Drive BASICS

SYSTEMS OVERVIEW

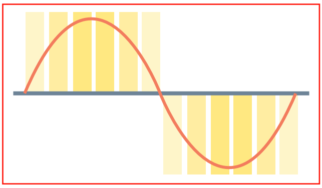
Systems

Concepts

Terminology

GE Industrial Control Systems

PWM pulse width modulated) is a square wave output chopped to approximate an AC sine wave.



SCR (silicon controlled rectifier) is an electronic power device that blocks the passage of current when the voltage across is negative. When the voltage across the SCR is positive, current can pass through it if a small positive signal is applied to its control input, which is called a gate. The SCR can convert AC to DC. Using a control activated when the SCR gate is triggered, the DC amount can also be controlled.

SLD (signal level detector) is a device that compares one signal to another. The SLD outputs the result as a zero if A < B and a one if A > B. The SLD device can be created in either hardware or software. Zero speed is one type of signal generated by an SLD. Speed is compared to a constant, zero (or around zero). The output is a zero when the speed is < zero and one when speed is > zero. SLDs usually have adjustments for taking absolute values of signals, adding time delays, inverting values, etc.

TOC (timed overcurrent) can be used interchangeably with TOL. Some manufacturers use TOL to pertain to motor protection and TOC for drive protection. In this case, it protects the drive bridge from thermal overloads. If the bridge rating exceeds the motor rating, a drive may use either one.

TOL (thermal overload) extended over a long period of time can cause motor overheating, which shortens the motor's life and could cause a fire. Electrical codes require motors to have protection against loads that exceed 100 percent of their rating after a specific time has elapsed.

UL (Underwriters Laboratories) is an independent testing organization for electrical safety.

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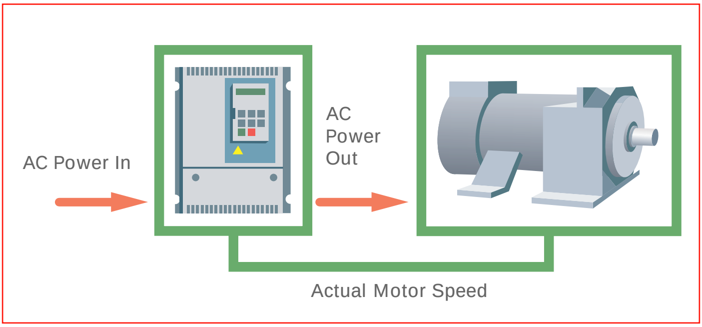
Adjustable Speed Drives

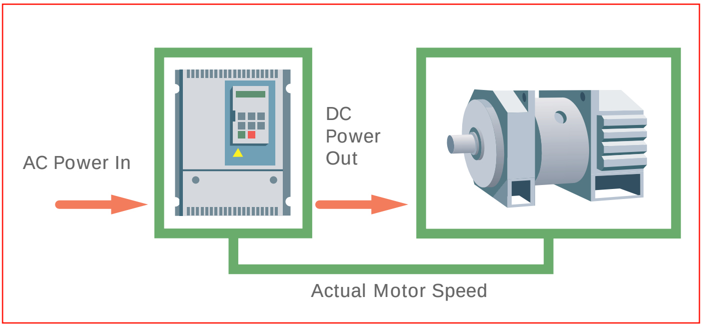
An adjustable speed drive is a packaged device that converts input power into another dynamic power output. This power output is fed directly to a motor in such a manner that it controls the motor's operations precisely. The drive considers such issues as motor load, motor speed, smooth stopping and starting, and, in some cases, the control of the motor shaft position. The drive itself typically includes features that protect the motor and the drive itself from damage, as well as diagnostics.

An inverter is a bridge that converts DC power into AC power or AC power into a controlled form of AC power.



A bridge refers to the power conversion components of a drive.

A converter is a bridge that changes AC power to DC power.



Feedback

In order for a drive to control motor speed precisely, it must receive feedback from the motor indicating its actual speed. This feedback takes the form of a signal from a device mounted on the motor shaft. The device producing the signal is called a tachometer. An analog tachometer on a motor outputs AC or DC voltage depending on speed.

Encoders produce digital feedback about motor speed and other motor shaft characteristics such as position and direction of rotation. An incremental encoder provides feedback as a variable frequency pulse train or in digital word. A sinusoidal encoder produces a frequency-dependent sine wave based on speed. Both incremental encoders and sinusoidal encoders are low-voltage devices with differential quadrature outputs.

PPR - (pulses per revolution) The number of output pulses per turn of the shaft.

Marker Channel (Z) - An output pulse once every full shaft turn.

TERMINOLOGY

Bridge · *A generic term referring to the power conversion components of a drive or device.*

Converter · *A device that changes AC power into DC power.*

Inverter · *A device that converts AC or DC power back into AC power.*

Tachometer · *A device on a motor shaft that generates a motor speed signal, AC or DC, whose output voltage depends on speed.*

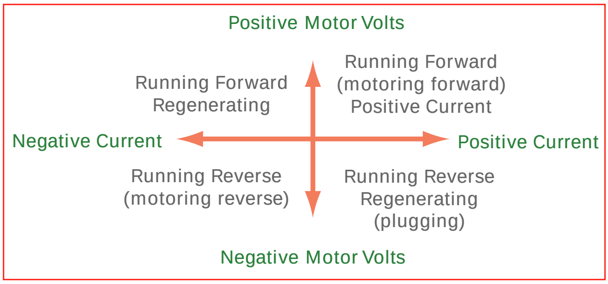
Encoders · *A digital device that can be used to feedback speed (velocity) or shaft position as a variable frequency pulse train or in digital word.*

Differential · *A signal or pulse train referenced to an inverted signal of itself (A,/A) or a common from another device. Using the signal as the difference, the 2 wires improve noise immunity.*

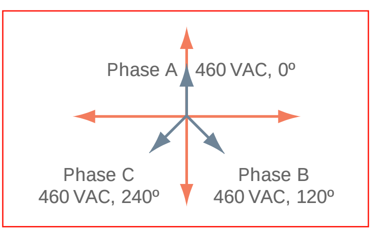
Quadrature · *(A, /A, B, /B) A second pulse train is output 90° out of phase of the first. The control uses this to determine the motor's rotation direction.*

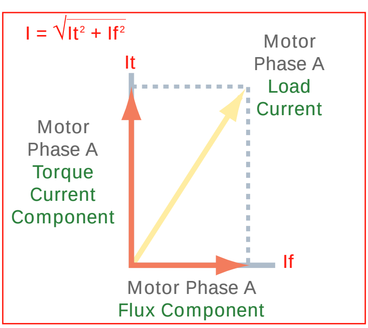
Quadrants

The quadrant describes the electrical operating capability of a drive and motor. In a one quadrant system, the drive can only produce forward current and forward voltage, and the motor can only output positive shaft power and run in one direction. In a four quadrant drive, the control can operate in both positive and negative voltages and currents, and the motor can output both positive and negative (regenerative) shaft power and run in forward and reverse. Regeneration refers to the ability of a motor control to convert motor mechanical power back into electrical power.



