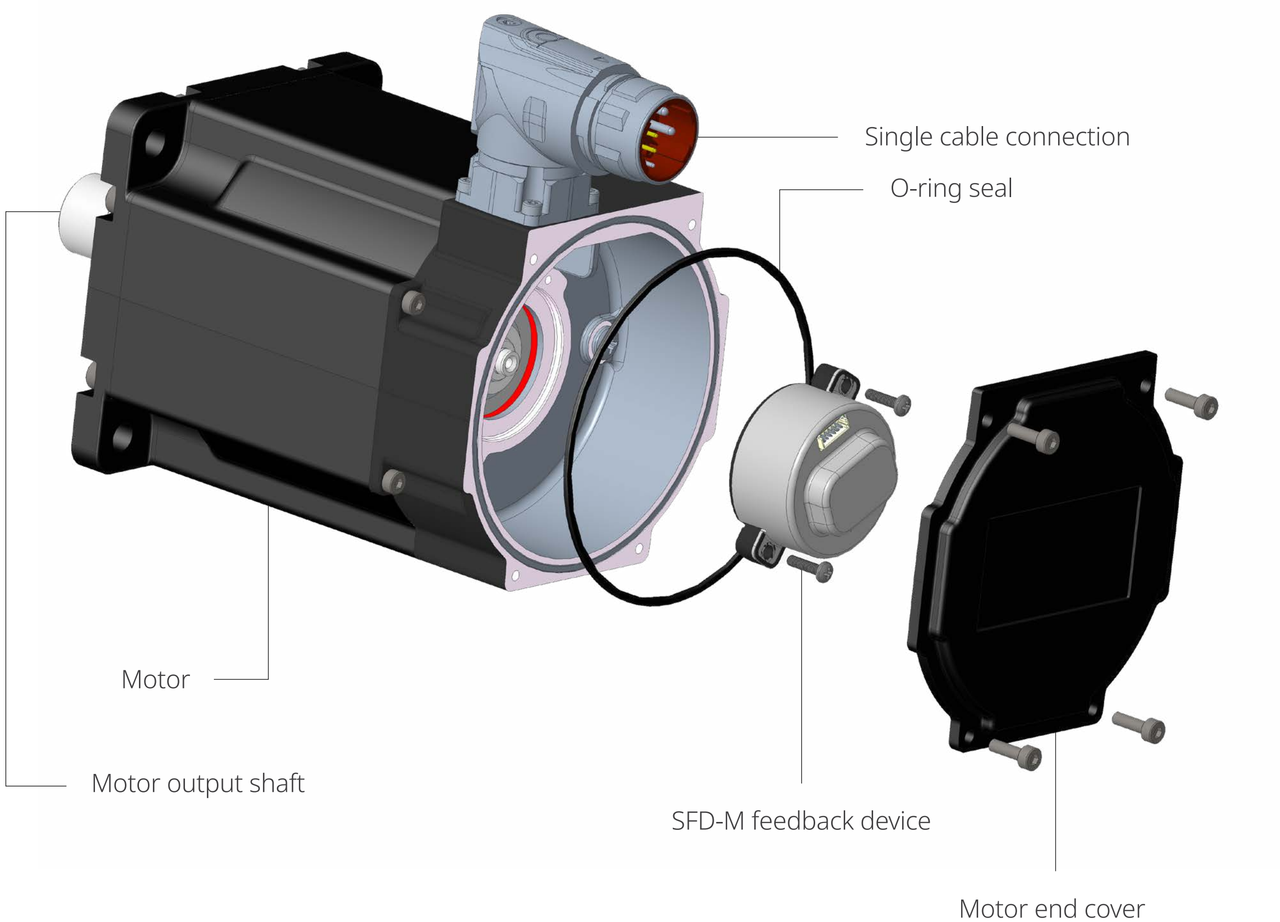


Figure 1. Exploded view of Kollmorgen AKM2G servo motor with SFD-M feedback

How is position feedback used?

Servo control loop

Measured motor position is data used in a servo control loop by an electronic controller known as a motor drive.

The goal of a servo control loop is to continuously drive the error value as small as possible—in other words, to drive the output of the feedback sensor block to be as close as possible to the input command value.

In Figure 2, the block labeled feedback sensor is the position feedback device for the servo motor in the system. Ideally, the servo loop tries to drive the motor output position, as measured by the feedback device, to be as close as possible to the commanded position. In a variant of Figure 2 the feedback sensor block takes the derivative of the measured position to provide velocity feedback, and the loop controls motor velocity.

