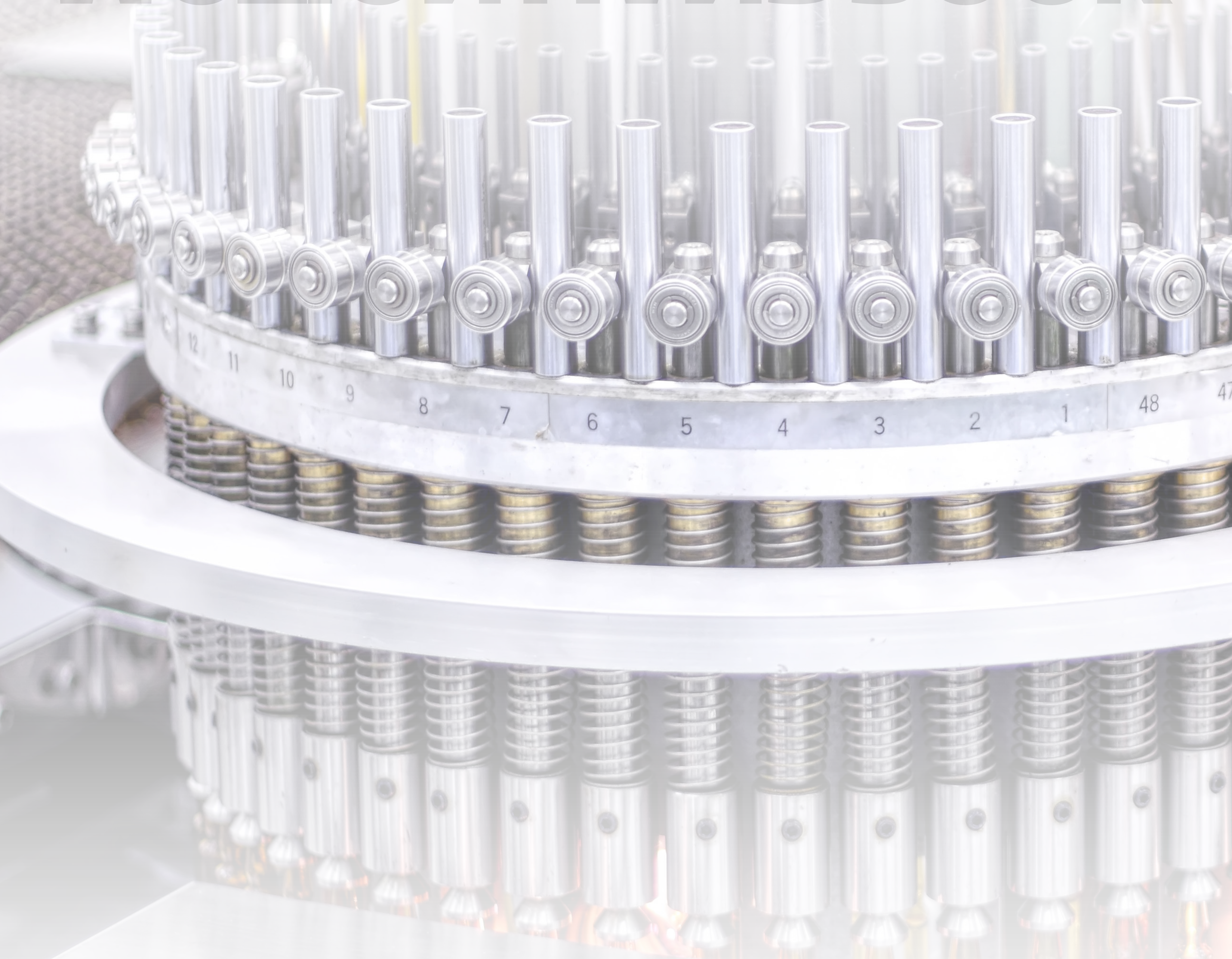
MOTION HANDBOOK



Practical Guide to Motion Control

from AUTOMATIONDIRECT.com

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Motion Control Handbook

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Motion Control Introduction

Anyone who has ever observed a modern factory in action, whether in person or perhaps via an episode of the "How It's Made" documentary television series, is aware of just how impressive machine automation can be. This is especially the case when witnessing robotic arms and other machine motion control, as mechanical apparatus and payloads shuttle rapidly and precisely from point to point.

Within the industrial automation arena, the term "motion control" usually refers to using an electric motor—either a servo or stepper motor—to precisely drive the position, velocity, and acceleration of a physical system, or to exert a specific amount of torque on that system. There are other motion control methods as well—pneumatics are economical, and hydraulics can provide great force—but electric motors often provide the right balance of accuracy, speed, power, durability, and operating cost.

There are many types of electric motors and motor systems that can operate at fixed speeds, and many that can provide excellent variable-speed control, but to be considered 'motion control' the motor must be capable of accelerating at a specified rate, to a specified speed and then decelerating (again at a known rate) to stop at an exact position.

Several technologies are relevant for the electric motors, drives, and controllers used to achieve comprehensive motion control. Additionally, the last decade has seen massive improvements in motor efficiency, drive intelligence, digital controller capabilities, and communications connectivity among these devices. Electrical motor motion control is now easier, more cost-effective, and exceedingly practical for all types of applications than ever before.

This eBook describes the products and technologies designers should become familiar with as they look to incorporate modern motion control into equipment, machines, and larger systems.

Motion Control Components and Basics

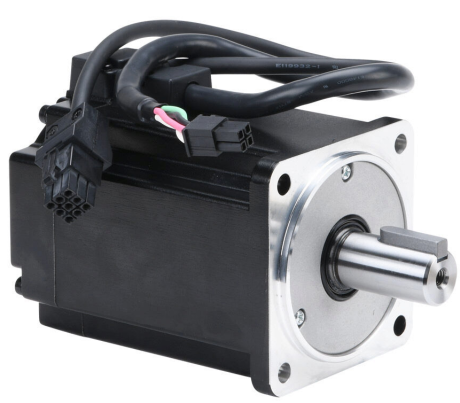
Motion control systems consist of motors, associated drive and control electronics, sensors, and driven mechanisms. They can be as simple as a single conveyor belt, or exquisitely complex with dozens of elements moving in coordination.

Motion Control Components

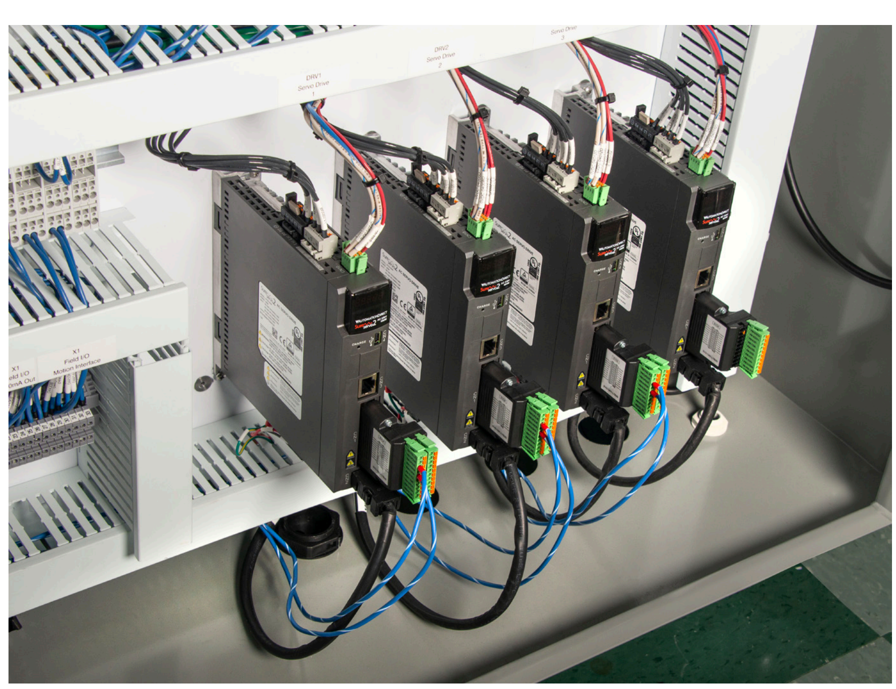
Any motion control system requires a drive of some type operating motor movements under the direction of a controller. Each application consists of at least two significant elements, but may incorporate three or more:

- Motor: While standard AC induction motors and DC motors are useful for basic on/off and less precise variable speed applications, servo and stepper variants are the most common motors used for motion control.
    - Stepper motors are commanded to operate in discrete steps, usually in an open-loop manner, and are useful for applications with lower speed and smaller force requirements. Closed-loop control with encoder feedback is becoming more popualar. Stepper motor torque falls off quickly as speed increases. They can provide many of the features of servo motors in an economical way. See Chapter 4 for more details.

    - Servo motors combine high speed, torque, and position/velocity/acceleration precision using an encoder for closed-loop feedback control. However, these solutions generally entail higher cost and complexity. See Chapter 5 for more details.



- Drive: Each servo or stepper motor needs a drive, with the basic functionality of applying power to the motor as needed to operate it. A servo drive handles closed-loop operation by monitoring an encoder to determine exact motor position, while a stepper drive typically operates the motor in an open-loop fashion. Most drives are separate components from the motor, but some motors are available with integrated drives. Many drives are even more capable, and include an on-board controller.



- Motion Controller: A motion controller commands one or more drives, to operate servo and/or stepper motors as needed to achieve the required motion control functionality, and may allow the coordination of multiple axis of motion. A motion controller may also interact with other motion controllers and/or supervisory automation controllers. There are three general levels or styles of motion controllers:
  - Integrated with drive: While a basic drive simply operates the motor based on external commands, a majority of modern digital-based drives incorporate varying degrees of controller capabilities, and can even interact well with peer drives and supervisory controllers.
  - Dedicated motion controller: A dedicated motion controller is not a drive, but is optimized to command one or more drives in concert to accomplish far more sophisticated movements and functions at the highest possible speeds. Dedicated motion controllers usually provide superior performance.
  - PLC-based motion control: Motion control systems often need to coordinate with other automation, which is commonly provided by a programmable logic controller (PLC) with input/output (I/O) modules for machines and similar equipment. Modern PLCs often include motion controller capabilities, ranging from basic, to mid-range, to high-performance.

Motion Controller Selection: PLCs

Selection of a motion controller for any given application requires some special attention, especially today because there are many options with overlapping capabilities. A simple, standalone application may work well using a drive with an integrated controller. On the other hand, complex multi-axis systems are best handled by dedicated motion controllers optimized for these tasks.

However, it is important to note that various PLC models incorporate motion control functionality ranging from basic to sophisticated, in addition to general automation capabilities. Modern PLCs are available in brick, modular, and chassis-based platforms that provide great all-in-one solutions for many motion control applications because other automation functionality is usually needed.

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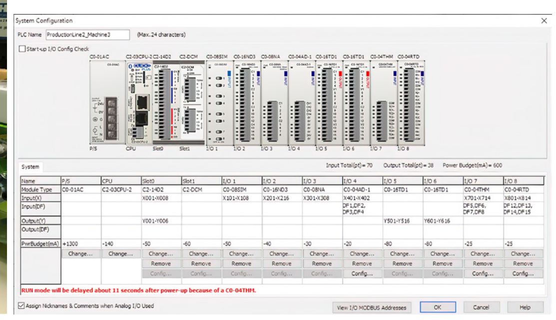
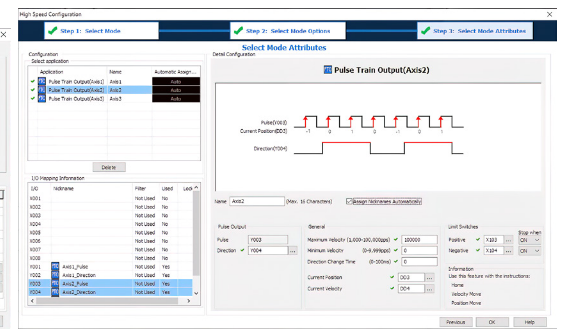
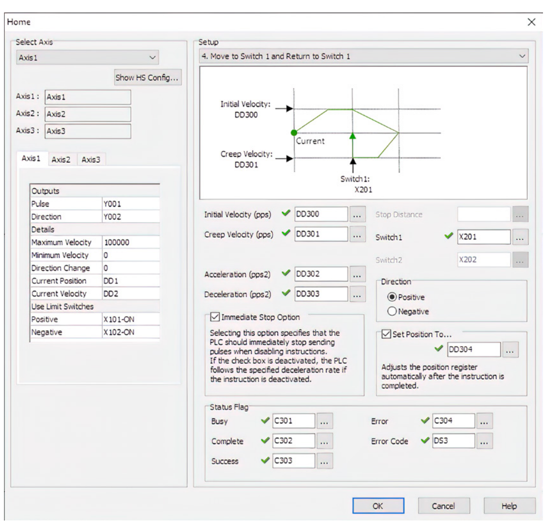
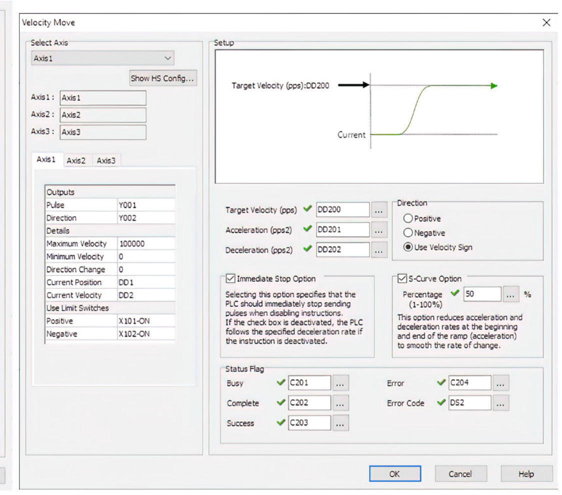
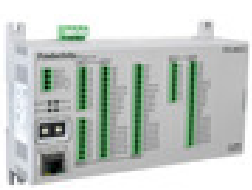
Here are a few guidelines for PLC options based on varying levels of motion control needs:

- Basic: Most PLCs can control at least a few axes of motion, usually with hardwired signaling. For example, the CLICK PLUS stackable micro modular PLC includes essential instructions—homing, position move, velocity move—so users can easily implement 3-axis motion control in conjunction with other automation, at an unprecedented low cost.