Vectors





A vector is a value that expresses both magnitude and direction. A three-phase AC input can be represented by vectors, which rotate at the line frequency, 50 or 60 times a second.

Vector control for AC drives refers to its ability to resolve the motor's output into vector components of flux current and torque current. Flux vector control can regulate both the torque current and the flux components. Torque vector control has a fixed flux and can regulate only the torque current.

Inertia

Inertia is the tendency of a body in motion to stay in motion and resist a rotational change in speed. The effective inertia equals the motor inertia + the gearbox inertia + (the material inertia + the mechanical inertia ÷ the gear ratio^2).

$$J \text{ lb ft}^2 = \frac{\text{coil width} \times \text{density} \times (R^4 - r^4)\,\pi}{2 \times g}$$

J = inertia, also called WK squared
coil width = ft
density = lb/ft^3
R = outside roll radius in ft
r = inside roll diameter in ft
g = gravity = 32.2 ft/sec^2
π = pi = 3.14

Inertia is a critical factor in all processes. A motor, its load, the gearbox, and the process equipment all contribute to inertia. This inertia must be overcome when accelerating or decelerating a motor by applying or subtracting additional increments of power. This process is called compensation.

TERMINOLOGY

Quadrant · *The electrical and mechanical operating capability of a drive and motor.*

Regeneration · *The ability of a control to convert mechanical energy into electrical energy.*

Vector · *A value that has dimensions, or angle, to describe it, more than just magnitude.*

Vector Control · *The ability of the control to resolve the motor's output current into vector components of flux current and torque current.*

Inertia · *The physical property for a body in motion to stay in motion and resist a change in rotational speed. Applied torque is required to change the rotational speed.*

Compensation · *The extra power automatically provided during the acceleration or deceleration of a motor to maintain speed or tension.*

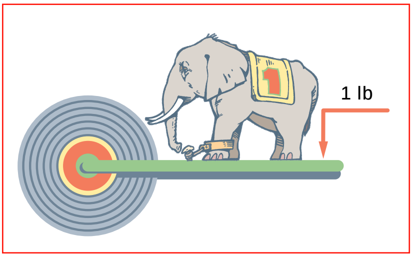
If this extra power is not added or subtracted to overcome inertia, undesirable process transients in speed and tension develop, causing strip breakage or web sagging.

Adjustable speed drives can compensate for inertia automatically. Compensations can be made for friction losses, motor windage losses, material bending losses, air resistance losses, changes in diameter, etc. Since actual losses may be nonlinear, compensation can be in the form of a table or curve based on speed and/or load.

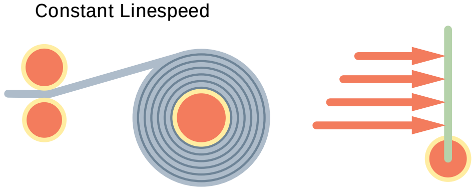
$$t = \frac{\text{inertia (ft lb}^2\text{)} \times \Delta \text{ speed (RPM)}}{308 \times \Delta \text{ time (sec)}} = \text{lbs}$$

Torque and Tension

The rotational force generated at the motor shaft is called torque. Torque is measured at a specified distance (radius) from the motor shaft. For instance, a one-foot lever attached to a shaft with a one-pound weight on it generates one foot-pound of torque at the motor shaft.



Tension is the amount of force on a process material (strip, web, sheet, etc.). It is a function of the motor's output torque and roll diameter. For most material transport devices, roll diameter is a constant. Roll diameter is a variable for a winder. Tension can be expressed in units of lbs., lbs./ft., kg., kg./m., etc.



The torque consumed by accelerating or decelerating the motor and gearbox is subtracted or added to the resultant material tension. If this torque is not compensated for, material stretching, tearing, or breaking can result.

Stall tension is a percentage of running tension that is requested from a drive when a process is stopped. Stall tension keeps wound material from unwinding and in readiness for a restart.

Taper tension is a feature that reduces tension as the material diameter builds, or as motor speed increases.

Tension in a DC motor can be calculated by :

$$F = \frac{CEMF \times Ia\ net \times 33000}{746 \times speed\ in\ FPM}$$

Tension can be equated to motor HP by :

$$HP = \frac{speed\ in\ FPM \times tension\ in\ lbs}{33000}$$

TERMINOLOGY

Torque · *The rotational force generated at the motor shaft. Torque is measured at some distance (radius) from the motor shaft.*

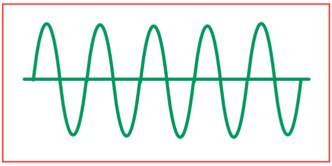
Tension · *The amount of force on a process material (strip, web, sheet, etc.) generated by motor power.*

Stall Tension · *A percentage of running tension that is requested from a drive when a process is stopped. Stall tension keeps material being wound prepared for a restart, and keeps the material from unwinding itself.*

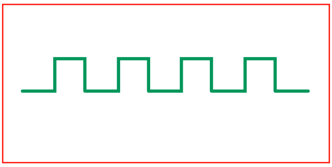
Taper Tension · *A feature that reduces tension as the material diameter builds, or as motor speed increases.*

Analog and Digital Signals

An analog signal is capable of being any value within a finite dynamic range during a given period of time. A common example of an analog signal is sound, a voice speaking, music, etc.



A digital signal is a signal that is either low (no voltage) or high (5 volts), nothing inbetween is valid. The signal can change over time, but only to a 1, high, or 0 (low). Each transition from low to high to low is called a bit. The tones you hear while a computer or fax transmits over telephone lines are a series of bits. The tone heard is the frequency at which the bits are changing.



Digital bits. 0V is "low" or zero.
5 V is a 1 or "high".

Measurements

A joule is an expression of energy in watt seconds. Watts are measured in voltage × amperes.

