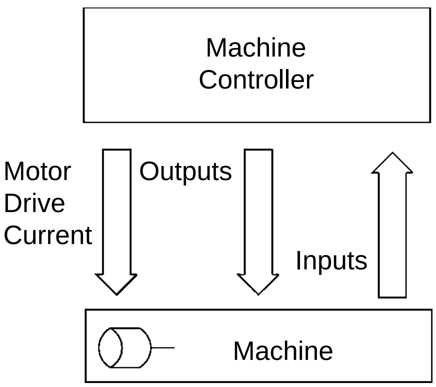
7) Control and Electronics

Control and electronics are the brains to any linear motion system. In general, a motor controller performs three main functions. First, it routes current to the motor windings according to rotor position. It also transforms input supply voltage into a controllable voltage and current supply for the motor speed and torque control. Finally, in the case of servo control, it handles all speed and torque feedback loops to meet prescribed static and dynamic requirements. There are many types of control, and each type has many different components. This section will discuss some of the more common types and introduce the major components associated with each.



Input and Output Devices are the interface between the controller and the controlled system and, in effect, tie the controller to the outside world. Input devices convert physical quantities to electric signals, while output devices allow the controller to act on the system. The electronic brain of a control system depends upon the network of input/output devices (I/O). In the case of closed loop servo control, the inputs are critical to operation.

Inputs include transducers, sensors and switches. Sensors and transducers convert physical data such as speed, position, temperature, acceleration and pressure into electrical signals that are recognized by the controller. Switches allow the operator to supply information that supplements or overrides input data. **Outputs** include power semiconductors and IC's, relays, and circuit breakers. By providing control over electric power subsystems that drive motors and solenoids, they allow the controller to initiate, halt, or modify action in the controlled system, including turning pneumatic, hydraulic, and electric devices on and off.

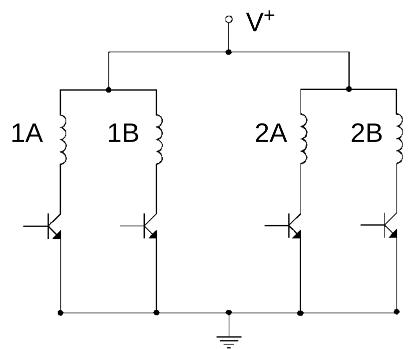
Sensors are used in combination with I/O for a variety of tasks. The most common task is to provide the controller with a defined work envelope, defining the physical capabilities of the hardware. Typical linear motion machinery will incorporate switches at both ends of the physical motion limit of each axis to provide the controller with "out of bounds" information. The switch towards the motor is generally referred to as the **home switch** while the switch at the far end is called the **limit switch**. Upon activating one of these switches, program execution is usually terminated. The most common types of switches are the *mechanical switch* which is activated by physical contact, and the *hall effect switch* which is activated by magnetic properties. Inductive proximity switches and optical sensors are also found on systems. Proximity switches have no moving parts and can be extremely repeatable and reliable if used correctly. Optical switches also have no moving parts, but they can suffer performance degradation due to dust.

Feedback Sensors are used to perform checks on the static and dynamic state of a system, and are generally used with servo systems. *Encoders and resolvers* are used to sense position information, and are further discussed in the servo motor section of this introduction. *Tachometers* are used to sense velocity information, and *accelerometers* are used to detect acceleration. Each type of sensor performs different tasks, and requires different types of interfacing to the control.

Proximity switches are commonly seen in process automation applications. A proximity switch is an electronic switch that acts when it is in the proximity of an object. *Inductive* proximity switches can detect any metal object based on local change of inductance, and are highly insensitive to harsh, dirty environments. *Capacitive* proximity switches are capable of sensing fluids and nonmetallic objects based on local changes in capacitance. Both should be applied with care as they can be sensitive when detecting objects that present small targets such as corners and edges.

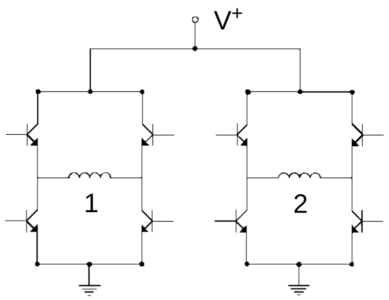
Power Supplies have the task of converting supply AC voltage into usable form. The most common type of power supply is the *regulated* type which uses transformers or switching transistors and a rectifying stage. Accurate power requirements will use different filtering techniques to eliminate AC supply line ripple. Motor voltage supplies can usually be simple or even unregulated DC supplies. Care should be taken with overvoltage protection. Since a motor is basically a generator run in "reverse", it generates a braking current when being stopped. This current either has to be dissipated through resistors or regenerated back into the voltage supply capacitors. Rapid or frequent braking could overcharge the capacitors, so a mechanism for "dumping" excess current must be used to protect the power supply.