- Mid-tier: More powerful PLCs can be quite adept at motion control, providing more extensive motion command sets and larger axis counts. The AutomationDirect Productivity line—Productivity1000 stackable micro , Productivity2000 micro modular, and Productivity3000 modular —and BRX stackable micro brick series PLCs can control from 4 to 27 axes.

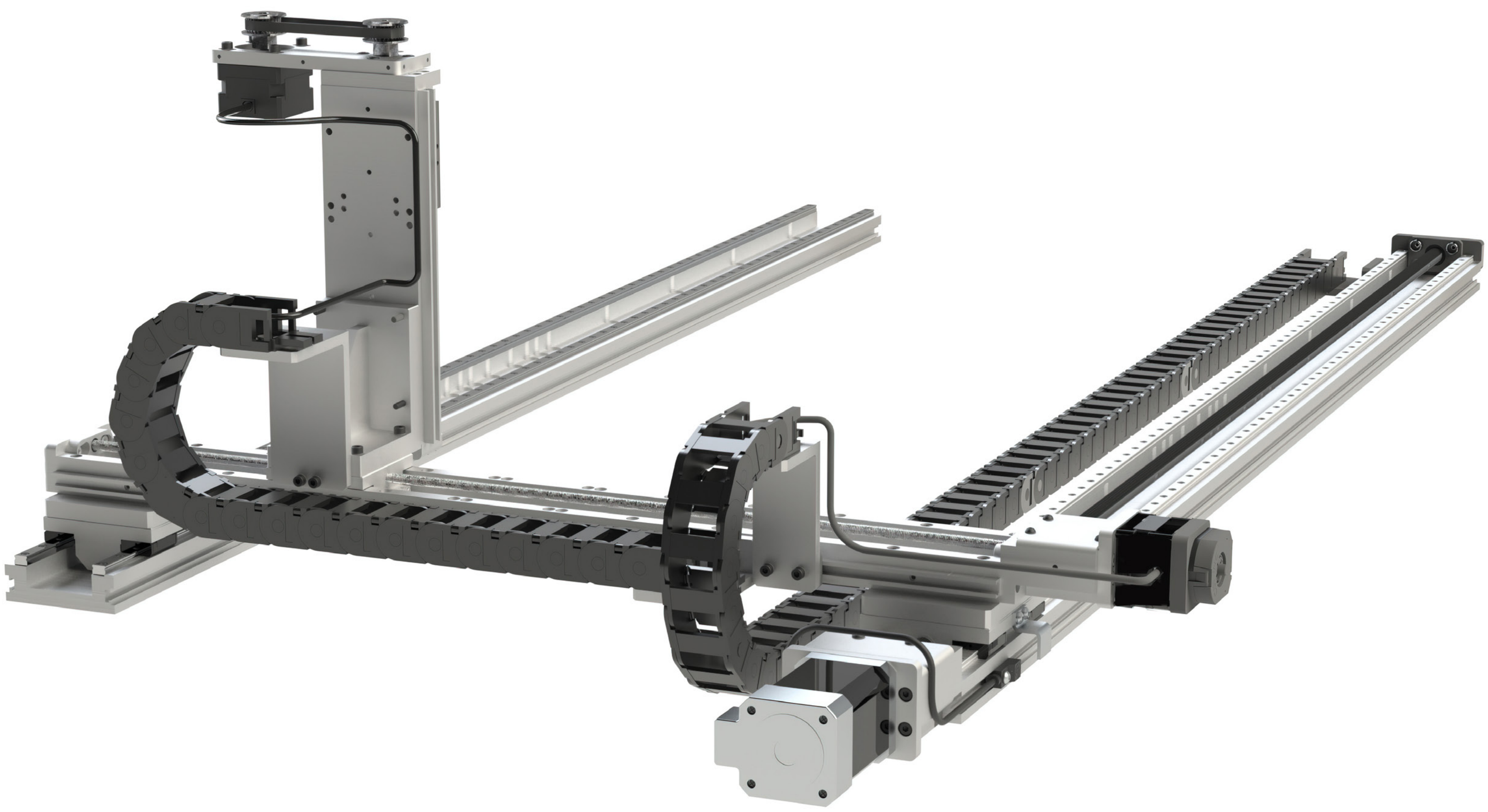



- High-performance: For the most advanced motion applications, designers should consider motion controllers with embedded PLC and logic functionality, as well as motion-specific digital communications. The LS Electric XGB PLC and XMC programmable motion controller platforms provide industry-leading performance, flexibility, and cost advantages for even the most demanding applications up to 16 axes.

Degrees of Motion

Motion control applications are classified by how many physical degrees of motion are controlled in coordination. Each motor to be controlled is called an "axis", and for larger machines it is often necessary to coordinate many "axes", potentially dozens, in conjunction with each other.

For example, a gantry moving back and forth with only one motor is a single-axis application, while a large printing press with many drives transporting and tensioning a continuous paper roll constitutes a multi-axes web control application.



More advanced motion controllers enable the use of one or more "virtual" axes, as a "perfect master" signal for driving other physical axes. A virtual axis behaves like a physical axis, but has no drive output.

Mechanisms

In some cases, a servo motor or stepper motor directly drives the target equipment. However, it is very common for the motor to drive a mechanism, which in turn manipulates the equipment, for purposes of modifying the speed, torque, accuracy, and/or mechanics of the result.

Some examples include:

- Gearbox: A gearbox or open gears provide a way to multiply or divide the motor rotational speed or torque to deliver the desired result.
- Cogged belts: A cogged belt (often called a 'timing belt') between toothed pullies enables transmitting motion positively; smooth belts are usually not used due to the undesirable effects of slippage.
- Rack-and-pinion or Ball Screw/Lead Screw: These mechanical devices translate rotational motion from a motor into linear motion, and is an excellent way to achieve linear motion in one or more axes—X, X-Y, or X-Y-Z—such as for a gantry.
- Combination: These and other mechanisms may be used in combination.

Sensors

An encoder is one of the most important sensing devices for motion control systems, but other sensors, such as position transmitters and limit switches, are also useful for automated functionality.

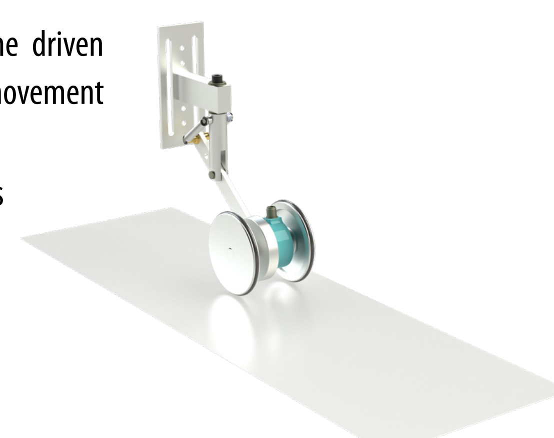
- Encoder: An encoder is a sensor that generates high-precision and -speed electrical signals (via pulses or digital communication) to a controller to precisely identify location. They are most commonly rotary devices installed directly on a motor shaft or driven equipment, but linear versions are available as well. Using an encoder, the drive or motion controller can monitor the position, and speed of a system, and "close the loop" to achieve precise, rapid, and sophisticated motion control.

Rotary encoders are offered in two basic types:

- Incremental encoders only provide information (usually via quadrature pulses) while the motor shaft is moving. Therefore, a homing routine is usually required upon power-up.
- Absolute encoders provide their location at all times, even upon power-up, so homing is usually only required once, during machine setup. Some absolute encoders transmit position information using gray code, a binary form of information where only one data bit changes at a time. Other absolute encoders employ a communication protocol, such as EtherNet/IP, Modbus (TCP or RTU), or EtherCAT to transmit information to a host controller.

Note that many servo motors are sold with the encoder built-in, so if the encoder type is critical for a particular application, that may drive the selection of a particular servo system. Some stepper are also sold with encoders factory attached - but it is also quite common to purchase a "kit encoder" separately for a stepper motor and affix it to the rear shaft of a dual-shaft stepper motor. This allows wide flexibility in the type of encoder signal that can be specified.

Secondary encoders can be used on some systems to account for slippage between the driven system and the product (example: a measuring wheel encoder monitors a web's actual movement because there is slippage between the web and the belts that are moving the web).



- Position transmitter: Potentiometer-based and magneto-resistive linear position sensors and laser-based distance sensors can be used in motion control automation schemes to locate equipment as needed.
- Limit switches: Mechanical, proximity (prox), and photoelectric (PE) sensors can detect a single equipment position, and are useful for homing routines and providing overtravel protection or for identifying equipment at a critical location for certain operations.

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Motion Control Concepts

Motion control equipment is not one-size-fits-all for variousapplications, and the complexity of motion control operations must guide component selection. After the platform, hardware, and sensors are selected, designers need to decide the best way to implement motion.

Homing, Position Verification, and Overtravel Detection

Most servo and stepper motion systems can only perform accurate, relative movements once the controller has learned the home position through a homing procedure. For robotics, the home position is sometimes called a perch.

Homing

One way to accomplish homing is by installing a position switch at a known equipment location. To learn the home position, the controller/drive travels the motor to the expected position and establishes the home once the position switch is triggered.

Servo systems with incremental encoders built into the motor usually perform a homing routine once upon power up, or when the operator first initiates the machine. Then drive accurately tracks the position of the motor shaft as long as the machine is powered up. One typical exception is in the case of some form of mechanical slippage, which might require re-homing or a power cycle to reaffirm the position.

Motion systems with absolute encoders may not require homing, or may only require homing in rare situations, such as when the encoder (or battery, if it has one) are replaced.

Stepper motor systems often do not include closed-loop control (no encoder), so in addition to homing, a periodic position verification may also be used to confirm accurate positioning at some interval, usually once per cycle of the machine.

Most motion controllers and drives support multiple types of homing. It bears noting that the home position for most systems is defined to be at (or very near) one end of travel. Here are some examples of popular homing routines (there are certainly others):

- Simple-home: The system moves at a specified speed until the home sensor is tripped. It stops and defines that position as "home".
- Two-speed-homing: The system moves quickly in a predefined direction until the proximity (home) sensor is tripped (but due to the high speed of the move, there is usually some overshoot). Then the system reverses direction and "creeps" back to the sensor to find a more accurate "home" position. This two-speed approach helps to quickly navigate large distances while still providing an accurate home position.
- Home-to-sensor-then-index: Many incremental encoders have an index (or z-pulse), a very accurate and repeatable pulse that occurs only once per revolution. Used primarily in multi-turn applications (lead screws, etc), the system moves (again in a particular direction, and possibly at high speed) until the proximity sensor is tripped, then the system moves again (either direction can be specified) until the index pulse of the encoder is detected. This can result in a very quick/accurate/repeatable home position AND this technique is tolerant of some movement or variation of the proximity sensor location (in case the proximity sensor needs to be replaced, for instance).

Position Verification

Position verification is similar to homing, but it is generally a quick check performed during normal operation. This can be achieved using position sensors.

Overtravel Detection

Most servo drives or motion controllers accept a pair of sensor inputs known as "overtravels". Proximity sensors are used to detect if the system has exceeded the limits of travel in either direction. Termed the "clockwise" and "counterclockwise" limits, it is typical for the drive or controller to immediately inhibit motion in the detected direction. So, if the drive detects that the system has reached the clockwise limit of travel then it will only allow motion in the counterclockwise direction, and vice versa.

In most servo drives the overtravel logic is fully implemented in hardware, so the motion is inhibited nearly instantly (as fast as the bandwidth and tuning of the system will allow) at the overtravel limits, and without concerns for software bugs or programming oversights. This may not rise to the protection levels of official safety systems (for human safety), but it is very effective at preventing mechanical damage to machinery.

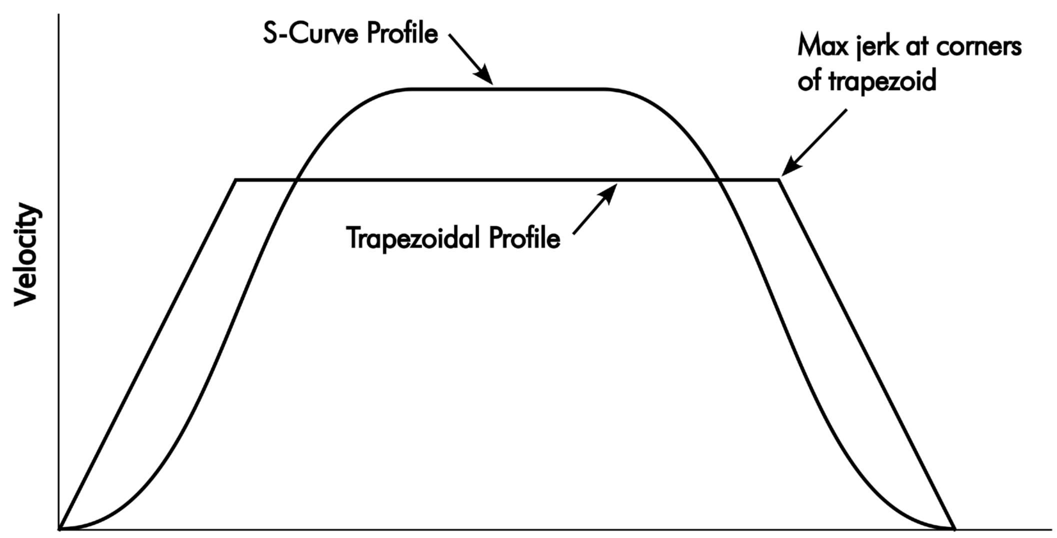
In systems where overtravel sensors are used, the overtravel sensor on one end of travel may also double as the home sensor.