Metric Conversions

Most electrical parameters are universal and do not require conversion into the metric system. The equations for those that do follow:

Power .746 kw = 1 hp 1 kw = 1.34 hp

Tension/Force 1 lb. = 2.2 kg = 4.448 N

Torque 1 ft lb. = 1.356 N m

N = newton m = meter

TERMINOLOGY

Analog Signal · *A signal that is capable of being any value within a finite dynamic range during a given period of time.*

Digital Signal · *A signal that is either low (no voltage) or high (5 volts), nothing in between is valid.*

Joule· *An expression of energy in watt seconds.*

Watt · *1 watt = 1 volt × 1 amp*

AC and DC Motors

A motor creates a rotational force when a current is circulated through a magnetic field. In a DC motor, the magnetic field, also called the magnetic flux or just flux, is generated by a separate magnetic circuit called the motor field. The magnetic flux is dependent on the core material, the number of windings, and the amps circulated through these windings.

An AC induction motor has only one circuit for both flux- and torque-producing current. The vector summation of flux current and torque current represents total current.

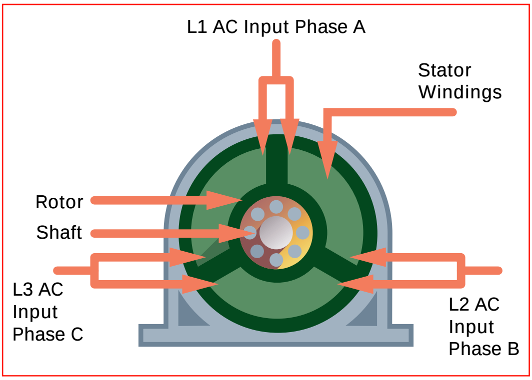
A DC motor runs when DC voltage is supplied to the armature. As it spins, it also generates voltage inside itself like a generator. This internal voltage is called the counter electromotive force or CEMF. CEMF is dependent on the field current (flux) and the motor speed.

The speed of an AC motor depends on its construction. The higher the input frequency, the faster it spins. This is because the input frequency determines the speed of the rotating field inside the motor that is generated by the stator windings. The speed is determined as:

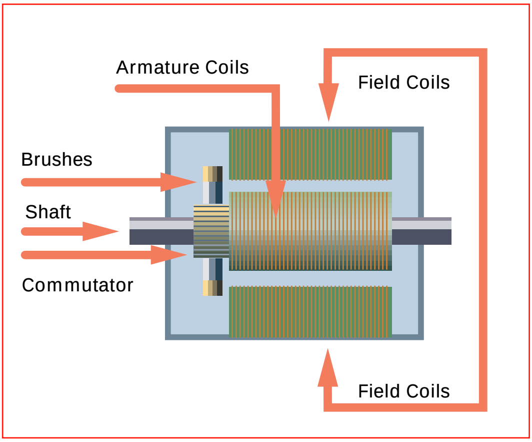
$$\text{synchronous speed} = \frac{120 \times \text{AC frequency}}{\text{number of poles}}$$

When an AC motor has a mechanical load, it is no longer synchronized with the input frequency. The speed difference between no-load speed and full-load speed is called slip. It is expressed as a percentage.

$$\text{Slip} = \frac{\text{synchronous speed - full-load speed} \times 100}{\text{synchronous speed}}$$



Poles are coils symmetrically spaced inside the motor (stator windings).



The armature is made up of the armature coils and commutator mounted on the shaft. Carbon brushes deliver the power to the armature.

TERMINOLOGY

Motor Field · *The group of stationary coils of a DC motor's magnetic circuit that provides the magnetic flux and torque flux to allow torque (and motion) to develop when current is passed through the DC motor's armature.*

Magnetic Flux · *The stator is the group of stationary coils of an AC induction motor's magnetic circuit that provides the magnetic flux and torque flux to allow torque (and motion) to develop at the rotor.*

Counter Electromotive Force (CEMF) · *The internal voltage of a DC motor generated as it spins, like a generator.*

Slip · *The ratio of speed difference between no load speed and full load speed to no load speed in an AC induction motor.*

Armature · *The rotating part of a DC motor.*

Rotor · *The rotating part of the AC induction motor.*

The DC motor terminal voltage is represented by:

Volts = load × motor resistance + CEMF + volts lost across the carbon brushes

Load is the percentage of a drive/motor system's rated current or amperage capacity in use at any given time. Full load means 100 percent of rated capacity. During overload, the capacity of the drive/motor system is exceeded. Many drive/motor systems can operate at more than 100 percent load for a short period of time. Motors are protected from prolonged overload conditions by thermal relays or by built-in features of the drives. Typical overloads include acceleration power or impact process loads.

Efficiency refers to the ratio of electrical input power to mechanical output power.

In a typical operation, short periods of overloads are usually followed by extended periods of lighter loads. The ability of a drive/motor system to accommodate these variations is called its duty cycle. The duty cycle provides a more realistic measurement of a drive/motor system's capability to handle overloads during routine use than a measurement focusing only on its overload capacity.

Motor Ratings

Volts/hertz (V/hz) is used to describe AC motor control by frequency. The drive's output frequency is related to the desired top speed. At no load, the motor is locked into this speed. At speeds below top speed, the voltage and frequency are lowered proportionately. As the load requirements of the motor increases, it will slow to its slip frequency speed at full rated load. To provide better open loop speed regulation, slip compensation is used. The speed reference is increased as the motor load increases, based on the percentage of slip. Dual speed motor rated DC motors are nameplated as follows:

RPM:
1750 (base speed) / 2300 (top speed)

Field Amps:
5.0 (base field amps) / 4.0 (top speed amps)

Top speed amps are also called weak field amps.

For example:
The motor operates at base field (flux) amps when the motor delivers rated horsepower at its rated motor voltage at base speed. Once the top motor voltage is reached, the motor can run at its top speed by maintaining rated output volts and then lowering field amps.

Once a motor reaches maximum voltage, the output power does not increase if its field (flux) is weakened to achieve higher speeds. The output torque is directly reduced as a function of the reduction of flux. This is referred to as operation in the weak field range or in the constant horsepower range. The point where maximum voltage is reached and the field (flux) starts to weaken is called the crossover.