Stepper Motor Drivers are supplied with the required step sequence from the stepper control card and, in turn, supplies stepper motors with current and voltage. The function of a stepper motor driver is to drive current through the appropriate phase windings of the motor to produce a stepped motion.



2-phase stepper driver in unipolar mode

Note that only half of each phase or coil is energized at any time. The electronics are less expensive to manufacture but the performance is degraded.



2-phase stepper driver in bipolar mode

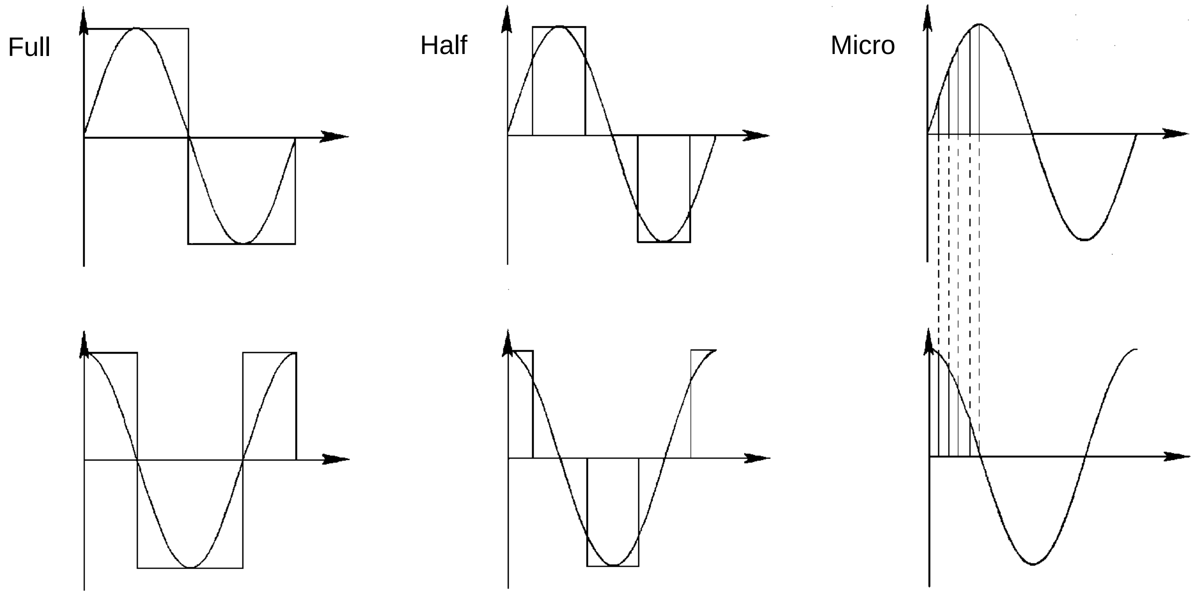
Note that the entire phase is energized, providing greater power. Also note that the drive electronics have twice as many power components as in the unipolar mode.

A **unipolar driver** is only able to supply current through a winding in one direction, and the voltage cannot reverse polarity. This means that the windings are split and only half of the winding is used at a time. A benefit to this approach is that the electrical time constant is reduced and the motor will have a faster response time; however, there are significant limitations. To change rotational direction of the motor, current must be channeled to the other half of the winding in reverse polarity. This creates mutual inductance in the unused portion of the winding, which reduces motor accuracy. Also, there is a significant loss of torque at low speeds and the motor becomes very inefficient.

A **bipolar driver** utilizes all of the windings simultaneously. When reversing direction, the current can be driven out which reduces current decay and enhances motor performance. In a bipolar drive, phase voltage switches from positive to negative — i.e., current is actively forced into and out of the windings. Best performance is usually attained with a four or eight lead motor wired for bipolar parallel drive due to the torque-speed curves associated with this type of arrangement.

Servo Motor Amplifiers perform a very similar task to the stepper driver; however, motion is not actuated in steps. Servos have smooth continuous motion capabilities, and the amplifiers are designed to provide the required voltage and current to the motor winding. Since servo motors have only two leads, the motor is reversed by reversing the polarity of the voltage across the leads. Servo amplifiers are supplied with the current and voltage requirements, from the servo controller card, which is updated in real time via feedback. Typically, the controller supplies a 10V analog signal and the amplifier produces a current proportional to this signal. Some of the newer amplifier/controller systems produce digital signals and skip the analog conversion. This arangement simplifies the circuitry.