Basic Motion Types

Establishing the home position provides users with a solid basis for configuring how the system should move. Exactly how far and fast an axis is commanded is called a motion profile. A motion profile can be completely custom, but it is more often constructed from one or more of the following basic movement types:

Trapezoidal (Position) Move
Move a defined distance from one stopped position to another, first linearly accelerating to a target velocity then linearly decelerating back to zero speed as the target position is approached.

S-curve Move
Accelerate from one velocity to another, but with a variable acceleration (or deceleration) that begins and ends gradually while reaching maximum midway. This action minimizes the "jerk" on payload and equipment, and reduces ringing or bouncing of a dynamic payload once the move is complete.



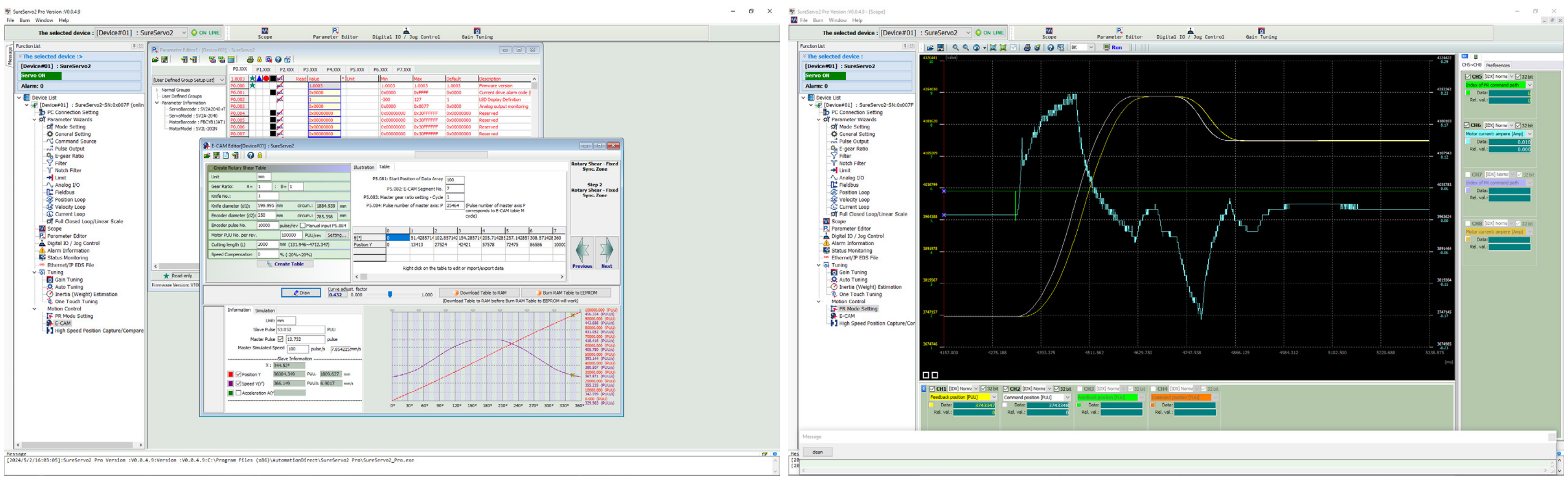
Velocity Move
Move at a fixed velocity continuously, or for a defined time duration or distance

Blended Moves
Also known as a blended transition, blended moves are used to smoothly transition between two or more movements, typically by overlapping or blending the move profiles of multiple axes. This allows for a smooth, curved movement instead of abrupt changes in direction, which can be beneficial in applications like cutting, welding, or dispensing.

Torque Control
Sometimes a motion axis is commanded to hold a specific amount of torque, regardless of the position or velocity of the axis. An example is a two-axis winding machine, where one axis might run in speed mode to turn a spool, while a second axis operates in torque mode to apply the proper amount of tension to the material as it is wound onto the spool (with that tension being unaffected by the changing diameter of the material as it winds on to the spool).

Advanced Motion Functions

Motion profiles can also include much more advanced motion-specific functions which apply to various application categories. The newest motion controllers—whether on board a drive, in a dedicated motion controller, or integrated with a PLC—take advantage of powerful processors and software to enable wizard-like access to advanced strategies.



Following are some built-in motion-specific control functions (usually intended more for servos than steppers) that users can lean on to quickly create solutions for many types of common and exotic motion and application needs. For each of these functions, users can always create their own custom code in a motion controller or PLC. However, inclusion of standard blocks for these regularly (and not so regularly) used actions in modern controllers simplifies and speeds up design, while providing a much higher level of standardization compared to custom code.

Electronic Camming

Physical cams and follower mechanisms create motions that produce a stroke and duration profile. Servos with electronic camming capability can reproduce these mechanical system movements with a software "cam profile," consisting of defined sets of X-Y points in a table. The advantage of electronic camming is the ability to change cam profiles quickly and easily in software to match the needs of machine and product changeovers, without requiring time-consuming and costly mechanical adjustments. Users can import a table of custom positions from a spreadsheet or other source to set up epicyclic motion.

Electronic Gearing

This feature enables driving many secondary axes at speed ratios of a primary axis. The ratios and even phase relationships can be changed instantly and on-the-fly so that machine elements move at the proper relational speed without requiring physical gearboxes.

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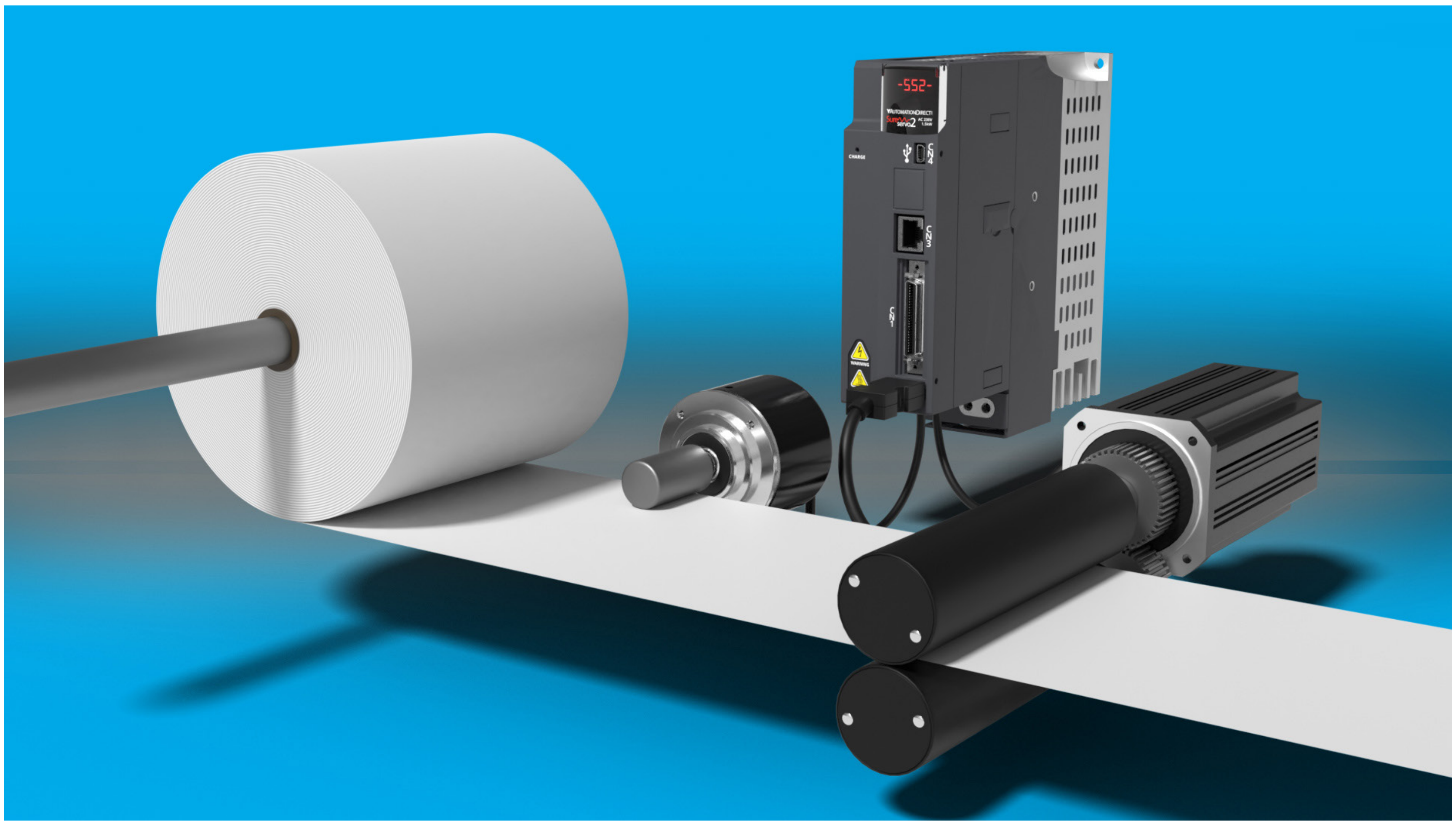
Encoder Following

Encoder following is when one axis of motion matches or tracks the position of a second axis. An external encoder signal might be wired to the motion controller or directly to the second axis' drive.

Full-Closed-Loop Control

Full-closed loop refers to the technique of placing the encoder elsewhere on the machine, instead of the motor shaft. Typically used to account for slippage, this allows the system to more accurately control the motion of film or paper, or any situation where the shaft mounted encoder is not accurate enough. Some drives allow a second encoder to be wired directly into the drive for full-closed-loop control. Most advanced motion controllers can also accept the second encoder signal and close this outer loop.



Linear Interpolation

Linear interpolation refers to the process of moving two or three axes in harmony to delineate a straight line between two points in 2D or 3D space.

Circular/Helical Interpolation

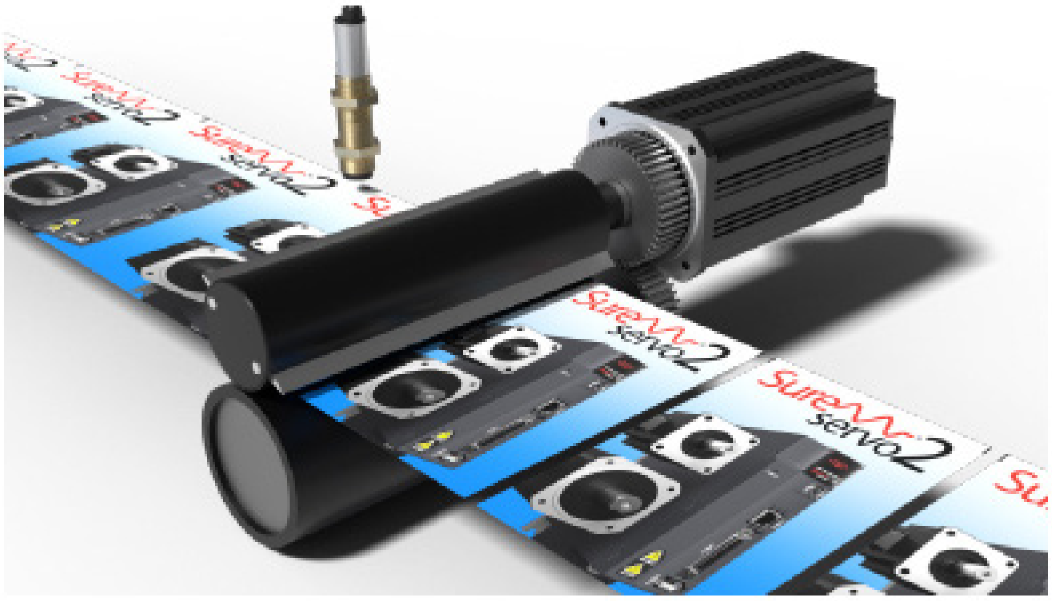
Similar to linear interpolation, circular and helical interpolation refers to the process of moving multiple axes in harmony to delineate a curve in 2D or 3D space.

Programmable Limit Switch (PLS)

PLS functionality is used to trigger outputs (I/O events) at preset positions during a machine cycle. For example, a controller might energize an output at a precise location to trigger a labeling machine to apply a label.

