High Performance Drive Systems

Herein will be examined the high performance drive and how it functions in a complete system. Topics included are:

1.) Definition
2.) Description
3.) Application objective
4.) Application fundamentals
5.) Application examples
6.) Closed loop regulator fundamentals
7.) Closed loop regulator examples

Definition

What is a high performance drive system?

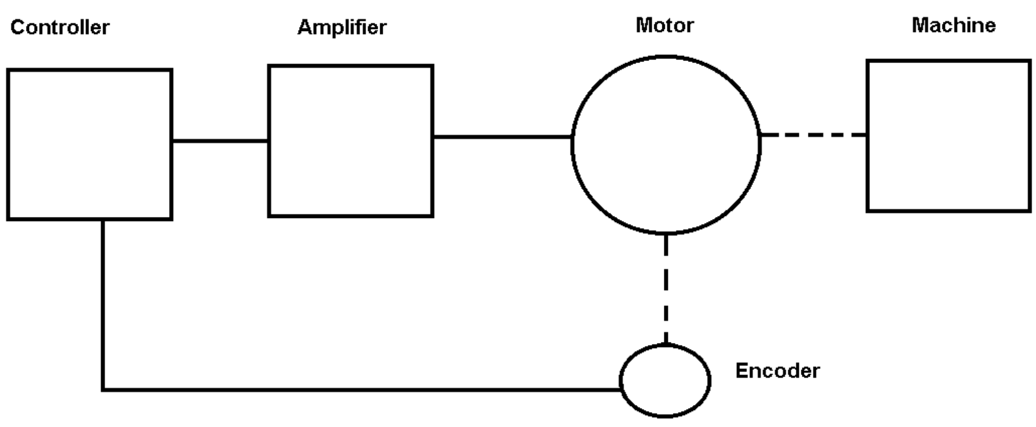
A rotary or linear motion positioning system that has:

1.) Precise speed regulation (0.1% or better)
2.) Full torque from zero speed to base speed and constant horsepower from base speed to max speed for systems that operate in a constant horsepower range.
3.) High dynamic performance

Description

A system is typically comprised of:

1.) Controller (CNC or PC)
2.) Amplifier
3.) Motor
4.) Position transducer (encoder or resolver) if position control is desired.
5.) Machine

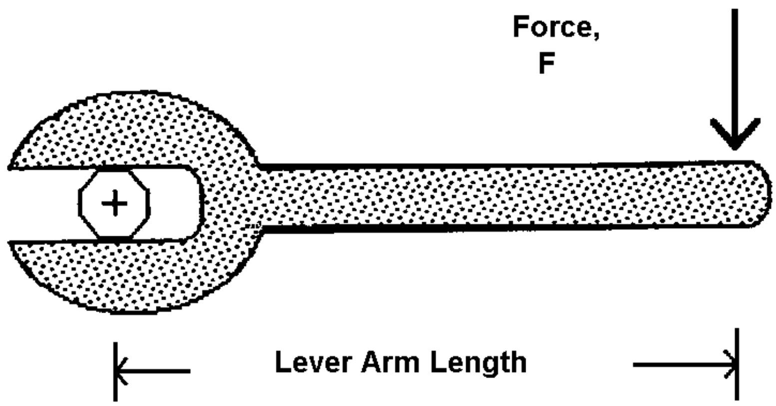


Application objective

The objective of a drive system is to control the motion (position and/or velocity) of a machine. This motion can be linear (straight line) or rotary (turning). The drive system accomplishes this by controlling the torque output to the machine.

Application fundamentals

Torque can be described as a turning effort that must be applied to an object in order to move it. Torque is the product of force x lever arm length and is measured in in-lb or ft-lb.



$$T = F \times R$$
$$(lb_f \times in);\ (lb_f)\ (in)$$

note: Clockwise and counter clockwise efforts are distinguished by difference in sign, **+** or **-**

As implied earlier, the effect of a torque on an object which is free to rotate is to cause a change in the objects rotational motion; specifically to cause a rotational acceleration. Rotational acceleration can be described as a change in rotational velocity per unit time. For example; If an object is rotating at 500 rpm and speeds up to 1000 rpm in 1 minute, it has accelerated at a rate of 500 rpm/min or 500 rev/min^2. The quantity of torque required to cause a specific rotational acceleration is determined by the amount of resistance the object has to a change in motion. This resistance is described as inertia. An objects rotational inertia depends on how much material constitutes the object and also, to an even greater extent, on the location of the material relative to the rotational axis. Specifically, for an object which is localized in space, its rotational inertia (J) depends on the mass (M) of the object and the square of the distance (R) of the object from the rotational axis. In symbols:

$$J = M \quad R^2$$
$$(in\text{-}lb\text{-}sec^2);\ \left(\frac{lb\text{-}sec^2}{in}\right)\ (in^2)$$