TERMINOLOGY

Motor Terminal Volts · *The volts directly applied to the motor terminals.*

Load · *The percentage of current or amperage a motor/drive is using while running. Full load means 100% of rated capacity.*

Efficiency · *The ratio of electrical input power to mechanical output power.*

Duty Cycle · *The effect of short time overloads intermixed with lighter load periods for a load profile that can allow the drive and motor to operate the overloads without overheating.*

Base Field (Flux) Amps · *The field current where the motor delivers rated horsepower at its rated motor voltage at base speed.*

Weak Field (Flux) Amps · *The field current where the motor delivers rated horsepower at its rated motor voltage at top speed.*

Constant Horsepower Range · *A method used to achieve higher motor speed at maximum volts by weakening the motor's field (flux).*

Crossover · *The point at which maximum motor volts are reached and the field (flux) starts to weaken in order to achieve higher motor speed.*

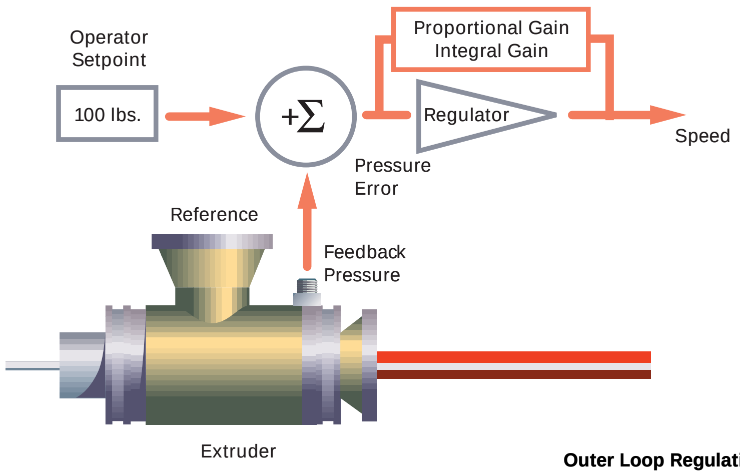
Regulation Basics

A regulator operates by observing the difference between a target setpoint and the feedback (a measurement taken of actual operating conditions). This difference is called the error. If there is no difference, the error = 0 and the regulator is satisfied and does nothing. If an error exists, then the regulator output will change until again the error = 0. These adjustments to provide proper regulator corrections are called gains. Setting these gains properly is known as tuning. In a real system, the regulators constantly adjust their output.

(Setpoint - Feedback) × Gain = Regulation Correction

There are several kinds of regulators. A current regulator controls the load of a motor.

A speed regulator controls the motor's speed. A speed regulator connected to a tachometer is an example of a closed loop control, because the tachometer provides a direct indication of the actual speed. A closed loop pressure regulator uses a pressure transducer that converts actual pressure to an electric signal.



Outer Loop Regulation

A speed regulator using a calculated or approximated value for speed feedback is an example of an open loop control. Open loop control is used when high precision is not required. Often the variable to be controlled does not have a feedback device or even a regulator. Its state is approximated by motor volts (as in the case of a speed regulator) or by current. A tension control running open loop refers to setting the current reference to a level corresponding to the desired tension.

TERMINOLOGY

Regulator · *A device used to maintain a setpoint by comparing the setpoint to feedback (a measurement of the actual operating condition) and adjusting its output so that the difference between the setpoint and the feedback is zero.*

Error · *The difference between a setpoint and feedback.*

Gains · *The adjustments made by a regulator to properly change its output in accordance with the amount of error correction needed.*

Tuning · *The process of setting regulator gains to provide the proper error correction.*

Integral Gain · *The timing adjustment and memory of the regulator. The integral gain keeps the regulator adjusting to maintain a "zero" error.*

Proportional Gain · *The amplification multiplier of the error that provides good regulator correction.*

Current Regulator · *A device which controls the load of the motor.*

Speed Regulator · *A device which controls the speed of the motor.*

Open Loop Control · *A process variable to be controlled that does not have a regulator, or a feedback device, and therefore its state is approximated by motor volts or current, standard to a motor control.*

An outer loop regulator can be used with a dancer or load cell or to regulate pressure, flow, or practically any process variable that is dependent on motor speed, position, or torque. The outer loop regulator adjusts the speed or torque of the motor in addition to other speed and current control inputs. In general, it is slower than a speed or current regulator.

Bandwidth

In many forms of regulation, regulator response speed is critical. Bandwidth is the performance measure of a regulator. The higher the bandwidth, the faster the regulator can correct a deviation from the setpoint or a change in setpoint. Drives can be tuned to a specified maximum bandwidth, although tuning the drive to its maximum bandwidth may stress mechanical equipment or overpower the process or processed material. In a precisely tuned coordinated line, all the drive responses are tuned to the same appropriate bandwidth.

Bandwidth can be specified in hertz and radians:

Hz = cycles/sec where 2π radians = 1 cycle

A specified 30 hz bandwidth is not the same as a 60π radian response. The measurement techniques differ:

Response in radians/sec = π/time to peak value of a 1% step
Response in Hz = 3/response time, where response is measured from 0 to the step value

The higher the bandwidth, the higher the potential response time.

Compensation

Inertia is a critical factor in all processes. A motor, its load, the gearbox, and the process equipment all contribute to inertia. This inertia must be overcome when accelerating or decelerating a motor by applying or subtracting additional increments of power. This process is called compensation. If this extra power is not added or subtracted to overcome inertia, the undesirable process transients in speed and tension develop, causing strip breakage or web sagging.

TERMINOLOGY

Outer Loop Regulator · *A regulator used for a process variable that is dependent on the motor speed, position, or torque. The outer loop regulator adjusts the speed or torque of the motor in addition to other speed and current control inputs.*

Bandwidth · *A performance measurement of a regulator. The higher the bandwidth, the faster the regulator can respond to correct a deviation from a setpoint or a change in the setpoint.*

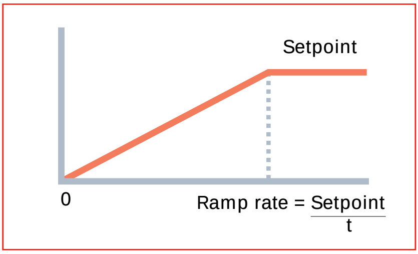
Compensation · *Extra power automatically provided during the acceleration or deceleration of a motor to maintain speed or tension*

Speed Referencing Techniques

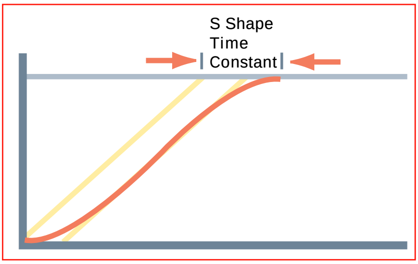
Speed referencing refers to achieving a desired speed setpoint. A jog is a brief speed regulation command sent to the drive/motor system, sometimes several times in close succession, to move the system to a certain position.

A step involves an abrupt change in the setpoint, a change that can place large mechanical stresses on equipment. A smoother process of attaining a setpoint is to use a ramp. For instance, if a speed reference is set to top speed, a ramp is used to make this acceleration smooth and easy. A ramp smoothly increments a setpoint from zero to the desired level.

There are two basic kinds of ramps: a linear ramp and an s-curve ramp. A linear ramp is a straight line from zero to the setpoint. The timing is set as the setpoint value/time taken from zero to the setpoint.