Arguably, the quality of the position feedback device is the single most important element contributing to the quality of motion attained by the servo system. This conclusion follows from the fact that a servo loop cannot directly drive the output position to be equal to the input command. Instead, it drives the feedback value to be equal to the command. Any measurement errors in the feedback sensor will necessarily cause errors/distortions in the actual motor position.

When the servo control loop is very tight, meaning the error signal is very small, then the actual output position has an error that is inverse to the measurement error from the feedback sensor. Consider a feedback position sensor that has cyclic ripple errors in its measured position. When the drive commands constant speed, the actual motor motion will have an inverse cyclic ripple that cancels the feedback sensor's measurement errors.

The better the position feedback device, the better the resulting motion. However, for devices mounted inside the motor, there is a limit to how good they actually need to be.

Most often, a motor drives some form of mechanical linkage, such as a pulley, gear box, coupler or lead screw. The motion at the end of these mechanics is what matters. Even if the motion of the motor shaft were perfect, the motion at the end of the connected mechanics is unlikely to be perfect. These connected mechanical systems would require substantial cost and care to avoid errors on the order of a few arc-min as measured at the motor shaft.

Therefore, a position feedback device with accuracy in the low arc-secs is unlikely to significantly improve the motion at the end of the connected mechanics, which is where motion quality actually matters.

Electronic commutation of a motor

Many motors require AC waveforms synchronized in an appropriate way to achieve the desired motion. In the original brush motors, this synchronization was performed by means of a mechanical commutator. In brushless permanent magnet servo motors, a position feedback device provides the drive with the information it needs to electronically synchronize excitation of the motor windings as required for specific motion tasks. Electronic commutation of motor windings provides many performance benefits, such as allowing for smaller, lower-cost motors to achieve given mechanical power and torque specifications. Electronic commutation for some motor types requires absolute position information within a motor electrical cycle.

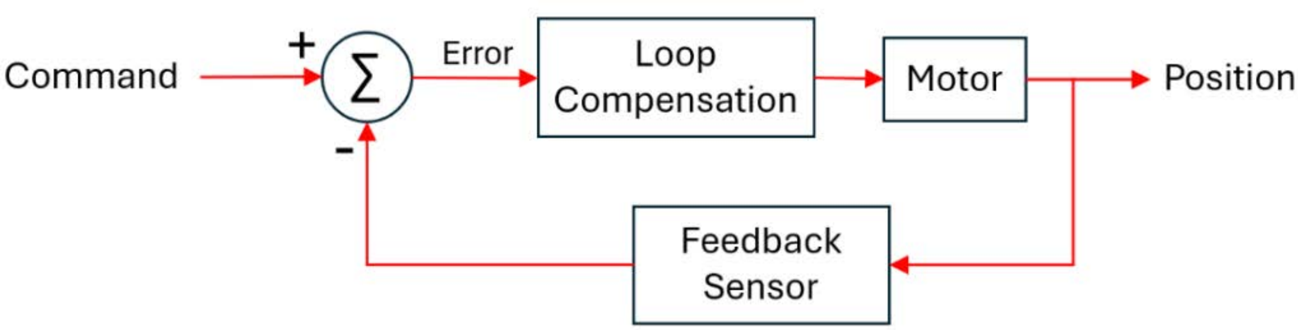


Figure 2. Basic Servo Control Loop

What is absolute position?

The most basic position feedback device provides incremental position. This means that when the device powers on, it always reports 0 position, regardless of the rotor's actual, physical position, and then measures the incremental distance moved since that last power-on. For some applications, like moving at constant speed, this is all the information needed.

However, most applications need to know the actual position within an operating space. Absolute position feedback devices provide position relative to a 0 position that is always fixed, rather than resetting in a different place with each power-on. This type of position is called absolute position. Absolute position feedback devices are available in various types, differentiated by their absolute position range:

Commutation Provides sufficient absolute position information within one motor electrical cycle at power-on to electronically commutate the motor. For position feedback, provides either only incremental or only absolute position within one motor electrical cycle, which is less than a full revolution of a motor. Examples include an incremental encoder + Hall effect sensor or a multi-speed resolver.

Single-turn absolute Provides an absolute position value that is exactly correct within one mechanical revolution of 0 to 360 degrees at power-on. Examples include single speed resolvers and some optical, capacitive or inductive devices.