The relationship between torque, inertia and acceleration is:

Torque = Inertia x Acceleration
$T = J \times \alpha$

Where:

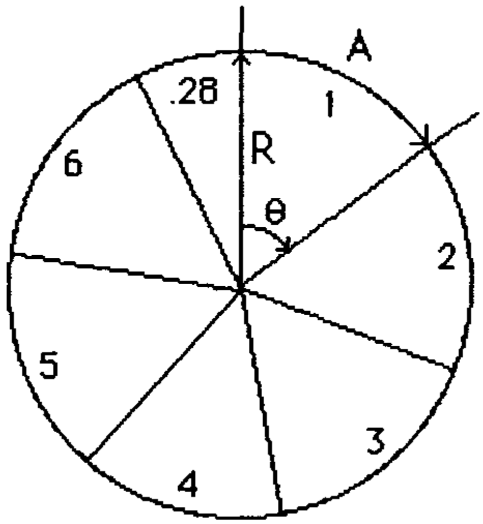
Torque = T (in-lb)
Inertia = J (in-lb-sec^2)

Acceleration = α (rad)/sec^2

We have introduced another new term; rad (radian) The term radian is used to describe angular measure. An angle measured in radians is a <u>ratio of radius to arc length</u>.
ex. if arc length = 6 in. and radius = 3 in. then: angle = 6 in./3 in. = 2 radians.

Notice the units of inches drops out. This shows why radian is dimensionless.

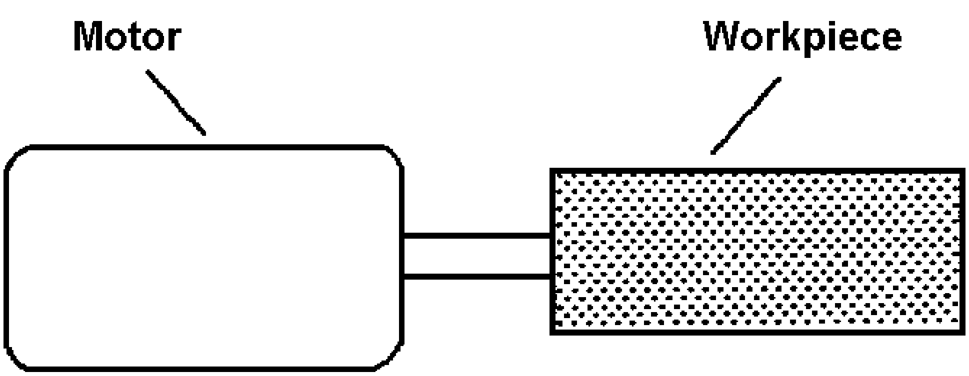
Angle θ (theta) = 1 radian
when R radius = A (arc)



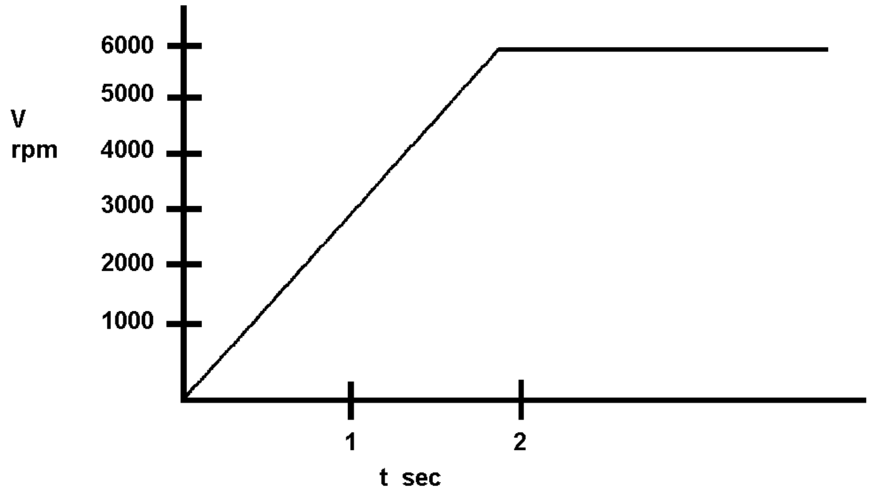
For any circle; the circumference is equal to 2π x its radius.