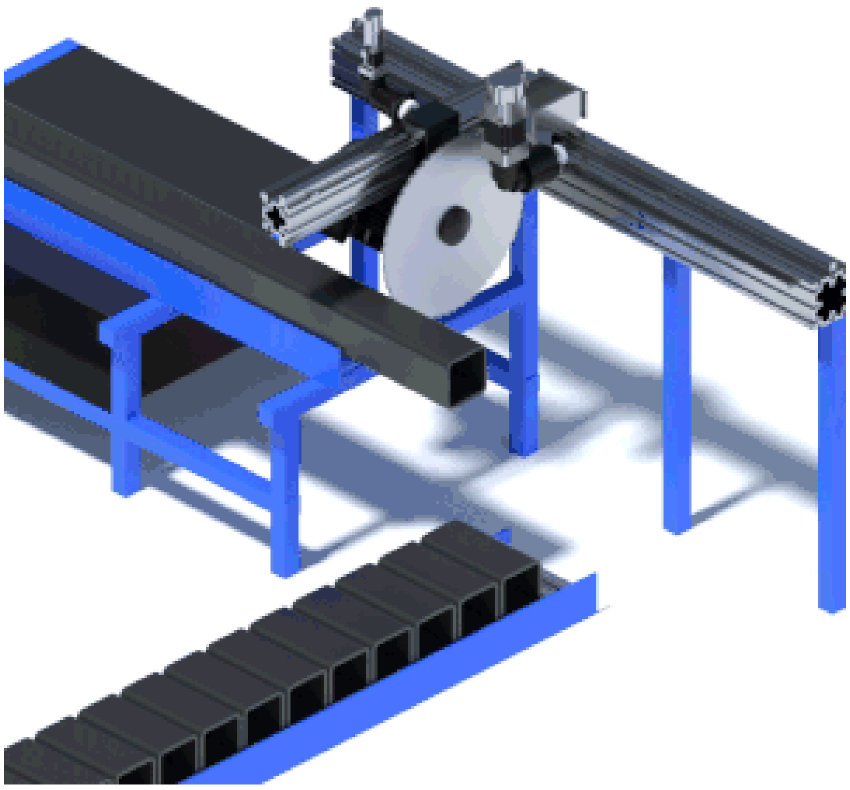
Registration

Packaging, cutting, and printing machines often take advantage of 'registration', which is using a detector to identify where moving product is located so a servo-driven portion of the machine can be commanded to the exact location where it is needed. Registration refers to the adjustment of one motion—often a point on a rotating axis—to coordinate it with a fixed or moving target. Printing applications often require registration to ensure alignment of print on a page, or when multiple ink colors must be aligned on a printed piece.



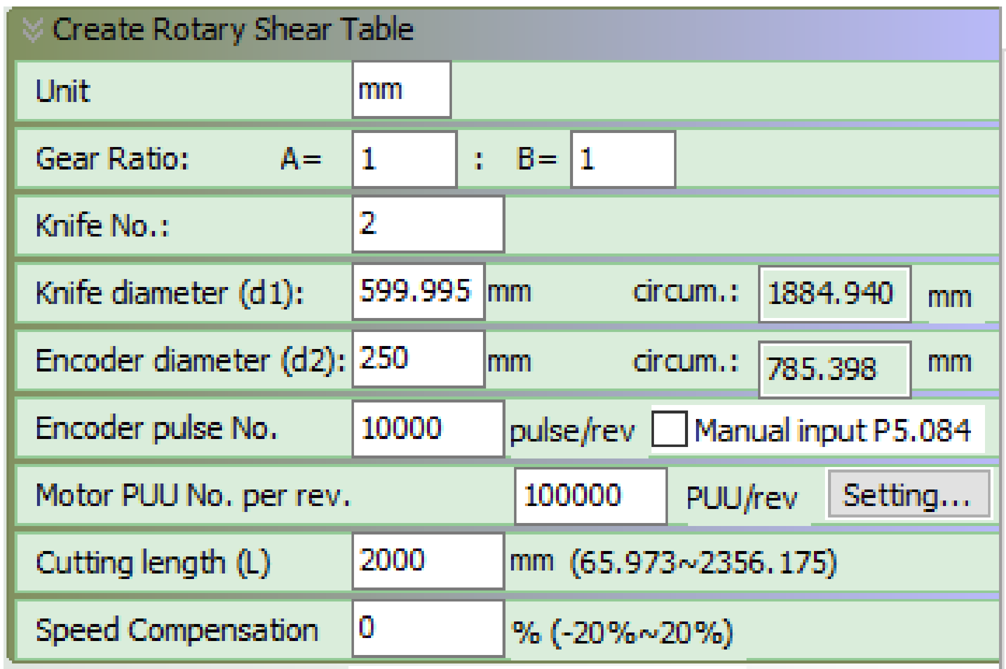
Flying Shear

These types of machines cut material 'on the fly' and therefore require precise servo operation to move the cutter to match the material speed. A flying shear uses a cutting device mounted to a precisely controlled trolly which can match the speed of moving material to make a straight cut across the material "on the fly". After the cut, the trolly returns to the starting position and readies for another cycle. Flying shears are required in many production processes where it is either not possible or practical to stop the material flow while making a cut.



Rotary Knife/Shear

A rotary knife/shear is used to enable a single or multi-bladed knife or die to cut moving material as it passes the knife's location. The knife/die axis must match the speed of the web while cutting, but may have to slow down or speed up when the knife/die is not in contact with the web to prepare for the next cut or stamping.



Synchronous Position Phasing

Synchronous position phasing is a process that synchronizes a follower axis to a master axis, ensuring that the follower axis reaches the synchronous velocity and position at the same time as the master axis.

Random Infeed Conveyer

This type of application, sometimes called a smart-belt conveyer, is used to precisely move conveyed items (products) into desired positions and with proper spacing for subsequent operations. A sequence of two or three short belts equipped with product sensors are used to accelerate or decelerate individual items to achieve the desired positioning and spacing as the product is transferred onto the final belt. The classic use case is at the entrance to a horizontal wrapping machine, which requires positioning the incoming products in sync with the wrapping material so they do not interfere with the sealing/cutting jaws at the wrapper exit.

Rotary Table

Rotary table applications typically involve indexing one or more workpieces on a round rotating table to align them with fixed workstations positioned around the table. The table then pauses at each station while various process steps are completed. Setup can be as simple as declaring the number of (equally placed) stations in the 360 degree arc, but more complex setup is possible as well.

Robot Control

Robotics equipment encompasses many geometries. For example, the LS Electric XMC motion controller includes built-in function blocks for handling several common robotics configurations such as X-Y-Z, Delta3, LinearDelta3, and T-Gantry. While it is possible to control robotics equipment with other motion controllers, the lack of robotics-specific function blocks means this approach may require significant custom coding, which becomes tedious.

G-code Interpreter

Geometric code (G-code) has been standardized by ISO 6983-1 and is one of the most widely used computer numerical control (CNC) and 3D printing programming languages. The LS Electric XMC motion controller includes a built-in interpreter for G-code, facilitating machine tool motion control operations.

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Stepper Systems

Stepper motors are named as such because they are commanded by pulses received from a drive to move in small discrete steps, and they can do so rapidly. Motion control is achieved when a controller commands the stepper drive to perform a sequence of steps to complete a desired move. Simple sequences create simple motion. More complex sequences can create many of the advanced motions described in the previous section.

Stepper Basics

Stepper systems typically work best below 1,000 rotations per minute (rpm) because stepper motor torque falls off rapidly as speed increases. It is best practice to oversize stepper motors and drives so that the expected load uses only 50% of available torque to avoid potential stalling conditions.

Stepper drives are commanded by a pulse train from a controller. The most common stepper motor model is a 4-wire bipolar type. In full-step mode those motors have 200 steps (at 1.8 degrees) for each 360-degree revolution, and each pulse moves the motor one step, but full-step mode is not frequently used because it lacks precision. Modern stepper drives can "microstep", commanding less than a full-step of motion with each pulse. Users typically select half-step, quarter-step, or other microstepping modes which operate at 400, 800, or even up to 50,000 steps per revolution. The key is to balance tradeoffs between accuracy and required control signal bandwidth.

Although stepper motors are considered a low-cost motion control alternative to servo motors, steppers have some other advantages. For example, they have no jitter/dither at zero speed. And in applications without a constant load from gravity or another force, some stepper drives provide an idle current reduction option, which saves energy and reduces motor heating when the shaft is at standstill.

Stepper Control Details

Stepper systems are most commonly operated open-loop (without an encoder), but closed-loop operation is possible.

Open-loop

Well-engineered stepper systems in certain environments can run open-loop for long periods without position errors. The problem with open-loop operation is that if a system experiences slippage, a jam, stall, or similar event, then positive positioning is lost.

Some open-loop models feature stall detection without an encoder because the drive monitors the motor back-EMF. However, this provides detection only, so the system must then stop and wait for service, or re-home on this event.

Many designers choose to improve operational robustness by testing for proper position cyclically with one or more discrete sensors. Based on this feedback, stepper systems may shut down or re-home if position errors are detected.

Closed-loop

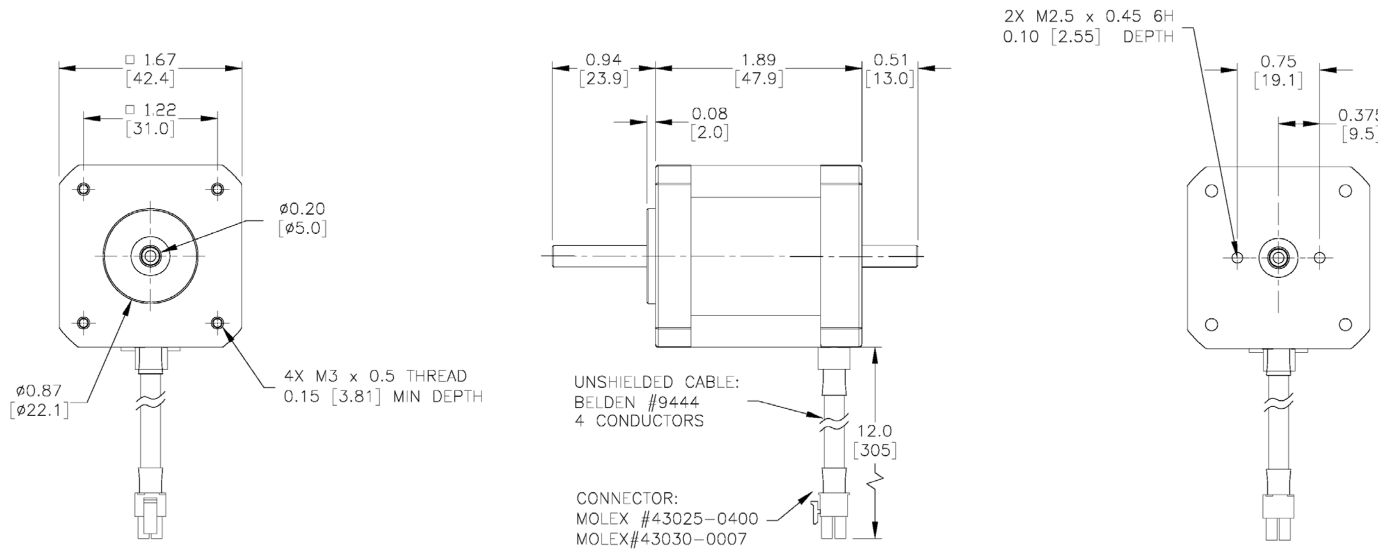
It is possible to design a stepper system as closed-loop by choosing a motor with a factory-mounted encoder, or by adding an encoder to the back shaft of a dual-shaft stepper motor or directly to the driven equipment. This enables the following possibilities:

- If the encoder is connected to a drive that accepts the signal, then loop closure is mostly automatic with little or no user intervention required, and it becomes possible to automatically detect and correct for many "out of position" errors.
- If the encoder is connected to the controller supervising the drive (for full closed-loop operation), then the controller must be configured to handle this signal and compensate for position errors as needed. Depending on the sophistication of the controller and available function blocks, this can be easy or comparatively difficult.

Stepper Motor Details

Stepper motors are available in various configurations, and with a variety of options, depending on the load, application, and environment. Here are some considerations:

- Stepper motors are standardized by NEMA sizes; 14, 17, 23, 24, 34, and 42 are common but there are others. A NEMA 14 motor has a 1.4" square face, 17 corresponds with 1.7", and so forth.

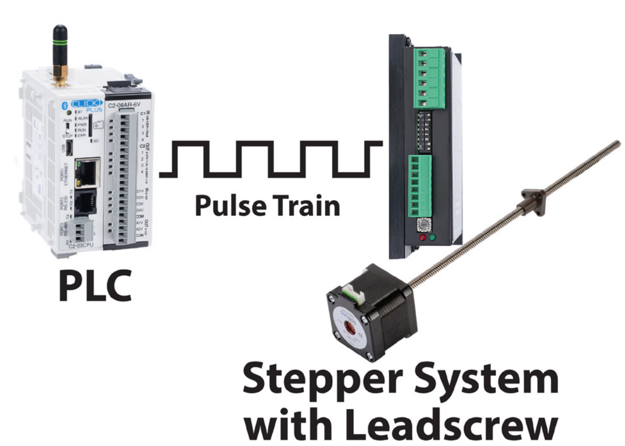


- Larger frame sizes generally produce more torque. Holding torques are possible up to 4532 oz-in for AutomationDirect's largest NEMA 42 frame motor.
- In addition to frame size, steppers have a "stack length". More stacks of laminated plates used in a motor add up to more torque
- Motors are available in single- or double-shaft options (where the second, rear shaft is shorter, generally intended for an encoder). Double-shaft motors are also available with an encoder factory mounted on the rear shaft.
- Shafts are smooth, or may have one or two "flats". While these flats may seem intended for set screws, it is recommended to use a clamping style coupling with a stepper motor, because set screws may vibrate loose.

- Most AutomationDirect stepper motors are IP40-rated for use in dry, clean environments. However, stepper motors are also available as IP65-rated high-torque versions with a sealed coating over the motor laminations, suitable for use in washdown environments.
- Stepper motors are also available in "high bus voltage" variants. The "STP-MTRAC" models from Automation Direct are designed to work with stepper drives that operate with line inputs ranging from 90-240 VAC. These motors do not actually receive AC voltage, but the voltage levels sent to the motor windings are much higher than normal stepper motors can handle, enabling them to generate higher horsepower.
- Specialized stepper motors are also available that incorporate a lead screw as the rotor. These "stepper motor linear actuators" are available in multiple screw lengths and leads/pitches. Shaft-end journal and rear-shaft for an encoder are optional capabilities.