Multi-turn absolute Provides absolute position within one mechanical revolution but also tracks how many complete revolutions have occurred. Typically, multi-turn absolute feedback devices range in their counting capability from 4,069 turns (12 bits, or 2^12) to 65,536 turns (16 bits, or 2^16). Multi-turn absolute feedback can be implemented in four basic ways:

1. Save current position to nonvolatile memory at power-off, restore at power-on.
    - Motor position must not be moved while power is off.
    - Lowest cost, narrowest range of possible applications.
2. Backup battery powers a turn counter.
    - Free to move the motor while power is off.
    - Battery is a cost and maintenance issue, requires space.
    - Risk that long periods of power-off could potentially create a life issue.
3. Use gears with individual readouts. For example, SICK DSL or Heidenhain EnDat.
    - Free to move the motor while power is off.
    - Gears make the encoder bigger, which can make the motor longer.
    - Gears are expensive, require tight mounting tolerances.
4. Energy-harvesting. With power off, moving the motor manually powers a turns-counter in nonvolatile memory. For example, Kollmorgen SFD-M.
    - Free to move the motor while power is off.
    - More robust and a larger turns-count range than gears.
    - Smaller than gears, less costly and requires less precise tolerances.

Nearly all applications can benefit from having multi-turn absolute position feedback. For example, in applications where the motor rotation is converted to linear motion of limited range, such as an X–Y table, multi-turn absolute feedback enables immediate productivity at power-on, without the need for time-consuming homing routines or costly homing sensors and wiring.

Historically, the high cost of adding multi-turn absolute functionality to position feedback devices has meant that many applications have gone without the benefits it provides. Today, there is less need to accept limitations. In particular, Kollmorgen's SFD-M position feedback device provides all the benefits of multi-turn absolute functionality with energy-harvesting technology at no extra cost over a single-turn incremental device.

Important specifications of feedback devices

Specifications that define the performance and utility of position feedback devices include:

Resolution The minimum motion distance that can be measured. Also known as position quanta. Resolution is usually specified as the number of binary bits/revolution. The more bits/rev the better, up to a point of diminishing returns. This value also determines the resolution of velocity as determined by differentiating position. For a typical industrial rotary servo motor, look for at least 16 bits/rev and preferably 24 bits/rev, yielding 2^24 = 16,777,216 distinct measured positions per mechanical revolution. Beyond 24 bits/rev, the return on investment diminishes quickly.

Accuracy The difference between the device's measured position and the motor's actual, exact position. Accuracy is usually specified as a worst-case error from the true position as +/– arc-min of angle. Accuracy is almost always much larger (worse) than resolution.

Velocity ripple When the actual speed is constant, then the differentiated measured position velocity estimate will have ripples due to errors in the measured position. Velocity ripple is expressed as % p–p because the amplitude of these velocity ripples in the measured value is directly proportional to speed. Ripple rpm = (ripple %)*(motor rpm). Velocity ripple is caused by position accuracy errors, but a given +/– worst-case position error does not directly determine the velocity ripple %.

Position noise When the motor is perfectly stationary, the measured position value will not sit at a fixed value. It will have random noise, causing the value to bounce around. This noise will be the sum of the inherent noise in the analog sensing method plus any noise coupled to it by EMI from noise such as PWM voltages on a motor winding. Noise is usually specified as position rms variation. In high-resolution devices, position noise amplitude is typically between the resolution and the accuracy specifications. Counterintuitively, a position feedback device with 0 noise, called an ideal quantizer, is not desirable. With random noise added, the position signal can be averaged or further filtered to achieve higher resolution than the resolution specification. It's best to have 1–2 least-significant bits of resolution random noise.

Bandwidth Every sensor has a limit on how fast it can respond to changes to its input. Position sensor bandwidth is expressed as the frequency in Hz when the measured sinusoidal motion compared to actual sinusoidal position motion drops in amplitude to –3 dB or 0.707x. The bandwidth of a position feedback device must be higher than the bandwidth of the desired closed servo loop motion.

Latency/phase Every sensor has phase lag or even latency (time delay) in going from the input to the measured value. The net phase lag is usually given in electrical degrees at a specified operating sinusoidal frequency in Hz. The phase lag must be small enough at the desired closed servo loop bandwidth to not cause stability problems.

Temperature How cold and how hot the device can be while still operating within specifications. Typically, motor components can operate at higher temperatures than feedback devices. This means that motor continuous torque is limited by the maximum operating temperature of the position feedback device.