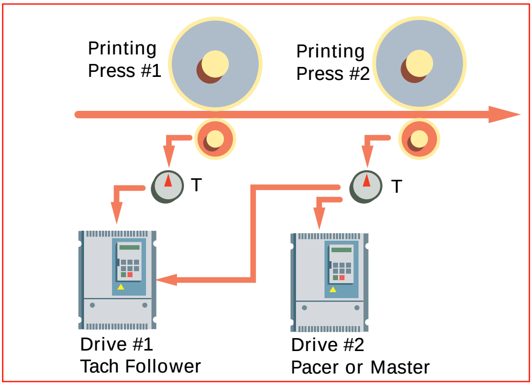


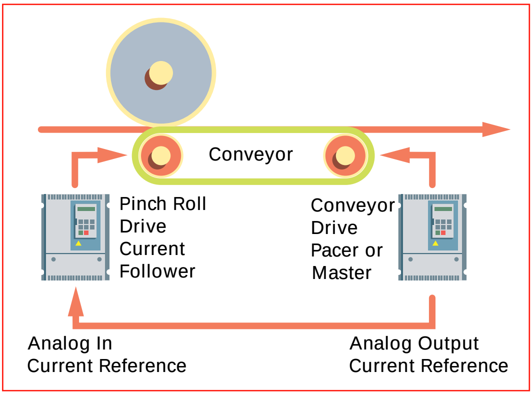
Even with a typical speed regulation of 0.1 percent, the speed transitions near zero and the setpoint using a linear ramp can be stressful for process and machinery. To soften the transition areas of the linear time, s curves are added immediately after zero and before the setpoint. The total ramp time in this case is the linear portion + the curved portion of the ramp.



Followers

A follower is a drive/motor system designed to run at the same speed as another motor or to run at the same load as another drive/motor system. A follower control is usually very simple. The tach or current reference of the motor to be followed is simply fed to the follower drive from the master roll or drive.





Speed Referencing · *Refers to achieving the desired speed to be regulated.*

Jog · *An operation where a speed regulated command to the drive/ motor is executed for a short time, sometimes many times in short succession for some type of operator manual operation.*

Step · *An abrupt change in setpoint.*

Ramp · *A smooth transition to a new setpoint from a previous setpoint.*

Linear Ramp · *A straight line transition from zero (or initial setpoint) to the new setpoint.*

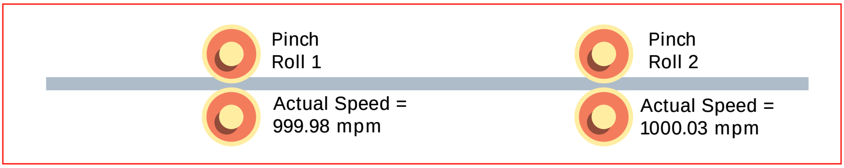
S-Curve Ramp · *A ramp with a curved portion at the beginning and end which softens its transition to the final setpoint.*

Follower · *A term for a drive/motor whose purpose is to run at the same speed or load as another motor or to track another process device.*

SPEED REFERENCING

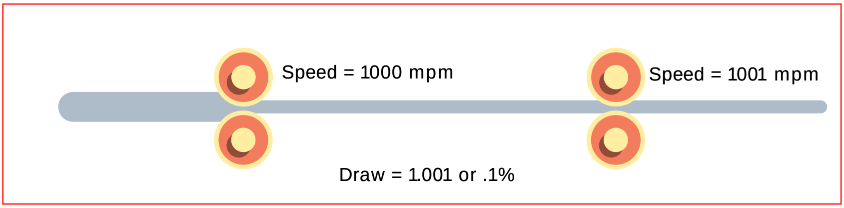
Complications can occur when a transported material, like sheet metal, is unyielding and the two motors have a good grip on the material. Because their speed calibrations can never be set exactly the same, they fight with each other and both motors may overload. This situation is corrected by adding droop. Droop takes a fraction multiplier of the actual motor load and subtracts it from the speed reference to slow the follower down slightly.

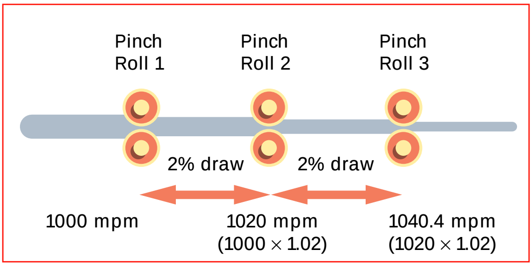
Pinch roll 1 will regenerate into current limit to regulate 999.98 mpm. Pinch roll 2 will motor into current limit to try and regulate 1,000.003 mpm. Adding droop to the speed reference will automatically slow down pinch roll 2, providing better cooperation and load sharing between the two rolls.



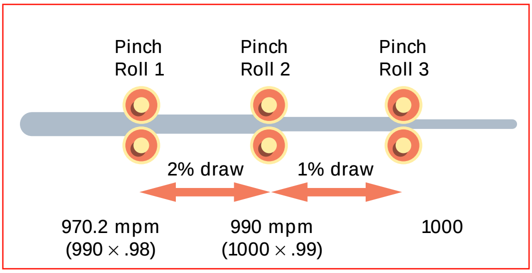
Elongation

Elongation is the process of stretching or lengthening of a material. This can be accomplished by intentionally setting two speed-regulated motors at different speeds to stretch material between two transport rolls. The difference in their speeds, expressed as a percent, is called a draw.





Progressive draw is used in coordinated systems involving several motors. Elongation is achieved by speeding up motors. The same draw is used to set the speed of a pinch roll in relation to the previous one in line. As a result, successive motors in a progressive draw system move slightly faster than the one before.



In regressive draw, rolls are slowed down to produce draw, rather than speeded up. A pacer roll is used as a reference point and regressive draw is applied to each roll down the process toward its beginning. As a result, each successive roll counting back from the pacer roll moves slightly slower than the one that follows it.

TERMINOLOGY

Droop · *Subtracts an adjustable setting times the actual motor load from the speed reference to slow the motor slightly in case of an overload condition.*

Elongation · *A process term for the stretching or lengthening of material.*

Draw · *A process of intentionally setting two speed regulated motors at different speeds to achieve some elongation, stretching or relaxation of material between two transport rolls.*

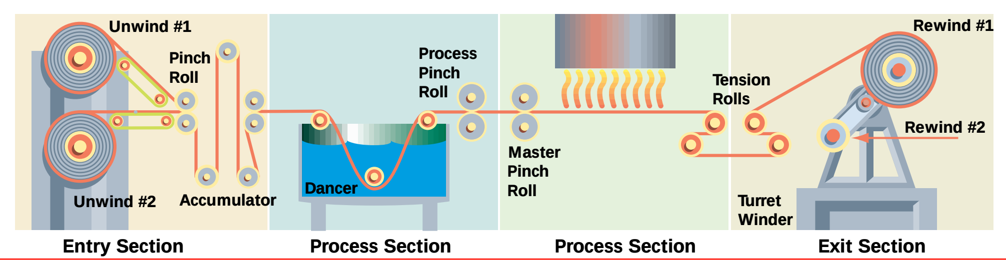
Progressive Draw · *The propagation of draw upstream of the process to maintain system coordination.*

Regressive Draw · *The propagation of draw downstream of the process to maintain system coordination.*

Coordinated Systems Basics

In drive systems, coordination is the operation of all individual drives and the overall control so that the process machine functions as a single entity. This means that all drives and devices must stop and start together, accelerate and decelerate together, and compensate for process variations similarly and smoothly.