Stepper Control (open loop): Stepper motor controllers typically operate in one of three modes. Full step mode provides the coarsest resolution, half step mode is next, and microstep mode offers the smallest resolution. Most positioning and machining applications are well served by half step mode, but microstepping may be necessary. **Microstepping** is when the control electronics divide each full motor step into many smaller steps by manipulating the current levels in the windings. If a servo system is not desired, applications involving very low speeds and much higher resolutions can utilize the advantages of microstepping.



Full stepping is a 4-point approximation of the sine/cosine waves. Half step is just an 8-point approximation of the sine/cosine waves. If more points are used to approximate the sine/cosine waves, this is called mini- or microstepping.

There are several key points to consider when analyzing a stepper motor control unit. Circular interpolation is when two stepper motors are controlled simultaneously to achieve circular motion. Due to the digital nature of stepper motors, all arcs have to be approximated by a series of very small line segments. The deviation from a true circular path is determined by the size of the line segment approximations. **Techno stepper motor controllers execute circular interpolation true to within 1 step at all points along the arc.**

Since stepper motors have decreased torque output at increased speeds (see **Figure 1**), it is important to understand how control electronics handle acceleration and deceleration. Machining and positioning applications often involve direction and velocity changes. The graphs indicate a velocity change, over time, from point A to point B. Two common types of velocity profiles, parabolic and trapezoidal, are illustrated. Since stepper motors can stall under dynamic shock, it is important to have a smooth velocity profile (see **Figure 2**). The most effective way to achieve a smooth profile is to use parabolic ramping functions

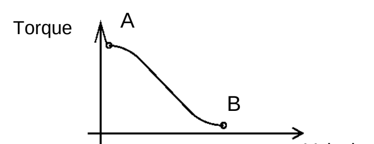


Figure 1

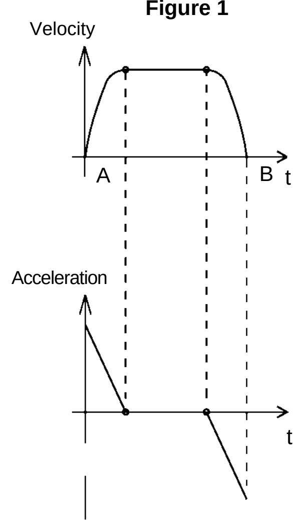


Figure 2 Parabolic

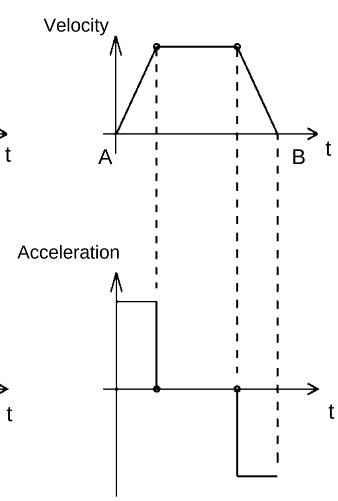


Figure 3 Trapezoidal

at all velocity changes. Parabolic changes in velocity take advantage of the torque versus speed characteristics of stepper motors. Acceleration during a velocity increase is highest at the beginning of the change, when the torque output of the motor is at its peak (see **Figure 2**). Since acceleration is proportional to torque, this situation is optimal. Trapezoidal profiles require high accelerations at all points, even when the torque output of the stepper motor is at a minimum (see **Figure 3**), and thus should be avoided. Parabolic changes provide a smooth transition from one point to the next, holding dynamic shock or change of acceleration, to a minimum. Trapezoidal profiles, in contrast, introduce large changes in acceleration, i.e. shock, two times at points in the velocity profile where torque is relatively low, making the motor susceptible to stalling (see **Figure 3**). Parabolic velocity control is especially effective when producing arc sections because arcs require constantly changing acceleration. **Techno stepper motor controllers have been designed to minimize the possibility of dynamic shock during program execution by incorporating parabolic ramping functions into the control electronics.**

Servo Control (closed loop): The presence of a feedback mechanism is what provides the signal checking, creating a closed control loop. Feedback is most often found in the form or position feedback, supplied from a rotary optical encoder. Even with the presence of a comparison routine, several methods must be employed to overcome system errors.