Ruggedness Servo motor applications often involve mechanical vibration and shocks as encountered, for example, in press machines or vehicle applications. Each position feedback device has a range of mechanical vibration and shock that it can accommodate while still operating within specifications. Some devices are more rugged than others.

Useful features of feedback devices

In addition to their primary function of measuring motor position, modern feedback devices may include a number of features that enhance functionality and value, including:

Motor ID

Position feedback devices that include digital communications links to the drive often include nonvolatile memory. Programming this memory with motor data sheet values means that, at power-on, the drive can know what motor it is connected to and automatically set itself up to be compatible with that motor. All Kollmorgen devices with memory are programmed with Kollmorgen motor ID information that can be used by Kollmorgen drives for auto setup.

Thermal sensor

Some digital position feedback devices have an input that can be connected to a motor winding thermal sensor and then communicate the measured value back to the drive over its digital communications link. This eliminates the need to wire the thermal sensor from motor all the way back to the drive.

Single cable

Position feedback devices that digitally communicate to the drive can work with a small number of wires, for example, four wires or even just two in devices like the Kollmorgen SFD-M or SICK Hiperface DSL. This compares very favorably, for example, to resolvers that require 8 wires, incremental + Hall effect devices that require 13, or EnDat 2.2/01 requiring 14 wires. With only 2 or 4 feedback wires, it's possible for just one hybrid cable to provide both motor power and feedback between the drive and the motor. By contrast, high wire counts or direct analog sensors require two cables: one for power and one for feedback data. Single-cable technology means less expense and less installation labor.

Functional safety

In modern machines, there is a desire to allow machine operators to have hands on without fully shutting down the machine. To ensure operator safety, servos can incorporate a third party-certified functional safety position feedback device. This certified functionality allows active servos to hold a fixed position while the operator works safely with the machine. Typically, this improves the machine's average productivity while providing a safer working environment for operators.

Feedback device comparison chart

Combining all the performance metrics, capabilities and features we've discussed, and adding relative pricing, we can build a comprehensive comparison chart showing good, better and best for a wide range of available position feedback devices. See Table 1.

Device	Price	Analog or Digital	Initial Position	Init Pos Type	Resolution	Accuracy	Velocity Noise	Motor ID	Single Cable	Mech Robustness	Temperature	Motor Length	Functional Safety
SFD-M	Low	Digital	16 bit	Eng Harvest	High	**High**	Very Low	Yes	Yes	High	High	Shorter	No
SFD-3	Low	Digital	Single	-	High	Low	Medium	Yes	Yes	High	High	Shorter	No
SFD	Low	Digital	Single	-	High	Low	Medium	Yes	Yes	High	High	Shorter	No
Resolver	Low	Analog	Single	-	Medium	Low	High	No	No	Very High	Very High	Shorter	No
Incremental Encoder + Halls	Medium	Analog	Commutate	6-Step	Low	Medium	Medium	No	No	Medium	Medium	Shorter	No
BiSS B Analog Optical	Medium	Ana/Dig	Single	-	Very High	Very High	Low	Yes	No	Medium	Medium	Longer	No
BiSS B Analog Optical	High	Ana/Dig	12	Gears	Very High	Very High	Low	Yes	No	Medium	Medium	Longer	No
BiSS C Digital	High	Digital	12	Gears	Very High	Very High	Low	Yes	No	Medium	Medium	Longer	No
Hiperface Analog Optical	Medium	Ana/Dig	Single	-	Medium	High	Low	Yes	No	Medium	Low	Longer	No
Hiperface Analog Optical	High	Ana/Dig	12	Gears	Medium	High	Low	Yes	No	Medium	Low	Longer	No
Hiperface DSL Optical	Medium	Digital	Single	-	Medium	High	Low	Yes	Yes	Medium	Low	Longer	No
Hiperface DSL Optical	Medium	Digital	12	Gears	Medium	High	Low	Yes	Yes	Medium	Low	Longer	No
Hiperface Capacitive	Medium	Digital	Single	-	Medium	High	Medium	Yes	Yes	High	Low	Longer	No
Hiperface Capacitive	Medium	Digital	12	Gears	Medium	High	Medium	Yes	Yes	High	Low	Longer	No
Hiperface DSL Capacitive	Medium	Digital	12	Gears	Medium	High	Medium	Yes	Yes	High	Low	Longer	Yes
EnDat 2.2/01 Analog Optical	Medium	Ana/Dig	Single	-	Very High	Very High	Low	Yes	No	Medium	Low	Longer	No
EnDat 2.2/01 Analog Optical	Very High	Ana/Dig	12	Gears	Very High	Very High	Low	Yes	No	Medium	Low	Longer	No
EnDat Inductive Analog	Medium	Ana/Dig	Single	-	Medium	High	Medium	Yes	No	High	Low	Longer	No
EnDat Inductive Analog	Medium	Ana/Dig	12	Gears	Medium	High	Medium	Yes	No	High	Low	Longer	No
EnDat 2.2 Inductive Digital	Very High	Digital	12	Gears	Medium	High	Medium	Yes	Yes	High	Low	Longer	Yes