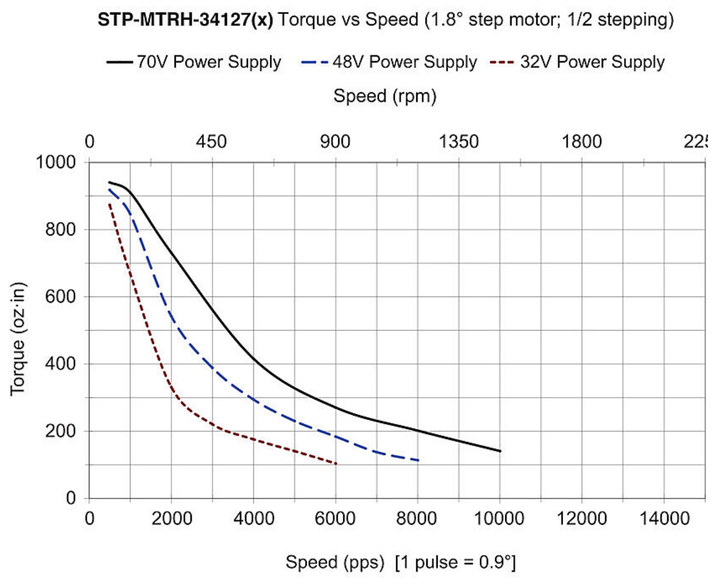

STP-LE17-3B06ADJ


STP-LE17-2A06ANN



Other Stepper Selection Criteria

Designers should consider the following aspects when selecting stepper motors for applications:



Torque vs Speed Curve

Stepper motor torque falls off rapidly as speed increases, and maximum speeds are not nearly as high as what servo motors are capable of. Torque applied is also dependent on the voltage level supplied, so while a particular stepper system might operate at anywhere from 32-70 VDC (as in the example image at right), the motor produces considerably more torque (at lower speeds) with higher voltage. It is highly recommended to carefully study the TS-curve of a motor during selection to verify it produces the required torque at all expected application speeds, as well as to determine the operating voltage required.

Stepper Drive Options

The simplest stepper drives require pulse and direction input (or CW/CCW pulse input). Most have optically-isolated inputs ready for +5 VDC logic (in some cases dropping resistors may be needed for 12/24 VDC signals). These simple drives do not require software for drive configuration, as all setup is via dipswitch and/or rotary dial selections. Dipswitches may also be used for built-in self-test, microstep resolution selection, current level selection, and optional idle current reduction.

Some drives add an on-board oscillator and can accept an analog velocity signal (0-5V or potentiometer). These drives may offer adjustable input filtering for smooth motion and quiet operation. Software setup is possible, but not required, and many of these drives can handle higher output currents (up to 10amp/phase).

More advanced stepper drives may have a built-in indexer and a communications port which can allow the stepper to complete simple moves with via ASCII commands or EtherCAT commands. These drives may support closed loop operation, with encoders mounted on the motors.

The most advanced drives include the ability to detect and possibly correct for step-loss, based on monitoring of the back-EMF from the motor. While detection of step-loss is possible without an encoder, the addition of the encoder allows the drive to correct for position errors without additional sensors or rehoming procedures.

Stepper System Power

Some stepper systems use high-bus-voltage, high-torque stepper motors with compatible microstepping drives that are powered directly from a 90-240 VAC source. But most stepper drives and motors operate on DC power, ranging from 12 to 80 VDC. So, in addition to the motor and drive selected for the application, the designer may need to specify a DC power supply to power the system. Note that if an application has multiple axes of stepper motion it is common to size a single power supply to power multiple stepper systems. Two basic varieties of power supply are typical:

- Linear DC power supplies are a historically popular choice for powering stepper systems. Linear supplies are generally less expensive. They don't regulate the voltage tightly, but the stepper systems are not affected by these voltage variations. In fact, it can be beneficial in the case where a particular stepper axis may go into regeneration mode (when the load actually drives the motor, during rapid deceleration, for example). The regeneration of current back to the power supply simply causes the voltage level to rise momentarily. Some linear power supply models also provide a small amount of 24 VDC power to be used for control signals.
- Switching power supplies are also an excellent choice for powering stepper systems. In some cases, a regeneration clamp may be required to prevent the power supply from faulting due to regen currents from the drive during regen events (see above).

Current Rating

Stepper motors are rated for the maximum current that they can handle. When pairing a motor with a compatible stepper drive, it is usually necessary to set the current limit on the drive to match the rating of the motor. Sometimes this is as simple as setting a rotary switch to the part number of the motor, but it is sometimes necessary to select the actual amp rating. Some drives are set up using a software product like SureMotion Pro to set many configuration parameters, including the current limit.

Rotor Inertia

Inertia is the resistance of an object to any change in its motion, including a change in rotation. To determine the rotational inertia of an object, its mass is multiplied by the square of its distance from the axis of rotation. The ratio of the load inertia (the mechanical apparatus being driven) to the rotor inertia can be an important aspect of stepper motor sizing, especially if the application requires high dynamic response (fast starts and stops with low overshoot). In these applications it is best to keep the load inertia within a factor of 10 (or less) of the rotor inertia; a 1-to-1 ratio is optimal. AutomationDirect's online stepper selector guide provides the rotor inertia for each motor, and it is up to system designers to determine the load inertia and calculate the ratio, if required. In some cases, a larger and oversized motor is desirable simply to improve the inertia ratio.

AutomationDirect Stepper Offerings

AutomationDirect offers a wide range of stepper motors, drives, controllers, and accessories for motion control , including:

• Single shaft stepper motors

• Dual shaft and encoder stepper motors

• IP65 stepper motors

• Stepper motor linear actuators

• Standard stepper drives

• High bus voltage (AC input) stepper motors and drives

• Integrated stepper motors/drives

• Ever Motion Solutions stepper drives: Closed-loop models can be used with encoder-equipped motors,and open-loop models include stall detection. Ever EtherCAT steppers: Significantly simplify wiring by leveraging digital communications.

Servo Systems

"Servo" is a term derived from a Latin word for servant, and indeed a servo system works by exactly and obediently following movement commands. Servos have reigned for many years as the high-performance, -speed, -torque, and -accuracy motion solution across industrial applications, including robotics, machine control, material handling, and much more.

While servo system hardware, installation, and implementation costs and complexity were traditionally high, a 'faster, better, cheaper' trend throughout industry—coupled with general technological improvements—has revolutionized today's servos. Servo systems increasingly incorporate built-in features to improve ease of use and enable them to work in more applications, while reducing material and labor costs.

Servo Basics

Servo motors, like stepper motors, cannot be run simply by applying a voltage. Instead, a drive (also known as an amplifier, or sometimes a controller) supplies multi-phase sinusoidal waveforms of power to the motor to elicit the desired response (movement or torque) of the motor's rotor/shaft.

In the servo drive, torque, velocity, and position loops are closed through a combination of feedback mechanisms and control algorithms. The torque loop, often referred to as the current loop, regulates motor current, which directly relates to torque. The velocity loop monitors motor speed and adjusts current/torque to achieve desired velocities. Position loops compare desired and actual positions, adjusting velocity commands to reach target positions.

Industrial servo motors always include a built-in feedback device, usually an encoder, identifying the shaft position to within a few arc seconds. With this information, the drive runs the motor as needed to positively achieve the desired motion or hold the target position, constantly compensating for any anomalies.

Servo motors can run at thousands of RPMs, providing full rated torque at all rated speeds, including at standstill. They can also provide considerably more torque for intermittent periods, and can run up to their maximum speeds with minor, if any, torque falloff. They are available in a wide range of sizes and form factors, with many useful options.

Servo Control Details

Servo systems are always operated closed-loop via the encoder on board each motor. It is also possible to install an encoder downstream on the driven equipment and wire this back to certain drive or controller models. This approach is called full-closed-loop control, which enables a system to compensate for slippage or play in a mechanical system downstream of the motor shaft. Some servo drives employ an additional external encoder input (referred to as an "axis and a half") to perform this function so the drive can close the external loop for full-closed-loop control.

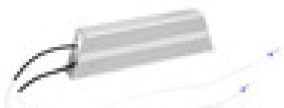
Some servo drives incorporate very capable motion controllers. In addition, many PLCs integrate extensive motion control functionality. However, the most advanced and high-speed functionality is usually only possible using specialized motion controllers because most PLCs do not scan their logic quickly enough and are often burdened with more mundane logic tasks that increase their overhead.

Servo Motor Details

Servo motors are available in various configurations, and with a variety of options, depending on the load, application, and operating environment. Here are some considerations:

- Servo motor frames are usually square, metric sizes such as 40mm, 60mm, and so on, up to 220mm or larger.

- They are sized with watt ratings, such as 100W, 200W, and so on, up to 15kW or larger.
- Servo motors generally offer smooth shafts, but some have keyed shafts. It is always recommended to use a clamping “servo style” coupling with a servo motor, because set screws tend to vibrate loose.
- Braking Options
  - Dynamic braking can stop the motor when it is disabled, overloaded or when a fault occurs.
  - Regen braking is used during normal operation and can take advantage of a regen resistor (either built-in or external) to maximize deceleration.



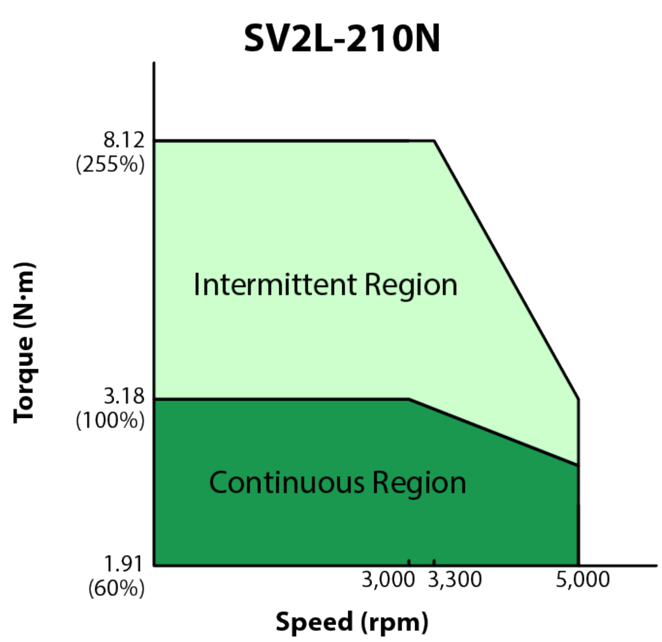
  - A magnetic brake (holding brake) is used to hold position while the servo system is stopped, disabled, or when power is disconnected. The holding brake is not for deceleration, as servo systems can decelerate quite effectively under program control. Instead, the holding brake is only used to hold the shaft still while the servo system is powered off, usually to fight the effect of gravity. Servo brakes are usually 24 VDC, and must be energized by the drive to allow motor operation (so that the brake engages if power is lost).

Other Servo Motor Selection Criteria

Designers should be aware of the following elements when selecting servo motors:

Torque/Speed (TS)

As with steppers, evaluating the TS curve for each motor is essential. Servo TS curves are quite different than steppers’. Servos can continuously produce their full rated torque from zero speed up to the motor’s ‘rated’ speed, and they can even be operated at higher torques—perhaps 350%—intermittently. They can also operate continuously up to their maximum speeds with minimal, if any, torque fall-off.

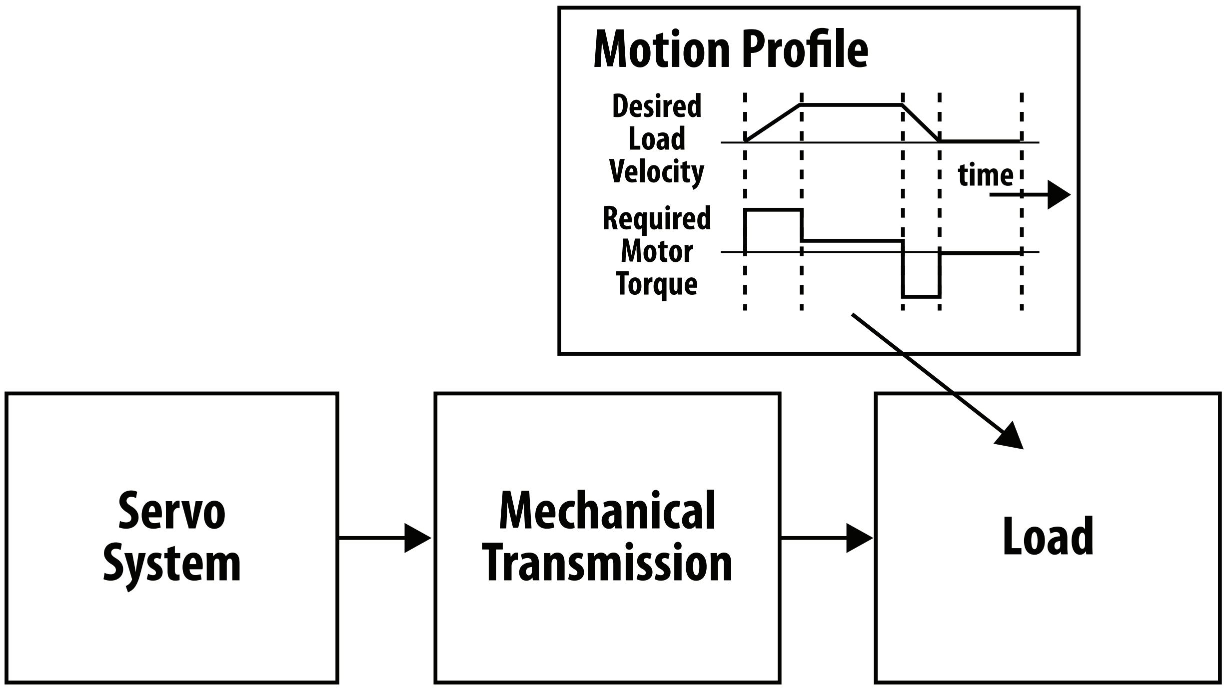


Rotor Inertia

For high performance systems, it is best to match the servo motor rotor inertia to the inertia of the load (often referred to as the "reflected load inertia"). Servo motors are available in low-inertia models offering speeds up to 6,000 rpm, and medium- or high-inertia models with speeds up to 3,000 rpm. Servo tuning also plays a role in how aggressively the drive seeks to command the motor response.