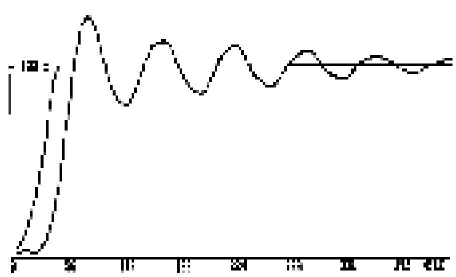
Proportional gain is a technique that supplies a correction force proportional to the magnitude of the detected position error. This adjustment puts the system back to close to the desired state, but is incapable by itself of fully correcting deviations. Integral gain is used to measure and cumulate position errors (steady state errors) so that a restoring force proportional to the cumulative position error can be applied to the system. A larger cumulative error results in a larger restoring force, and the system becomes more accurately corrected. Differential gain is a method that utilizes the time rate of change of the position feedback information and compares it to the desired velocity. A restoring force proportional to the difference of velocities will act to minimize deviations from actual and desired velocity rates. These concepts are designed into a PID (Proportional, Integral, Differential) chip on the controller card. **The Techno Servo Controller Card utilizes all three types of system correcting techniques, providing PID control.**

A second factor to be aware of when choosing a servo controller is the degree to which the system is damped. There are three different scenarios to consider with respect to damping, as shown below.

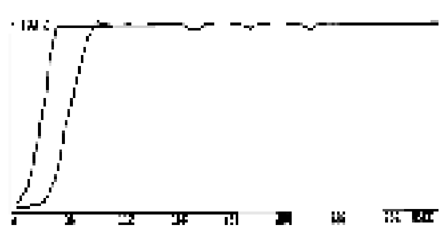
An **underdamped system** will overshoot its destination, then oscillate back and forth about its desired state. This causes large inaccuracies and vibrations, which should be avoided.

A **critically damped system** is provided with enough motion damping to overshoot the target one time, then asymptotically approach the steady state. This is preferred in theory, but it is a difficult state to maintain in reality.

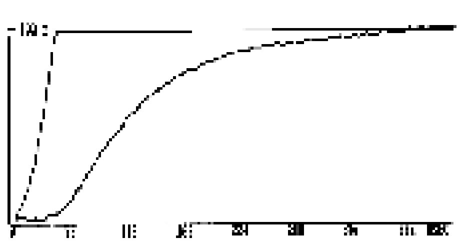
An **overdamped system** will take a very long time to reach the desired position, asymptotically reaching the desired state without position overshoot. This will tend to put a higher burden on the driving motors.



Underdamped



Critically Damped



Overdamped

Changes in speeds and loads which are common in machining and positioning applications, contribute to changes in the tuning of the system. Although most of the dynamic impact of changes are absorbed in the mechanical reduction unit (ball screw, gear train), there is enough transmitted to the motor to create a slight disturbance. This causes an “untuning” of the system. Lighter than normal loads can cause a system to approach an underdamped state, while heavier loads can cause a system to approach an overdamped state. To account for this, **the Techno Servo Controller PID chip has been designed to provide critical to slightly overdamped tuning, so that an underdamped system is avoided.**

PLC’s are another common control type in industry. They are advancing very rapidly, and are becoming smaller, less expensive, and easier to use. The primary function is to logically link and control I/O. This can be very useful for repetitive operations that can be actuated by solenoids or other digital devices, as found in pneumatic applications. However, only more advanced and expensive PLC’s have developed to the point where they can effectively control complex motor functions. If an application requires extensive logical operations in conjunction with motor automation, then a motor controller can be operated in conjunction with a PLC by means of the proper handshaking and data exchange. If an application requires moderate logical operations along with motor automation, then a Techno controller with I/O capabilities may well serve the entire application.

8) Wiring

Once the task has been reduced to a wiring stage, there is still a lot to consider. In fact, a well chosen system can perform poorly or not at all if mistakes are made in the system wiring. Resulting inaccuracies may be experienced, or worse yet, system failure and hardware damage may follow.

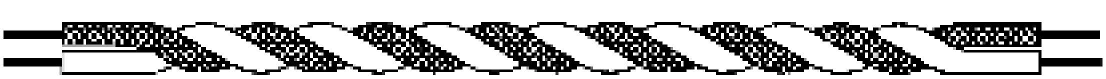
Current carrying capacity of conductors is defined as the amperage a conductor may carry before melting either the conductor or the insulation. The mechanism of failure for an overloaded wire is excessive heat caused by electric current flow. There are many factors which limit the amount of current that can be passed through a wire. The major factors are conductor size, insulation temperature rating, ambient temperature, number of conductors bundled or twisted together, and installation conditions (heat dissipation is lessened by installation into conduits, races, and trays). The following table acts as a guide to wire size selection.