A process can be divided into several zones. For instance, an extruder often has several heating zones. Each zone can have different temperatures and different heat capabilities. A single zone process line starts and stops together completely as a unit. A three-zone process line consists of an entry zone, a process zone, and an exit zone. The entry and exit zones can function independently of the process zone when required, but they usually operate synchronously with the process zone. A continuous three-zone process line has a process zone that is rarely stopped.



The material speed in a coordinated process is called the linespeed. Usually all transport devices run at linespeed and accelerate to this speed together, even though their actual rpms and gearboxes are different. A pacer, or master, is the driven roll that sets the linespeed for the process in a coordinated system.

E-stop stands for emergency stop. The nature of an emergency stop can vary from industry to industry and even from customer to customer. An E-stop can mean stopping everything by whatever means as quickly as possible. In some industries, it may mean letting all rotating equipment naturally coast to a stop. In others, it means using dynamic DC braking in a specified amount of time, or unconditionally stopping the rotating load over a specific distance using electrical and mechanical brakes.

Scan Time

An important issue in coordinating real-time control of a system is scan time. It is the measure of time it takes for a digital device to read inputs, execute a program, and update outputs. For example, consider the situation when someone pushes a button connected to an I/O module on a fieldbus connected to a PLC and a motor starter. The scan time of the fieldbus is 200 milliseconds, and the scan time of the PLC is 100 milliseconds. It takes 200 ms for the signal from the button to reach the PLC, 100 ms for the PLC to react, and another 200 ms for the signal to reach the starter motor from the PLC, for a total

TERMINOLOGY

Coordination · *The synchronous and harmonious operation of multiple drives to appear as a single machine.*

Zone · *A section of a process.*

Single Zone Process Line · *A line which completely starts and stops together as a unit.*

Three Zone Process Line · *A line which consists of 3 zones: an entry zone, a process zone, and an exit zone. The entry and exit zones work independent of the process zone when required, and operate synchronously with the process zone.*

Linespeed · *The material speed of a coordinated process.*

Pacer · *The drive/motor in a zone that sets the actual linespeed.*

E Stop · *An emergency stop which is dependent on customer standards, applicable industrial codes, and use.*

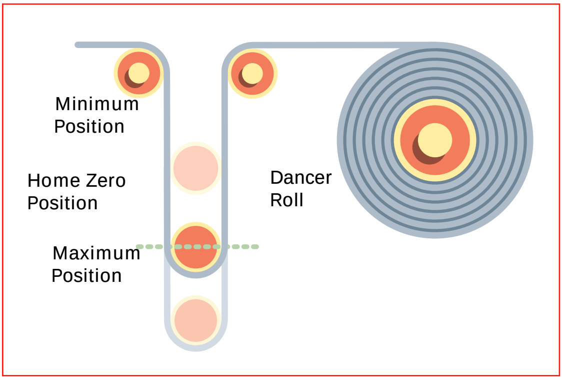
Scan Time · *A measure of time for a digital device to complete one cycle of reading its inputs, executing a program, and then updating the outputs.*

of 500 ms. A system can respond to an operator control or automatic adjustment quickly only if the intervening digital devices have a relatively short scan time.

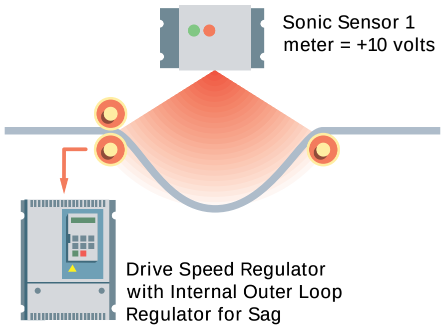
Compensations automatically adjust for extra motor power required for overcoming motor and load inertia with speed changes, friction losses, and a variety of process inefficiencies that cause speed or tension variations. Outer loop refers to a generic regulator that can be used for a dancer, load cell, pressure regulation, flow regulation, etc. or most any process variable that is dependent on the motor speed, position, or torque. The outer loop regulator adjusts the speed or torque of the motor in addition to other speed and current control inputs. It is in general slow as compared to a speed or current regulator.

Dancers

A simple system arrangement used to maintain linespeed along a system and provide rudimentary tension control is with a dancer. A dancer is a mechanical roll or wheel that rides on a material, moving up and down while the roll builds. Feedback on the dancer position is fed into a regulator that automatically adjusts the winder speed reference to maintain the dancer at its home position.



Weighting or loading the dancer provides a way to change the tension setting. In this example, the winder is running as a speed regulator. Adding dancer weight increases tension and will produce increased motor load. The weight applied will be diameter dependent. This configuration operates similarly with a roll that doesn't wind.



When used in a coordinated system, the dancer regulator correction is usually fed to all other drives to maintain coordination of speed references. This is usually accomplished using an outer loop.

Load Cells

Another device used to allow regulation of process tension is a load cell. A load cell is a device that measures force and converts it to an electrical signal. The measured force is also a measure of tension. The signal if fed to a PID controller or directly to a drive.

TERMINOLOGY

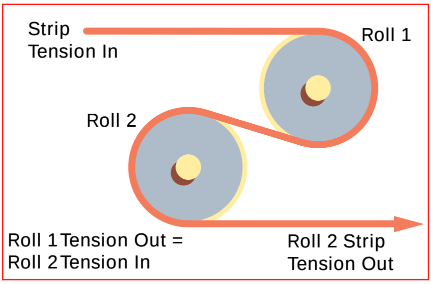
Dancer · *A dancer is a mechanical roll that rides on the process material. The position of the dancer roll is converted to an electrical signal to provide information on the dancer's relative location.*

Load Cell · *A device that measures process force and converts it to an electrical signal. The measured force is also a measure of tension.*

COORDINATED SYSTEMS

Bridles

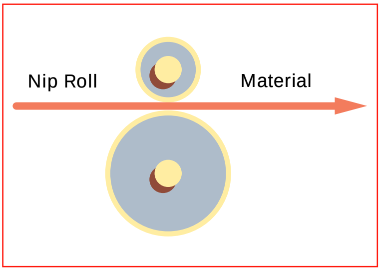
A bridle is an arrangement of between two to four rolls used to provide tension amplification or tension isolation in a process system.