Every rotating system experiences inertia associated with the driven load and any interposing transmission elements. All load inertia must be determined and translated into an equivalent inertia as if it was directly attached to the motor shaft (driven load). Mechanical transmissions can dramatically impact the amount of driven load inertia reflected to the motor shaft. Therefore, a suitable motor must be selected to accommodate reflected load inertia.

For the best system responsiveness, designers should seek to minimize reflected inertia because high-inertia systems have lower bandwidth and are not as responsive. For systems requiring high responsiveness, applications benefit from keeping the load-to-motor inertia ratio as low as possible, ideally under 10:1. Systems with ratios as high as 200:1 can be implemented, but with correspondingly lower responsiveness.



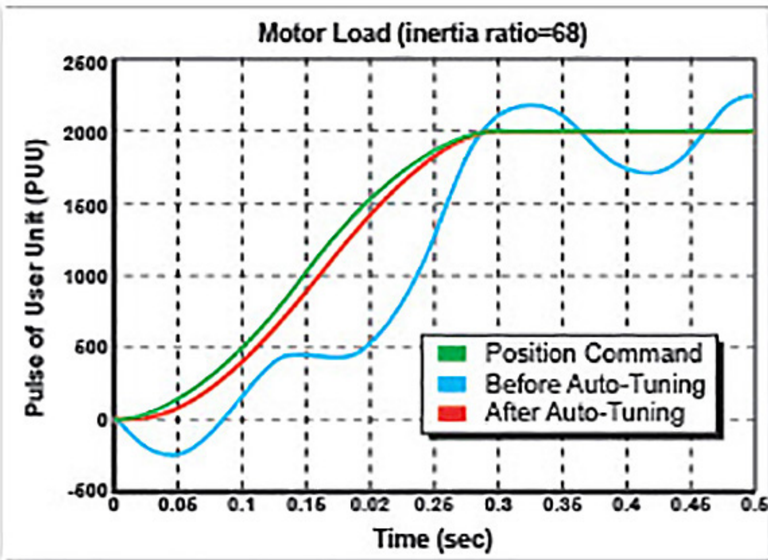
Many CAD packages can determine the reflected inertia quite well based on an accurate model, or designers can use simple equations based on the rough geometry of the load or use online tools such as https://calcresource.com/moments-of-inertia-table.html or the AutomationDirect VisualSizer https://support.automationdirect.com/products/sureservo.html. Estimates are typically fine to get in the proper range.

Gearboxes

Gearboxes and other mechanical transmission devices—such as leadscrews, rack and pinion mechanisms, pulleys, and timing belts—are used to change the motor speed and torque transmitted to a load. For example, a gearbox can increase the available torque (available torque = motor torque x gear ratio). Of course, the resulting top speed of the output from the gearbox is also reduced by that gear ratio, which may or may not be acceptable in some applications.

Gearboxes are sometimes used to improve inertia mismatch with servos, as the "reflected inertia" of the load through the gearbox is reduced *by the square of the gear ratio*. However, a design must consider the gearbox's added inertia in addition to the reduced top speed output. Generally, using a gearbox is only possible when maximum speed of the application is a fraction of the motor's top speed.

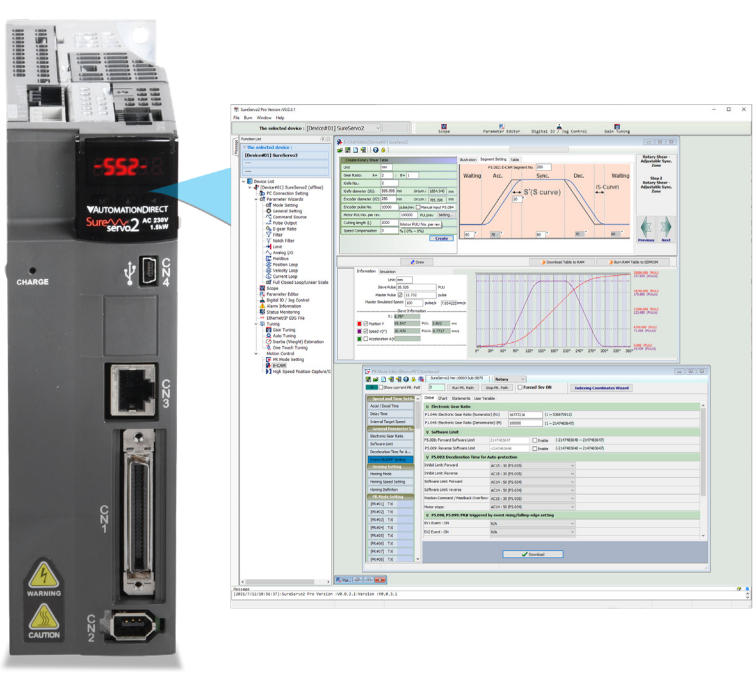
AutomationDirect offers an online gearbox selector that helps users understand the dynamics of the speed/torque/inertia relationship so they can size a gearbox for a particular motor, or for the required torque or speed of the application: https://www.automationdirect.com/selectors/suregear.



Automatic Tuning

Servo drives must be tuned for optimal operation with the motor. AutomationDirect's servos offer several tuning methods: fully manual tuning, assisted tuning (where the drive can be tuned as the motor moves), normal automatic tuning (used for point-to-point moves), and one-touch automatic tuning (which works without any motion, and is also known as static analysis). SureServo2 includes a fully digital velocity loop response up to 3.1 kHz to ensure precise control and easy tuning. LS Electric servo drives includes auto-tuning features as well, but the bandwidth is only 1.0 kHz.

Watch the Auto Tuning video



Setup/Diagnostics

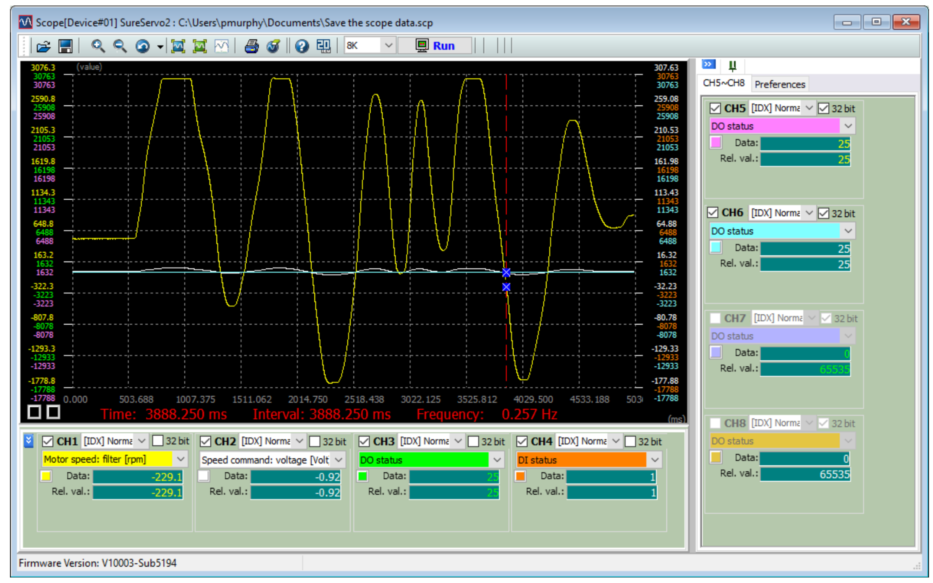
SureServo2 and LS Electric drives can be configured, monitored, and diagnosed using built-in keypads/displays, or with PC-based software. Firmware is field upgradeable, ensuring drives can always be upgraded to the latest operating system.

Safe Torque Off (STO)

SureServo2, certain LS Electric servo drive families, and certain Ever EtherCAT stepper drives include onboard STO, eliminating the need to install bulky external contactors that disconnect power during emergency stop conditions.

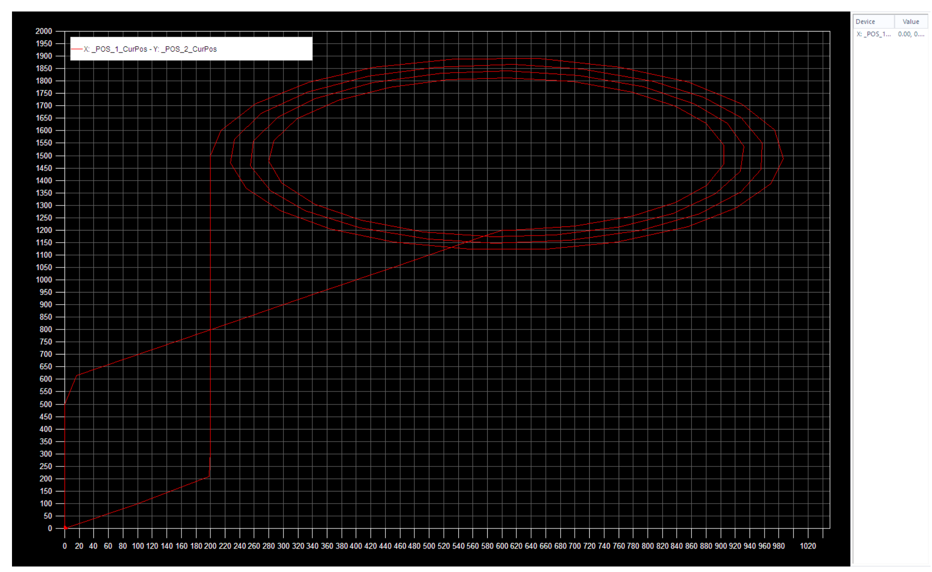
Oscilloscope

The SureServo2 and LS Electric free configuration software packages both offer built-in oscilloscope functionality that empowers users to monitor command signals and operating values to diagnose timing problems and optimize system operation. SureServo2 provides an eight-channel scope, and LS Electric offers four channels.



Trend Charts

Motion systems can be notoriously difficult to fine-tune, so the ability to analyze them during commissioning, troubleshooting, and other activities is a clear advantage. Modern automated systems demand extensive data, and trending is essential for developing and commissioning complex motion applications.



AutomationDirect Servo Offerings

AutomationDirect offers a wide range of servo motors, drives,ccontrollers, and accessories for motion control .

- AutomationDirect SureServo2 (SVA Series) AC servo systems

- LS Electric L7C (L7CA Series) AC servo systems

- LS Electric L7P (L7PA & L7PB Series) AC servo systems

- LS Electric iX7 (iX7NH Series) EtherCAT/ModTCP AC servo systems

- LS Electric PHOX EtherCAT/pulse/indexing DC servo systems

Monitoring and Control Communications

The motion control narrative up to this point has barely touched on an extremely important differentiator amongst platforms and solutions: control communications. Higher-performance systems require motion-specific communications, and various digital protocols offer extensive advantages over traditional hardwired methods.

Communications Basics

Motion control communications are not always needed. For example, built-in indexers in a stepper or servo drive can control simple (usually single-axis) applications, such as position and velocity moves (with trapezoidal and S-curve profiles), torque control, basic registration operations, indexing tables, programmable limit switch handling, and more. But they are limited by their single-axis scope and must be initiated by an individual "execute" signal from a PLC, or even a pushbutton.

However, most motion control systems rely on a separate controller—a PLC, a dedicated motion controller, or a combination—to do the path planning, and to send the motion commands to the servo or stepper drive.

The following sections provide a summary of popular methods for sending these control commands.

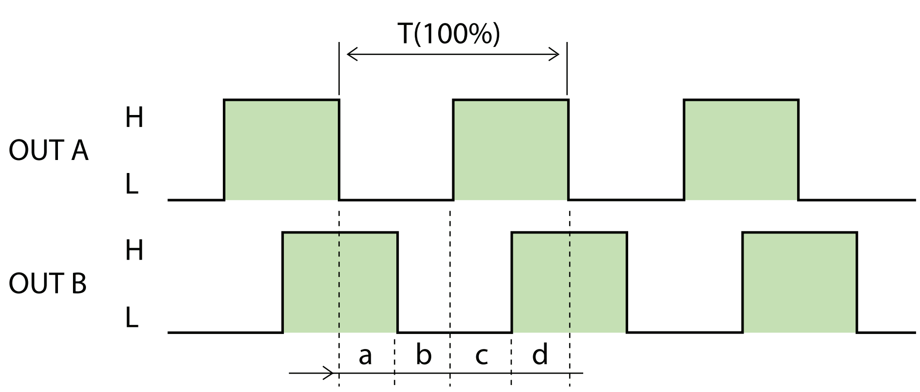
Hardwired I/O

Hardwired I/O is the most basic form of motion monitoring and control communications, and many drives and motion controllers are provisioned with multiple discrete inputs and outputs for this purpose. A PLC or other control system can provide a single discrete output signal to a drive to initiate a pre-configured move, and can monitor operation of the drive using discrete feedback inputs. The AutomationDirect SureServo2, for instance, provides up to 99 predefined index moves that are stored in the drive for selection and execution using digital inputs on the drive.