<u>Application examples</u>

Lets consider an example of a high performance drive system used to rotate a work piece on a lathe.



The work piece on the spindle is to be accelerated from 0-6000 rpm in 2 sec. The total system inertia is 0.5 in-lb-sec^2.
What is the torque required to accomplish this task?



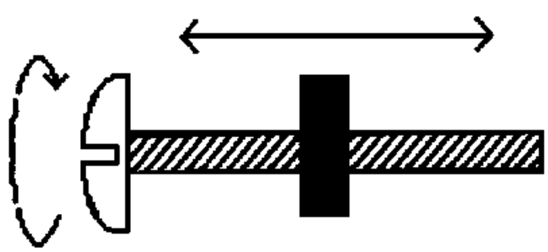
Recall:

$$T = J\alpha$$

$$\alpha = \frac{\frac{6000 \text{ rev}}{\text{min}}}{2 \text{ sec}} = \frac{6000 \text{ rev}}{(2 \text{ sec})(\text{min})} \frac{(2\pi \text{ rad})}{\text{rev}} \frac{(\text{ min })}{60 \text{ sec}} = 314 \frac{\text{rad}}{\text{sec}^2}$$

$$T = (0.5 \text{ in-lb-sec}^2)\left(314 \frac{\text{rad}}{\text{sec}^2} \right) = 157 \text{ in-lb}$$

Up to now we have been discussing rotary motion and we said that we can control linear motion as well. Usually to get linear motion we need to convert rotary motion into linear motion. This can be done a number of different ways One example would be to use a ballscrew or leadscrew. A ballscrew is analogous to a nut on a screw. As the screw is rotated, clockwise or counter clockwise, the nut moves back and forth on the screw.



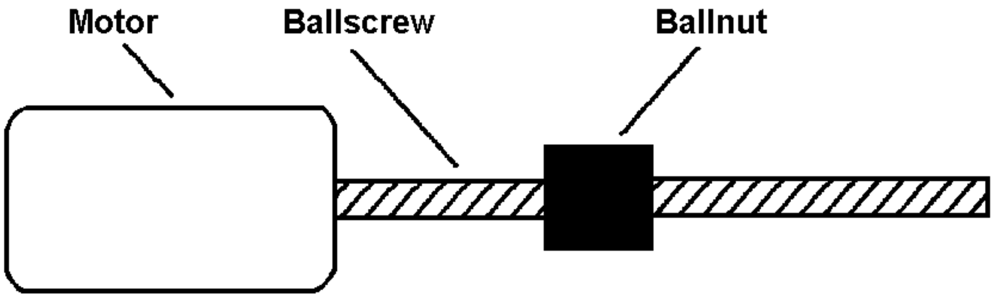
A term used to describe the characteristics of a ballscrew is lead. Lead defines the linear distance traveled when the screw is rotated one revolution.

Lead = in/rev

Another term that is used is pitch.

Pitch = 1 = rev
Lead in

Lets consider another example of a system that uses a motor driving a ballscrew.



An object on the ballnut is to be moved, starting at rest and ending at rest, 8 inches in 4 seconds. The total system inertia is 0.2 in-lb-sec^2 and the ballscrew pitch is 5 rev/in. What is the torque required to accomplish this task?

Recall:

$$T = J \alpha$$

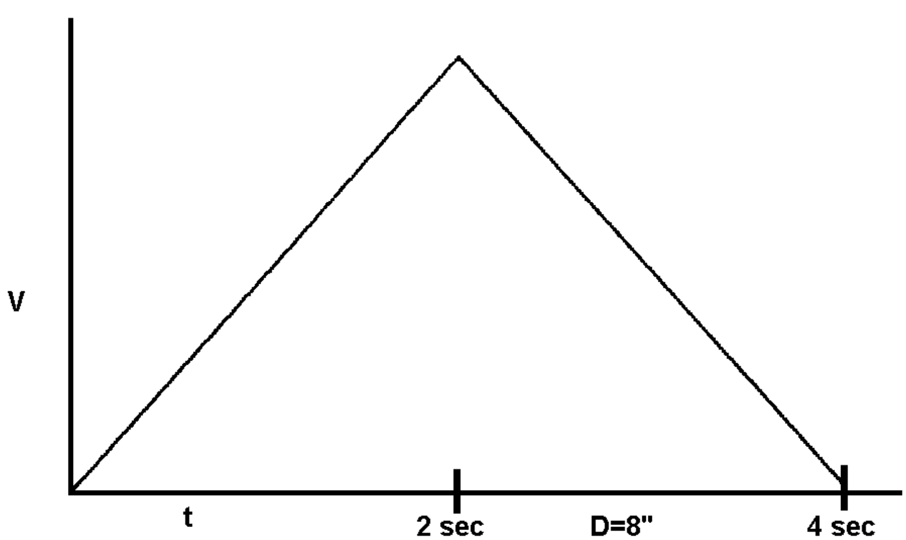
In order to solve this problem we will need to review some simple equations of motion.

$D = vt$; $\Delta \theta = \omega t$
$v_f = a t$; $\omega_f = \alpha t$
$D = 1/2\, a t^2 + v_o t$; $\Delta \theta = 1/2\, \alpha t^2 + \omega_o t$

Where:

t = time, D = distance, v = velocity, a = acceleration, $\Delta \theta$ = angular distance, ω = angular velocity, α = angular acceleration

Now we can graph the profile for the required move for our machine.



To keep our example simple, we will accelerate for 2 seconds and decelerate for 2 seconds.

Recall:

$$D = \frac{a\,t^2}{2} \qquad \alpha = 62.8\ \frac{\text{rad}}{\text{sec}^2}$$

So:

$$4\text{ in} = \frac{a\,(2\text{ sec})^2}{2} \qquad J = 0.2\text{ in-lb-sec}^2$$

$$T = (0.2\text{ in-lb-sec}^2)(62.8\ \frac{\text{rad}}{\text{sec}^2})$$

$$8\text{ in} = a\,(4\text{ sec}^2)$$

$$a = \frac{2\text{ in}}{\text{sec}^2} \qquad T = 12.56\text{ in-lb}$$

$$\alpha = \frac{2\text{ in}}{\text{sec}^2}\left(\frac{5\text{ rev}}{\text{in}}\right)\left(\frac{2\pi\text{ rad}}{\text{rev}}\right)$$

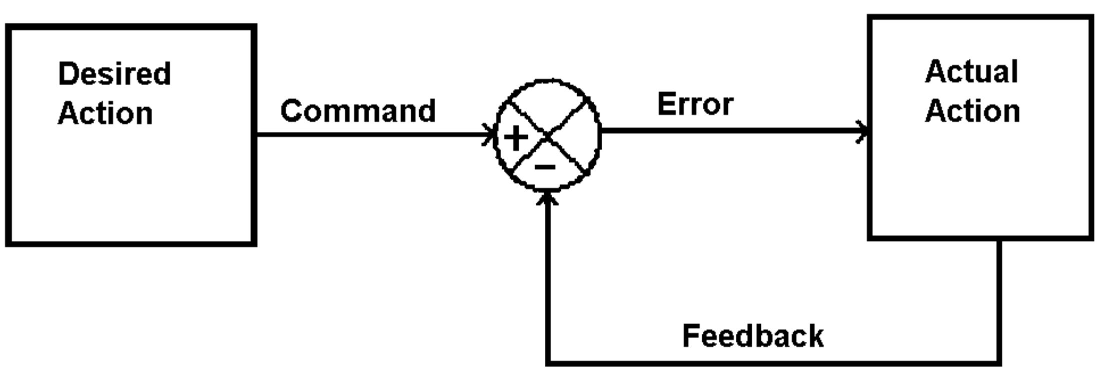
Now we know how much torque the machine requires to accomplish the task. But how does torque get to the machine? How can we regulate the torque so we get enough to do the job but not too much that we would overshoot the desired speed or position? To answer these questions we will introduce the concept of a closed loop drive system.