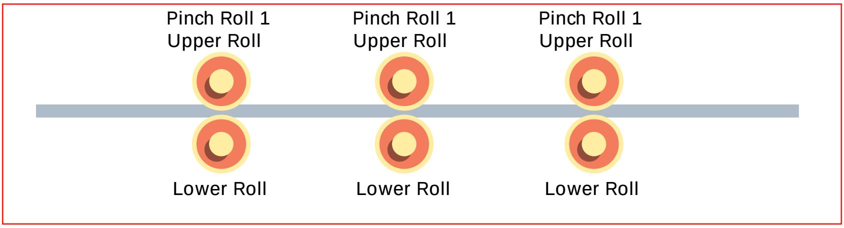
Tension out = Tension in $\times$ e^{fa}
f = coefficient of friction
a = wrap angle in radians

Nip Rolls and Pinch Rolls

Both nip and pinch rolls are rolls that press against another roll, belt, or conveyor to help transport material and keep it in place. They are usually current regulators or speed regulators with droop, since the belt, conveyor, or work roll typically has the motor power needed to convey the material.



Pinch rolls are sometimes used in pairs. In this case, one roll functions as a speed regulator and the corresponding roll acts as a current regulator or speed regulator with droop. In a coordinated system where the material is not yielding, only one pinch roll acts as a speed regulator, called the pacer.



A mandrel is a cylinder some winders use to wind on, instead of a core or tube.

A follower is a roll whose speed or load is set to by another drive or roll.

TERMINOLOGY

Bridle · *An arrangement of 2 to 4 rolls in a process system that are used to provide tension amplification and or tension isolation.*

Nip Roll · *A roll that presses against another roll, belt, or conveyor to help transport material and keep it in place.*

Pinch Roll · *A roll that presses against another roll, belt, or conveyor to help transport material and keep it in place.*

Chokes, Reactors, and Inductors

A choke is another name for a reactor or inductor. It is a magnetic device usually built of coils of wire wrapped around a magnetic core. Its impedance (AC resistance) to AC power increases with frequency according to the equation $\mathbf{Z = L \times 2 \times \pi \times f}$ (where Z stands for impedance, L for inductance, and f for frequency).

A choke is used in series with drives to filter out high frequencies generated by the drive from reaching the power system. They are also used to limit the amount of transient power that is delivered to the drive. Transistors, SCRs, and insulation systems can fail when the current and voltage rates change too rapidly, as well as when they are exposed to excessive current or voltage. Chokes, reactors, and inductors limit the rate of change of these transients and restrict the available fault current.

Harmonics

Harmonics are multiples of a base frequency in an electrical signal. A DC drive uses SCRs to divide the AC input power into DC. In the process, high-frequency harmonics are generated. Because the reactors and inductors that coexist in the AC power system and in the drive itself are frequency dependent, harmonics can cause them to overheat and fail. Harmonics can cause stress and failure by increasing voltage and current rates of change.

Grounding

Grounding is the proper referencing of electrical power to the earth. Improper grounding can cause ground loops, which can be very destructive. In a ground loop, two points of power referenced to the ground are not the same.

The resistance to ground between the power is very small. Even one volt difference in grounds can cause a great deal of leakage amps to circulate through the motor bearings and ground conductors, burning out equipment. This one volt difference can also cause a 10 volt analog signal to be off by 10 percent in this example.

In addition, improper grounding can allow noise to enter the power supplies and the common bus, throwing off the accuracy of low level control signals and even causing digital controls to make errors.

Suppression

Suppression is the practice of adding MOVs or resistors and capacitors around a solenoid, AC coil, starter or contactor coil, relay coil, etc. to clip or reduce electrical noise generated by these devices when turned off. Coils are inductive and generate a large voltage spike when turned off by other relay contacts. The voltage spikes can cause electrical noise that interfere with the operation of high-frequency digital electronics.

TERMINOLOGY

Choke · *A device used in series with drives to filter out high frequencies generated by the drive to the power system, and to also limit the amount of transient power that is delivered to the drive.*

Harmonics · *Multiple frequencies of a base frequency existing in an electrical signal.*

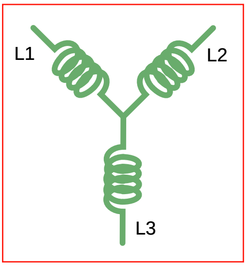
Grounding · *The proper referencing of electrical power to the earth.*

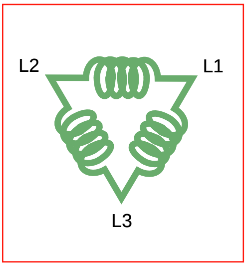
Suppression · *A term used for adding electrical devices to a solenoid, AC coil, starter or contactor coil, relay coil, etc. to clip or reduce the electrical noise generated by these devices when turned off.*

Isolation Transformers

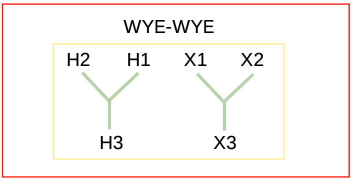
An isolation transformer serves a similar purpose as a choke or reactor, with the added capability to increase or decrease output voltage. Multiple transformers in a drive system can be selected to cancel out the harmonics that solid state switching generates.

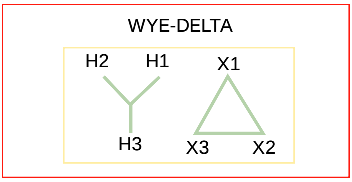
Three-phase transformers have the same input voltage per phase, but each input is out of phase with the rest by 120 degrees. A wye configuration results when the transformer input (or output) is arranged so that one side of each phase is referenced to a common point. A delta configuration results when each phase coil of a transformer is referenced to another coil in the transformer.

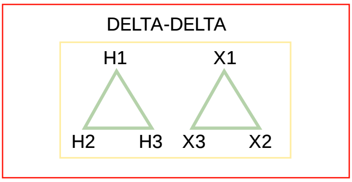


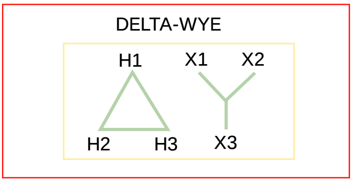


When transformer combinations are described, the first term refers to the transformer primary and the second to the transformer secondary.