Derating Factors for Bundled Conductors

Bundle #	Derating Factor (X Amps)
2 — 5	0.8
6 — 15	0.7
16 — 30	0.5

Amperes

Insulation Materials	Polyethylene Neoprene Polyurethane Polyvinylchloride (Semi-Rigid)
Copper Temp.	**80°C**
26 AWG	4
24 AWG	6
22 AWG	8
20 AWG	10
18 AWG	15
16 AWG	19
14 AWG	27
12 AWG	36
10 AWG	47
8 AWG	65



Twisted Pair Wire

Electronic Noise is a term used to describe unwanted disturbances as a result of electrical equipment. There are two sides to electric noise: the generation (or emission) of noise and the susceptibility of the equipment to noise.

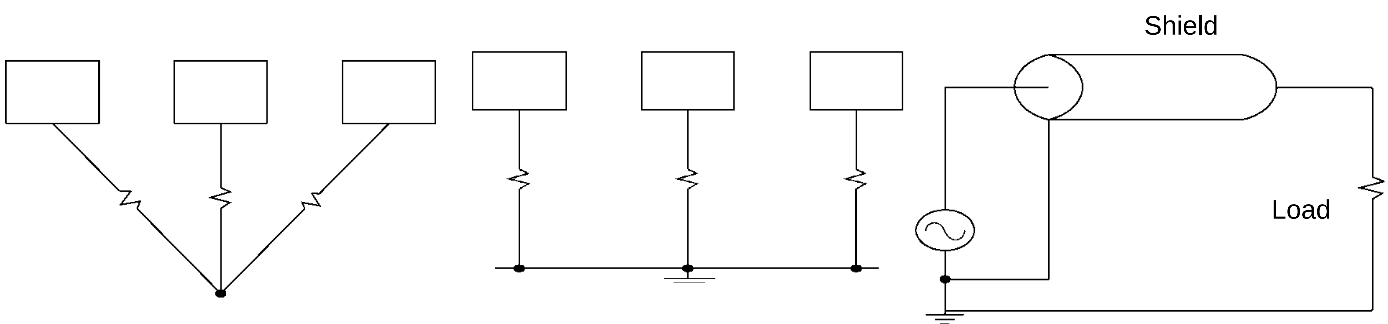
Susceptibility to noise can be dealt with at the design level by taking several precautions. Encoders with TTL outputs should be avoided, and line driver encoders should be used. Similarly, differential input should be used when possible rather than single-ended analog inputs. Finally, digital I/O should be electrically isolated. One further precaution is to use an isolation AC power transformer, even if not required.

Electrical Noise Generation can be handled in a number of ways, and the following precautions should be observed to minimize the possibility of system disturbance:

- avoid creating ground loops in an electronic design
- keep the low level logic wires (encoder wires) separated from the power wires (motor cables). If they need to cross each other, do so at 90 degrees to minimize the effects of magnetic fields
- use twisted pairs whenever possible
- use shields when possible and necessary, and connect one end of any shield to ground
- put surge suppression components on all electric coils (RC filters, diodes, MOV's)
- filter the power line using common RC filters

Having taken these precautions, electric noise should be kept below the system disturbance level.

Grounding of machinery is often done incorrectly. Some applications require that electrostatic discharge on system hardware be kept to a minimum. The correct procedure is to connect a ground wire directly into the ground at the back panel of the controller used. Any other grounding technique may produce a slight mismatch of ground potentials and subsequent noise problems.



Use single point ground for frequencies less than 1 MHz

Use multipoint ground when frequencies are greater than 1 MHz. Note that the ground leads must be kept short, or even more noise could be introduced into the system.

The shield conductor should be connected to the signal reference ground. It should be connected at one point only.

Motor Cable Gauge selection should be made in accordance with standardized wire gauge selection tables. The gauge is determined based on power requirements. If a longer cable is preferred after selections have been made, it is recommended as a rule of thumb to move to a wire of heavier gauge, even if the desired length can handle the current. Quick calculations can be made as follows: Increasing a wire by 3 gauge sizes doubles the amount of copper in the wire and reduces the resistance by half. For example, going from 22 gauge to 19 gauge doubles the amount of copper and halves the resistance.