Table 1. Position Feedback Device Price, Performance, and Features Comparison Chart

Make the right choice

General motion control applications

Based on the comparison chart, the SFD-M is the clear choice for most applications. It is:

- Value-priced
- Has 16-bit multi-turn absolute resolution
- Offers high performance

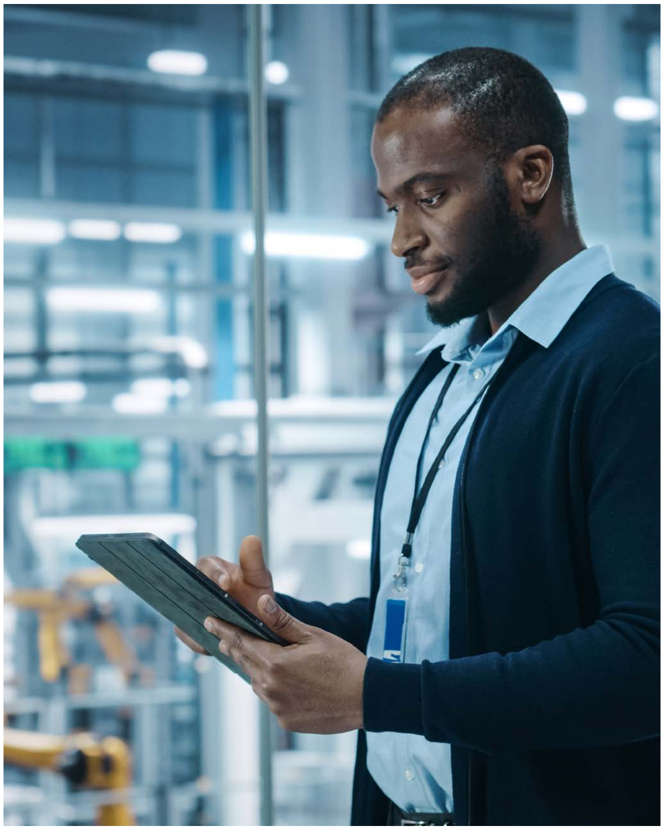
Special applications recommendations

However, there are specialized applications where the SFD-M would not be the best fit. These special cases are listed below along with appropriate feedback devices and their order codes.

1. Certified functional safety required:
- GU BiSS capacitive safety
- LD EnDat inductive safety
    - Higher or much higher cost and longer motor than SFD-M

2. Highest position accuracy required for direct drive:
- DA, DB EnDat optical
- AA, AB BiSS optical
    - Higher cost and longer motor than SFD-M

3. Not using a Kollmorgen motor drive:
- Choose a feedback device compatible with the drive



Kollmorgen is with you all the way, with proven processes and reliable delivery

We'll work with you in the initial design phase to understand your exact requirements, then provide the engineering support you need to simplify motion system selection, sizing, configuration and programming. With our extensive configuration capabilities, we'll rapidly prototype, deliver and iterate your solution as needed to potentially save months in your development process.

When the final design is ready, we'll fully document it and help usher it through any required certifications, in any region. With our lean manufacturing, repeatable processes and quality controls, we'll quickly transition from prototype to full-rate production, delivering your motion systems on time, every time. And we'll provide long term support, in-region/for-region, to sustain product delivery throughout the lifecycle of your application, managing costs while scaling production as needed.

Ready to move forward?

Contact Kollmorgen to discuss your needs and goals with a Kollmorgen application expert.

About Kollmorgen

Kollmorgen, a Regal Rexnord Brand, has more than 100 years of motion experience, proven in the industry's highest-performing, most reliable motors, drives, AGV control solutions and automation platforms. We deliver breakthrough solutions that are unmatched in performance, reliability and ease of use, giving machine builders an irrefutable marketplace advantage.

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