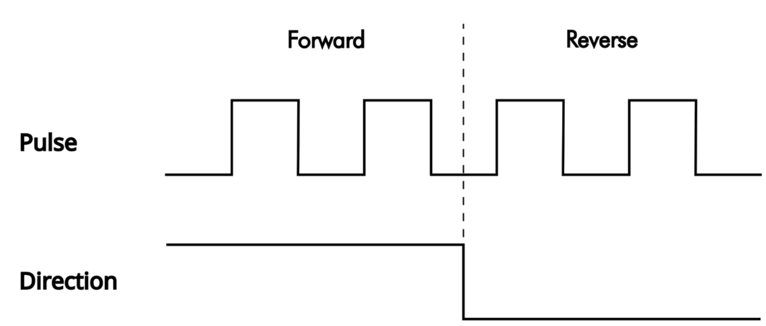
Pulse Train Output (PTO)

PTO signals—possible with many PLCs, including those from AutomationDirect—provide a more advanced form of using I/O to control the motion of stepper or servo systems. Pulse signals to command a drive are discrete outputs, capable of being cycled on/off at very high frequencies.

The most common PTO version is "pulse and direction," where one output from the controller pulses rapidly to command small increments of motion, while a second output dictates the direction of travel. Clockwise(CW)/counterclockwise(CCW) pulses are a second option, with one output commanding motion increments in one direction, and vice versa. Sometimes A/B quadrature pulses are used for encoder following applications because encoders commonly use these signals.



Quadrature Encoder Waveform Example



Pulse and Direction Example

PTO is a well-established method of control, but it has limitations. The wiring can get complex, especially as the number of axes increases. While most servo—and some stepper—systems close the loop internally (on a per-axis basis), there is no provision for loop closure with the controller, so full-closed-loop applications may require additional hardware and wiring.

Coordinated motion between axes is possible using PTO, as one drive or controller may be able to generate a PTO signal to another, but this is usually only feasible in applications with limited axis counts (two to four axes of coordinated motion). Some PTO controllers allow the use of virtual axes to create/simplify drive trains and encoder following applications.

Serial: ASCII and Modbus

Serial Command Language (SCL) is an ASCII protocol supported by some AutomationDirect SureStep drives, while the SureServo2 can accept ASCII or Modbus serial connectivity (RS-232 or RS-485 depending on the drive model).

Streaming commands from a controller (usually a PLC) to a stepper or servo drive using a serial protocol is an effective way to gain more functionality than using hardwired or PTO I/O. This method is useful for straightforward applications with no coordination between motion axes. Because there is little or no feedback from the controller using a serial connection, discrete and PTO I/O signals are sometimes still required for the PLC to obtain operating data.

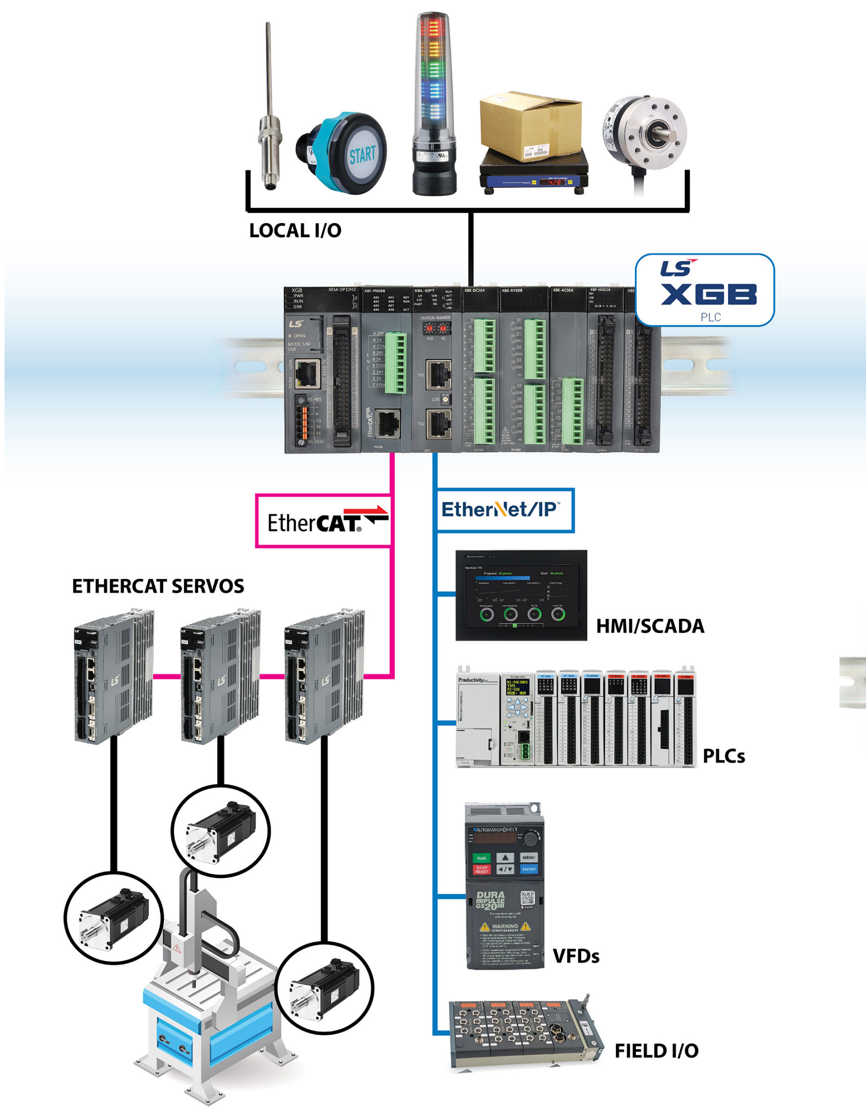
Ethernet: ModbusTCP and EtherNet/IP

Ethernet media and protocols have developed over the years to work in a multitude of industrial applications. Specific Ethernet variants are reliably used as industrial communication fieldbuses for handling I/O, controller and PLC peer-to-peer, and human-machine interface (HMI) connectivity at high speeds and data volumes, sometimes with redundancy capabilities. Three of the most popular industrial Ethernet protocols are EtherNet/IP, PROFINET, and Modbus TCP/IP (ModbusTCP).

Some motion applications are suitably controlled using industrial Ethernet fieldbuses, and AutomationDirect offers drives and controllers for ModbusTCP and EtherNet/IP networks. While industrial fieldbuses are fast enough and capable of handling large amounts of data for many processes, there are some limitations for their use in motion applications.

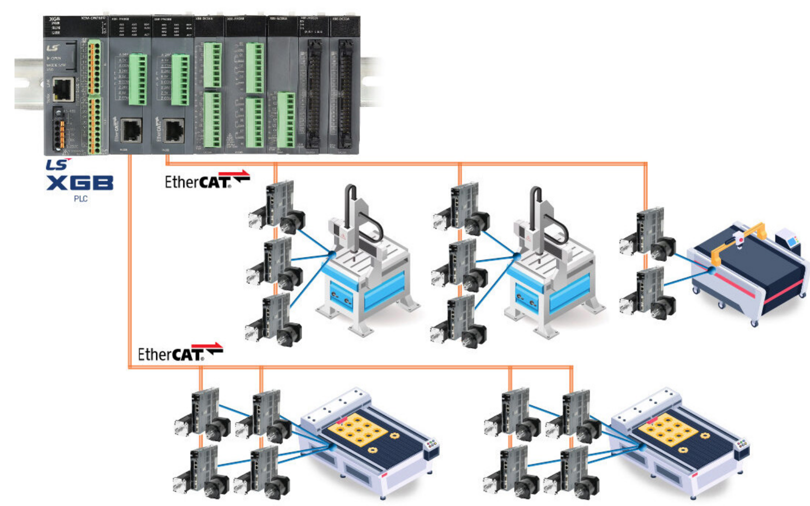
First, there is no synchronization among axes for coordinated motion when using a fieldbus connection, and only certain stepper and servo systems are available with the appropriate networking hardware/ports. Other functionality is often dependent on the drive hardware:

- Registration is possible over EtherNet/IP or ModbusTCP networks with LS PHOX and iX7 drives, because they include Capture/Probe inputs. But the correction calculation must be performed in the controller (and a native function block for these calculations may not exist in the controller, requiring programming with standard ladder functions) and response times are subject to the scan time.
- SureServo2 servo drives can handle some registration applications natively (completely in the drive hardware), and report success over the EtherNet/IP or ModbusTCP network.
- LS Electric DC PHOX systems and SureServo2 servo systems can accomplish encoder following (full-closed-loop) control, with the controller and drive connected via EtherNet/IP or ModbusTCP, but the external encoder must be hardwired into the drive. Therefore, this is more of a drive feature/function, and it is limited to a single axis of following, unless the encoder signal is cascaded or daisy-chained to other drives. In contrast, an external encoder wired directly to an EtherCAT controller allows considerable flexibility with external loop closure and multi-axis drive trains.

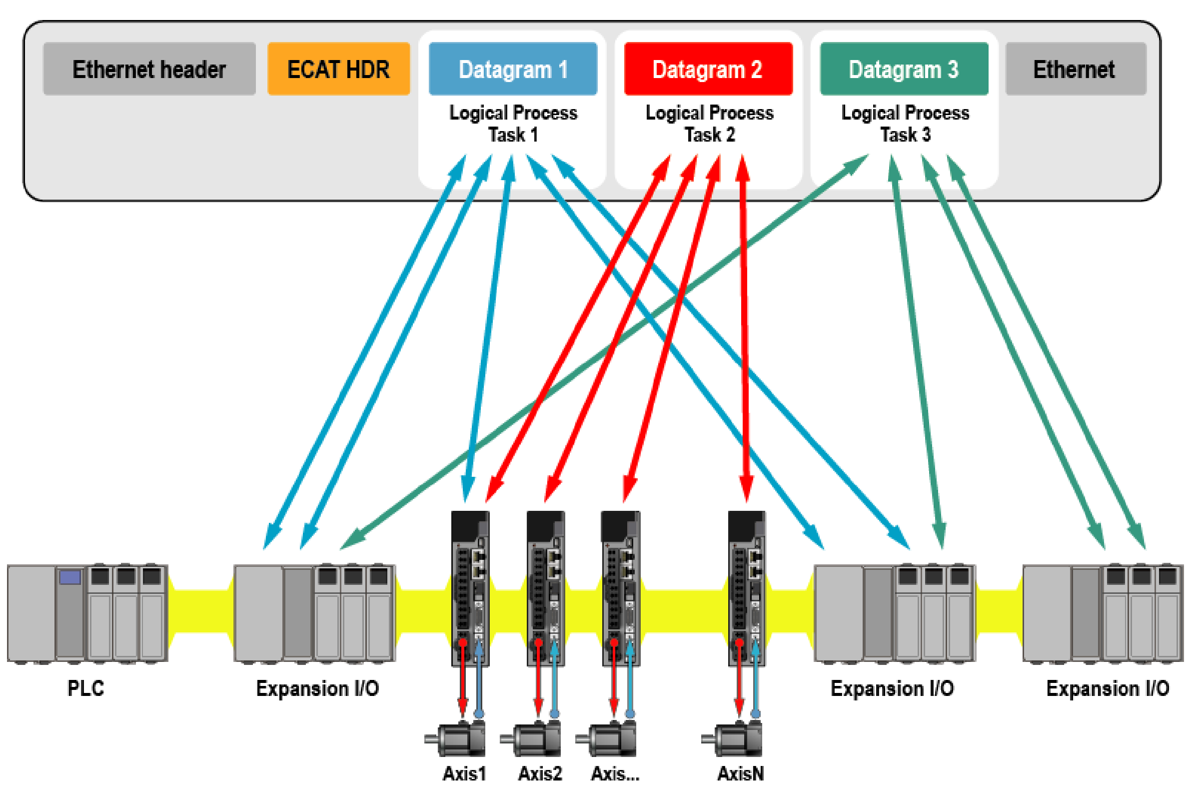


EtherCAT

The Ethernet for Control Automation Technology (EtherCAT) protocol is a preferred and popular option for motion control over Ethernet. Developed by Beckhoff Automation in the early 2000s, and then standardized under IEC 61158, the EtherCAT protocol works over standard Ethernet media and architectures much more efficiently than other general industrial protocols. It is designed to deliver deterministic cycle times, which is essential for maintaining accurate synchronization among all communicating devices in high-performance applications.



An EtherCAT network uses a single MainDevice to initiate a datagram frame which is sequentially passed through associated network nodes (the drives and other I/O devices). This messaging structure eliminates data collisions, supporting short and deterministic cycle times, so that accurate synchronization can be maintained among all communicating devices.



EtherCAT enables a wide range of motion applications, and the network wiring is simple and easy to implement. An EtherCAT controller has access to the position, velocity, and torque of all axes of motion—with very low latency—so there are few application limitations.

Jump to Chapter
Chapter 1 Motion Control Introduction
Chapter 2 Motion Control Components and Basics
Chapter 3 Motion Control Concepts
Chapter 4 Stepper Systems
Chapter 5 Servo Systems
Chapter 6 Monitoring and Control Communications
Chapter 7 Accessories
Chapter 8 Component Selection

Coordination of motion across high numbers of axes (eight or even 16) is possible. And many virtual axes are usually available (controller dependent), permitting encoder following and complex drive trains across numerous axes.

Accessories

AutomationDirect offers a full portfolio of motion control accessories to simplify designs, speed installations, and streamline ongoing support. Brands include SureStep, SureServo, SureGear, SureMotion, LS Electric, Ever Motion, and more.

Power Requirements and Power Supplies

Stepper Systems

Stepper drives are typically energized by DC voltages, which are frequently supplied using inexpensive linear (unregulated) power supplies. Switching power supplies are also a popular choice for powering stepper systems, but users should be aware that regen clamps are often needed with the switching supply if the stepper system is expected to decelerate significant loads quickly or often.