Isolation Transformer · *Filters out high frequencies generated by the drive to the power system, and limits the amount of transient power that is delivered to the drive. Multiple transformers in a drive system can be selected to cancel out harmonics that solid state switching generates.*

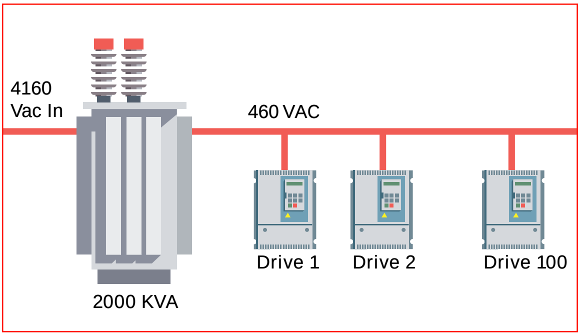
Three Phase Transformer · *A transformer that operates with 3 phase power. A missing power phase results in transformer failure unless properly protected.*

Delta Configuration · *A transformer arrangement in which each phase coil wire is referenced to another transformer coil on the same input or output side of the transformer.*

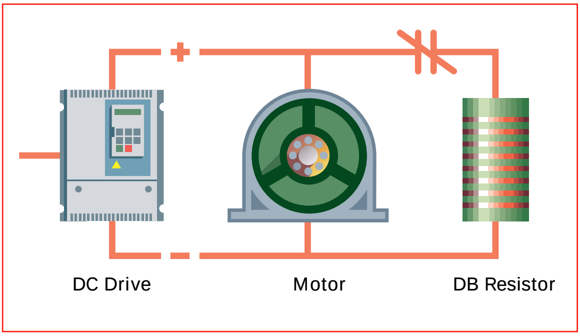
Wye Configuration · *A transformer arrangement in which each phase coil is referenced on one side to a common point.*

DC Drives

Sometimes power can be distributed to drives through a common bus. For DC drives, the common bus (also called common transformer) refers to the use of a single large transformer to supply AC power to many drives.



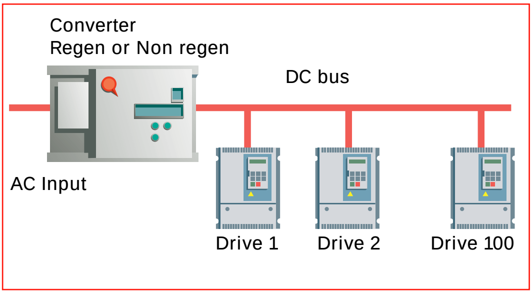
In DC motor control, dynamic braking refers to a technique used to stop a DC motor. When a stop or emergency stop is activated, the drive output is abruptly shut off and a resistor is inserted across the DC motor terminals. The motor CEMF acts like a generator, converting the rotating mechanical energy to electrical energy, which is quickly dissipated into the resistor.



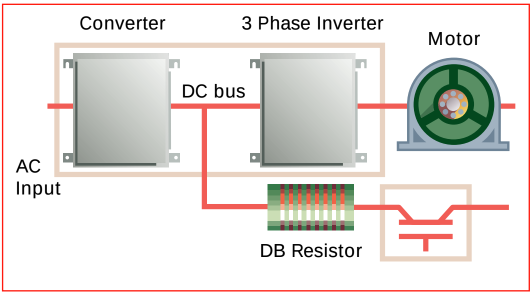
AC Drives

AC drives can be fed DC power from a common bus (usually a common DC bus). Economies can sometimes be achieved when a single converter converts AC to DC and the DC is fed to a number of AC drives. The common DC bus is efficient because it supplies only the net power used by the process.

Any regenerative power being generated by the motors lessens the amount of external power needed.



Dynamic braking for an AC drive occurs when the motor acts like a generator during deceleration or while holding a load back. The mechanical energy is converted to electrical energy and dissipated into the resistor. The AC drive converts the generated AC power to DC, and the dynamic braking resistor dissipates the power to keep the DC link voltage from becoming too high. The dynamic braking solution is simpler to implement than the DC common bus, but can waste power in the resistor.



TERMINOLOGY

Common Bus · *(DC drives) Also called a common transformer, refers to the use of a single large transformer to supply AC power to many drives.*

Dynamic Braking· *In DC motor control, a resistor is inserted across the DC motor terminals. The motor CEMF acts like a generator and the rotating mechanical energy is converted into electrical energy and quickly dissipated into the resistor.*

Common Bus · *(AC drives) Usually when a common bus is referred to in discussions of AC drives, the meaning is a common DC bus. Economies can sometimes be seen, if a single converter converts AC to DC, and the DC is fed to a number of AC drives. The common DC bus is efficient in that the DC bus only supplies the net power used by the process.*

ACRONYMS

CE is the mark of compliance with the European Community standards for such issues as noise emission, reaction to voltage transients, component ratings and protection, and overloads.

CEMF is the counter electromotive force. DC motor runs when DC voltage is supplied to the armature. As it spins it also generates a voltage inside itself just like a generator. This internal voltage is the CEMF. It is dependent on the field current (flux) and the motor speed. The motor terminal volts is represented by Volts = load x motor resistance + CEMF =volts lost across the carbon brushes.

CPT (control power transformer) is a general term for a step-down transformer that supplies 115 VAC or 230 VAC for relays, fans, PLCs, and other low-voltage power supplies from a higher voltage power feed.

CSA (The Canadian Standards Association) establishes electrical code standards in Canada and in portions of the United States.

FLA (full load amps) is a rating found on AC motor nameplates to specify the rated amps.

IEC is a European standard for the rating and derating of electrical devices.

IOC (instantaneous overcurrent) is a type of motor protection. It can be accomplished either electrically or with fuses.

IGBT (insulated gate bipolar transistor) is commonly used for AC drives. Injecting a very small electrical signal into the gate of the transistor causes it to turn on quickly. It is popular for AC drives because the gate can be driven directly by electronics very quickly.

LAN (local area network) is also known as a fieldbus. It consists of a two-wire (or optical) serial communications lines. Each device on the network has a unique address, so it can recognize network information sent to it. LANs generally require a master to coordinate the communications exchange.

LCD (liquid crystal diode) are popular for key pad displays because they require very little power. LCDs are sandwiched between plates of glass. The LCD is transparent until a small DC current is applied, causing the crystals to line up and the LCD to become opaque.

NEC (National Electric Code)

NEMA (National Electrical Manufacturers Association) is a standards group.

PID (proportional, integral, and differential) is a regulator.

PLI (pounds per linear inch) is an expression of tension in some industries.

PPR (pulses per revolution) is a measurement used for digital tachometers, also known as incremental encoders.