Closed loop regulator fundamentals

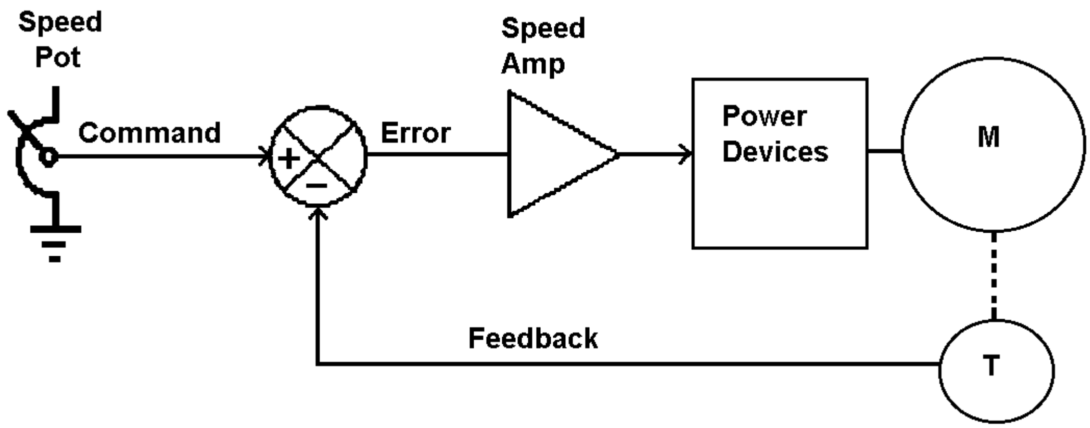
A closed loop system primarily deals with 3 components.

1.) command or reference
2.) feedback
3.) error

The command is what the desired action is. The feedback is what the actual action is. The error is simply the difference between the command and the feedback.



These 3 components (command, feedback, error) allows the system to regulate the actual action very accurately to the desired action. An example of this could be someone driving a car. The command is for the car to go 55 mph. The feedback is the speedometer and the error (the difference between the command and the feedback) is the resulting pressure on the accelerator pedal. When the command is initially given to go 55 mph, the car is at rest (0 mph). So the error is: 55 mph - 0 mph = 55 mph. This causes the accelerator pedal to be pushed and the car begins to accelerate. Once the car gets to 55 mph, the error will be: 55 mph - 55 mph = 0 mph. This will cause the accelerator pedal to be released and the car, due to wind resistance and road friction, will begin to decelerate. When the car reaches 54 mph, the error will be: 55 mph - 54 mph = 1 mph, which will cause the accelerator to be pressed again and bring the speed back up to 55 mph. This process regulates the speed of the car between 54 & 55 mph. Lets apply the concept of a closed loop regulated system to controlling a motor.



The command, coming from the speed pot, is an analog voltage that is algebraically summed with the feedback which is an analog voltage coming from the tachometer. The difference is again the error signal which is amplified to drive the power devices which delivers the voltage and current to required to turn the motor. If, for example, 0-l0 volts represented 0-100% speed and the speed pot was turned up to 5v, the feedback would be 0v initially because the motor isn't turning and the error would be: 5v - 0v = 5v. This would be amplified and cause the motor to accelerate. Once the motor achieved 50% speed, the tach would output 5v and the error would be: 5v - 5v = 0v. This, due to friction in the motor and load, will cause the motor to decelerate. When the motor reaches 49% speed, the tach will output 4.9v and the error will be: 5v - 4.9v =0.1v. This will cause the motor to be accelerated back up to 50% speed. This process regulates the speed of the motor between 49 & 50% speed. We have seen two simple examples of a closed system. We saw how the error signal caused our car and our motor to accelerate when they dropped below the commanded speed. But at what rate did they accelerate. Both examples accelerated at the maximum rate to get back to the commanded speed. But is this practical? Lets reconsider our first example (the car). When the command to go 55 mph was given, the error was: 55 mph - 0 mph = 55 mph. The objective is to make the error equal zero to satisfy the system. The only way to do that is to accelerate the car to 55 mph. If we do that at a maximum rate, it would mean pushing the accelerator all the way to the floor when ever the car was not up to 55 mph and releasing it when it was up to 55 mph. This would give any passengers in the car a very uncomfortable ride. What we need to do is control our rate of acceleration.