Some stepper drives can accept line voltages (120/240 VAC) and rectify them to a corresponding “high bus-voltage” to power suitably rated motors. Care is required when specifying a power supply to match the drive and the motor.

Servo Systems

Industrial servo drives are typically energized by 120 VAC single-phase, 240 VAC single- or three-phase, or even 480 VAC three-phase power, so no separate power supply is required. Drive derating is sometimes required when running a drive on single-phase power input, which can subsequently require upsizing the drive.

Some servos are available with DC power inputs. For example, the PHOX line from LS Electric accepts 24-48 VDC, and multiple drives can share a DC power supply. This is particularly advantageous for mobile, battery-powered applications.

Regeneration Resistors

Similar to the regen clamp offered for steppers, servo systems also need a way to deflect regeneration current when the application requires frequent or fast deceleration of heavy loads. Most servo drives have small regen resistors built in, but these can be easily bypassed when a larger external resister is required. Some multi-axis servo systems allow the connection of the DC buses across multiple servo axes so other axes can use this regeneration energy.

EMI/RFI Filters

Active and passive EMI/RFI filtering may be desired or required for some systems. LS Electric offers a range of EMI input filters to be placed on the incoming power lines for the servo systems.

TB6-B010LBEI

SV2-T0R1

Toroids are also used on the motor cabling between servo drives and motors, and are especially effective when long motor cable lengths cannot be avoided.

Cables and Wiring

Control and I/O Wiring

PTO systems (stepper or servo) usually require discrete wiring between the controller and each axis of motion. While this is fairly simple for each axis, the sheer number of connections can become complex and burdensome as the axis count grows. Installation and maintenance costs also increase with axis count.

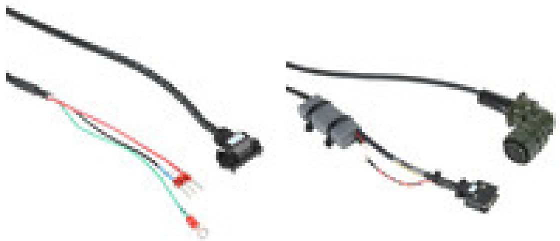
I/O breakout boards are commonly used in servo systems to simplify control and I/O wiring. A choice of cable lengths connects a high-density connector on the servo drive to a DIN-rail mount terminal block module for connections to the various signals. Stepper drives typically include a pluggable terminal connector for the various connections.

Serial communications may allow the use of factory-made cables, or they may be discretely wired, depending on the connectors at the controller and drive.

The wiring is simplified greatly on networked drives communicating via Ethernet-based ModbusTCP, EtherNet/IP, or EtherCAT protocols. In these cases, standard Cat5 (or greater) Ethernet cables are typically daisy-chained from the controller to each drive in the system.

Motor and Encoder Cables

Simple open-loop stepper systems usually require only a motor cable connected between the drive and motor. Motor extension cables are usually offered for longer distances. Closed-loop systems also require an encoder cable to provide feedback to the drive or controller. Integrated motors/drives typically have internal connections for these signals, removing the need for additional cables.



Servo systems typically require both motor and encoder cables between the servo motor and drive, and external encoders may require additional cabling or wiring.

Sensors

Encoders

Encoders are high-resolution position detection instruments, usually optical-based in motion control applications, that generate pulses based on motion. When used with a typical PLC, servo motor controller, or other controller, an encoder is typically the best way to precisely determine the position, velocity, and direction of equipment motion.

Closed-loop stepper motors are often available with factory-installed encoders, but any dual-shaft motor can be outfitted with a field mounted encoder. "Kit encoders" can make this mounting easier by including the required hardware, couplings, and bore reducers for specific motors.

Servo motors are almost always supplied with the primary encoder built into the motor.

However, for any stepper or servo motion system, and often for advanced applications, a designer may choose to add external encoders to the motors or on the driven equipment to achieve full-closed-loop control.

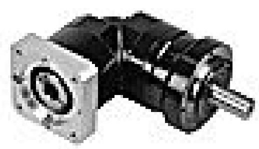
Discrete Sensors

Motion control system automation often requires discrete sensors to determine the position of equipment in normal operation and to detect overtravel conditions. AutomationDirect offers a complete portfolio of proximity sensors, photoelectric sensors, linear position sensors, inclination sensors, and limit switches that communicate via a variety of wiring configurations or protocols to meet nearly any design requirement.

Downstream Mechanical Apparatus

Gearboxes

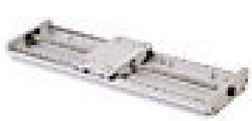
Precision planetary, helical, and strain wave gearboxes are designed for servo motor duty with low backlash, high efficiency, and quiet operation. Strain wave gearboxes provide much higher ratios—up to 200:1—than planetary or helical designs, with lower heat and noise generation, and zero backlash. Properly sized gearboxes can facilitate the use of smaller and less costly motors in many cases. Gearboxes are offered in inline, right-angle, and hub styles, along with mounting hardware.

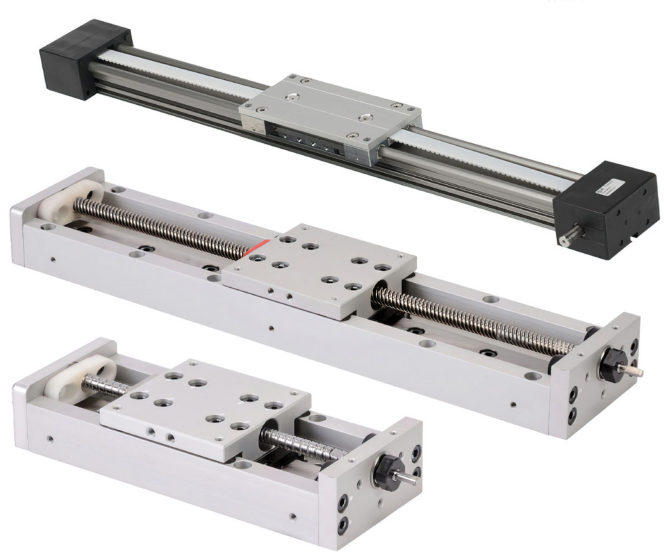

Linear Motion Slides and Actuators

Linear actuators and sliding components turn rotary motion into linear motion, as well as providing a variety of X-Y and X-Y-Z positioning system solutions. These are often used for applications like pick-and-place, both commercial- and industrial-grade cutters, CNC machines, 3D printers, laser engravers, routers, and more.

A variety of actuator types, including ball screw, lead screw, and belt-driven linear, help meet price/performance needs of numerous applications, along with a collection of other sliding elements to complete the system. Check out this link for videos of linear actuators in action.







Drive Couplings and Bushings

Drive couplings are power transmission components used to couple the shafts of various mechanical devices and compensate for shaft misalignment, reducing stress on shafts and bearings. A selection of servo-style clamping couplings are available. Bore reducers, which are mechanical adapters, can be used in drive coupling hubs to reduce bore size.


Component Selection

The task of selecting the appropriate motors, drives, controllers, and more for a complete motion control solution can be daunting. AutomationDirect understands the challenge, and on top of assembling a wide-ranging portfolio of products, we created user-friendly online selection and configuration tools to help guide the process. Here are a few helpful links:

- Stepper system configuration tool: https://www.automationdirect.com/selectors/steppers
- SureServo2 system configuration tool: https://www.automationdirect.com/selectors/sureservo2
- LS Electric servo system configuration tool: https://www.automationdirect.com/selectors/ls-servo
- PLC/Motion Controller Selector: https://www.automationdirect.com/systembuilder

Use our selector tools to make sure you get ALL the required parts and accessories you need on your FIRST order.

Check out this link for videos of many different motion control elements in operation.

Stepper System Features

The following charts summarize servo system and stepper system features by product offerings, to help speed system specification.

	L7C Basic Servo Systems	L7P Intermediate Servo Systems	iX7 Advanced Servo Systems	PHOX DC Servo Systems
Motor power range	100W to 1kW	100W to 7.5kW	100W to 3.5kW	100W to 300W
Input power	230VAC 1-phase	230/460VAC 3-phase (230 1Φ up to 2kW)	230VAC 3-phase (110VAC 1Φ up to 400W, 230VAC 1Φ up to 2.2kW)	24-80VDC
Bandwidth (velocity loop)	1 kHz			
Motor encoder resolution	131,072 ppr (17 bit)	524,288 ppr (19 bit)	524,288 ppr (19 bit)	262,144 ppr (18 bit) 524,288 ppr (19 bit)
Encoder output	Line Driver	Line Driver & Open Collector	Line Driver, up to 6.5 Mpps	Line Driver, up to 6.4 Mpps
Absolute encoder	No	Yes (with included battery)		
Pulse input (PLS/DIR, CW/CWW & AB quadrature modes)	Yes 1MHz line driver and 200kHz open collector		None	Yes 4MHz line driver
Speed modes	+-10 VDC analog control Up to 8 predefined speed registers selected via discrete inputs		Yes: via EtherCAT® or ModbusTCP	Yes: +-10VDC analog control or Up to 8 predefined registers or EtherCAT®
Torque modes	+-10 VDC analog control		Yes: via EtherCAT® or ModbusTCP	Yes: +-10VDC analog control or EtherCAT®
Analog input deadband option	Speed and Torque Modes	Speed Mode	No	Speed and Torque Modes
Torque limit in speed mode	Yes			
Speed limit in torque mode	Yes			
Vibration elimination	No	Yes		
Notch filters	4			
Max inertia mismatch	up to 20:1	up to 30:1	up to 30:1	up to 30:1
Safe Torque Off (STO)	No	No	Yes	Yes
Indexing modes	Position Registers up to 64 Relative and Absolute Moves Simple motion sequencing Simple Registration Blended moves Rotary Table indexing (up to 64 indexes)		One position register Supports Cyclic Mode via EtherCAT® Profile Mode via EtherCAT® or ModbusTCP.	Position Registers up to 16 Relative and Absolute Moves Simple motion sequencing Simple Registration Blended moves Rotary Table indexing (up to 16 indexes) Supports Cyclic Mode via EtherCAT® Profile Mode via EtherCAT®
Electronic camming (E-Cam)	No	No	Yes: via EtherCAT®	Yes: via EtherCAT®
Registration	Basic	Basic	Yes: via EtherCAT®	Yes: via EtherCAT®
High speed capture/compare	No	No	Yes: via EtherCAT®	Yes: via EtherCAT®
Software config and troubleshooting	Yes			
Software oscilloscope	Up to 4 channels			
USB software connectivity	Yes			
Communications available	Serial: RS-422 Modbus-RTU (compatible with RS-485)		EtherCAT® or ModbusTCP	EtherCAT®
Communications ports	Discretely wired	Two dedicated RJ45 serial ports	Two dedicated RJ45 Ethernet ports	
Regenerative and dynamic braking	Yes			No
Digital inputs	10 configurable	16 configurable	6 configurable	4 configurable
Analog inputs	2 (+/- 10VDC)	2 (+/- 10VDC)	1 (+/- 10VDC) for torque limit only	1 (+/- 10VDC)
Digital outputs	5 configurable, 3 fixed for alarms	8 configurable	3 configurable	4 configurable
Analog outputs	0	2 (+/- 10VDC)	2 (+/- 10VDC)	2 (+/- 10VDC)

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Stepper System Features

	Leadshine®	SureStep® Standard		SureStep® Advanced		Ever® Standard	Ever® w/EtherCAT
Stepper Drive Features	Separate Drive & Motor	Separate Drive & Motor	Integrated Motor/Drive	Separate Drive & Motor	Integrated Motor/Drive	Separate Drive & Motor	Separate Drive & Motor
Input power	AC or DC	AC or DC	DC	DC	DC	AC or DC	AC or DC
Input voltage	12-24VDC, 24-48VDC, 24-70VDC, 24-90VDC, or 24-70VAC	12-24VDC, 24-48VDC, or 90-240VAC	12-48VDC	24-48VDC	12-48VDC, or 12-70VDC	24-75VDC, 24-80VDC, or 100-240VAC	12-48VDC, 18-56VAC, 85-120VAC, or 100-240VAC
Max microstepping (steps/rev)	12800, 25600, or 51200	20000 or 25600	25000	51200	51200	51200	65536
Feedback type	Open loop	Open loop	Open loop or Closed loop	Open loop	Open loop or Closed loop	Open loop, Open loop with stall detection, or Closed loop	Open loop, Open loop with stall detection, or Closed loop
Stall detection	No	No	No (Encoder models provide position feedback to controller)	No	Yes (On select models)	Yes (Using back-EMF from the motor)	Yes (Using back-EMF from the motor)
Control options	PTO	PTO		PTO, Internal indexer, Analog velocity		PTO, Internal indexer, Analog velocity	EtherCAT
Amps per phase	up to 7A	Up to 7.5A	up to 5A	up to 10A	up to 6A	up to 10A	up to 11.3A
Safe Torque Off (STO)	No	No	No	No	No	No	Yes
Models available	7 basic , 1 advanced	4	6	2	10	3	5
Compatible/Attached Stepper Motor Features							
Motor frame sizes (NEMA)	14, 17, 23, 34, 42	14, 17, 23, 34, 42	17, 23	14, 17, 23, 34, 42	17, 23, 24	14, 17, 23, 34, 42	14, 17, 23, 34, 42
Motor holding force	up to 4390 oz in	Up to 4532 oz in	Up to 210 oz in	Up to 4532 oz in	Up to 340 oz in	Up to 4532 oz in	Up to 4532 oz in
Environmental rating	IP40 or IP65	IP40 or IP65	IP20	IP40 or IP65	IP20	IP40 or IP65	IP40 or IP65
Dual shaft available	Yes	Yes	Yes, with preinstalled encoder	Yes	Yes, with preinstalled encoder	Yes	Yes

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