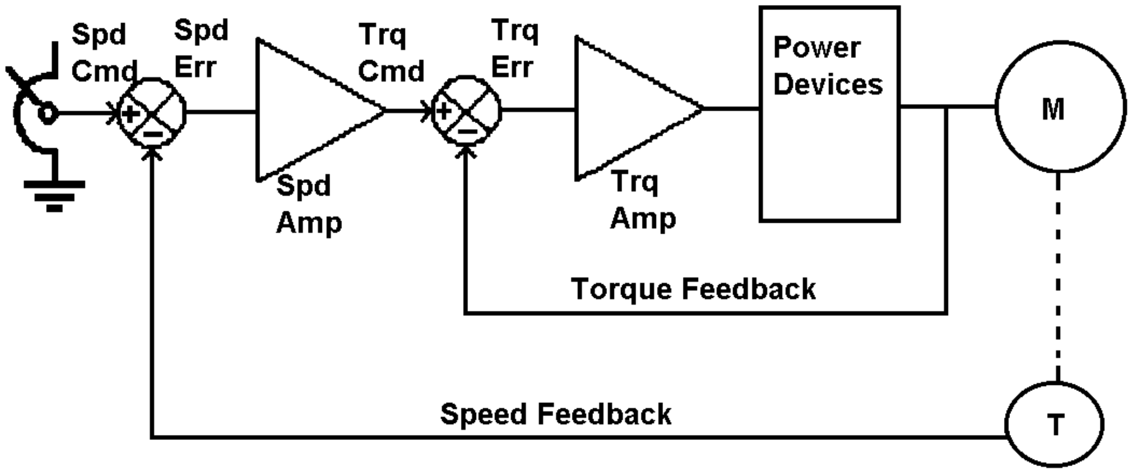
Recall:

$T = J \alpha$

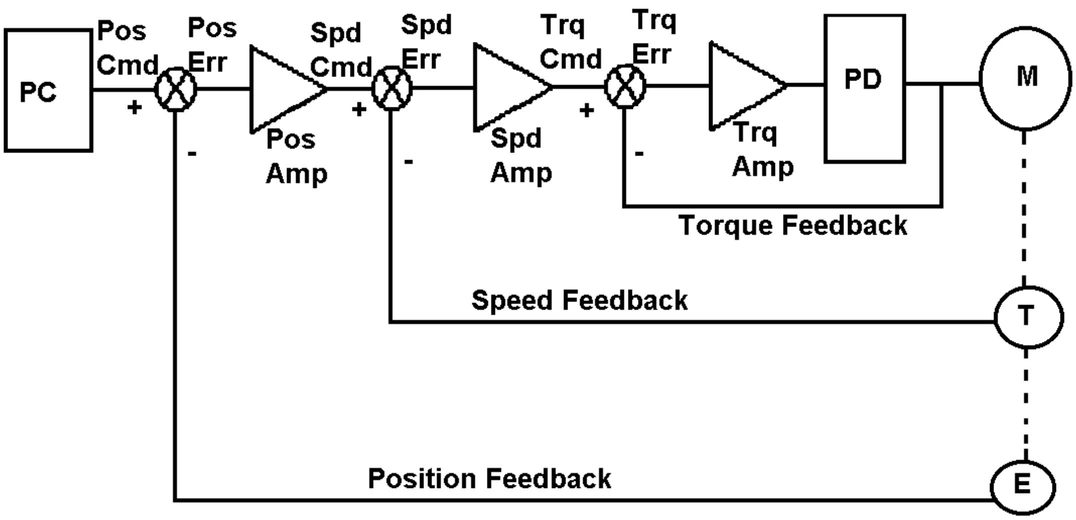
So:

$\alpha = T / J$

If we control the torque output, we will also control the rate of acceleration. This also applies to our motor. The way we can control the torque output would be to add another loop in our closed loop system.



As we can see, the loop we added looks a lot like the first loop. It is comprised of the same three components (command, feedback, error) and functions much the same way. Now we can not only control speed with the speed regulator (speed loop) but we can also control torque with the torque regulator (torque loop). We have seen how to use a speed loop to control speed and a torque loop to control torque. If we want to control position of the system, all we have to do is add another loop.



The position loop looks very much like the speed and torque loops. Its comprised of the three familiar components (command, feedback, error) and it functions much the same way. A desired position is given in the form of a position command from the position controller (PC). The actual position is given in the form of a position feedback which can be output by a number of different devices (encoder, resolver etc...). The difference of the two is the position error which is amplified and used as a speed command which eventually becomes a torque command which accelerates the motor up to a specific speed and runs until the desired position is achieved. Now that we have a basic understanding of the mechanics involved in drive systems, we can explore them in more detail, examine the components that make up a complete system and analyze their function in the complete system. This will allow us to effectively troubleshoot and maintain high performance drive systems.