The actuation of cams, detents, and levers has long been the forte of pneumatic or hydraulic systems in machines. Due to increased requirements and constraints on these systems, there has been a gradual increase in the use of servomotor and servo actuators in these applications.

Accuracy, dependability, speed and contouring are a few of the options available in a servo-controlled system that separates it from the open loop predecessors. The selection of components, previously limited to mechanical engineers, has been increasingly left to individuals of multi-technological experience. The results are often a mix of technology better suited for the application.

Servo indexing, combined with an electric cylinder or direct drive permanent magnet linear motor can work together to supply cost effective, precision motion. Additionally, ease of integration has removed some of the barriers previously associated with servo systems. With the advent of Graphical User Interfaces (GUI), many paradigms have been removed.

**Closed Loop versus Open Loop**

Servo systems, along with some stepper systems, can operate in a closed loop configuration. Closed loop is a method of control where the system is commanded, monitored and adjusted to achieve the final value. The monitoring time, called the sample rate, can be measured in segments of milliseconds or microseconds. A commanded position-time reference, called the trajectory command or profile is sent to the drive. The amount of error that the system is allowed to ‘lag” is called the following error. The system is compared to the commanded position in each sample period and adjusted accordingly to compensate and minimize the error. The system will command whatever current, within limits of the system, is required to follow this command. If no fault has occurred, operation can be virtually guaranteed within the sample rate.

Air cylinders and typical stepper indexers, on the other hand, are open loop systems. They are commanded to actuate and must have additional electrical verification that actuation has actually taken place. The position/time motion will be unknown. No compensation for variances in air pressure, friction, heat or obstruction takes place. Final
position in an air cylinder is usually accomplished by an adjustable mechanical stop. An adjustable mechanical or Hall effect switch is typically located near the mechanical stop. This is the verification of final position.

**Slow to Change**
One reason for the slow migration to servo-based systems may be attributed to the premature selection of electric actuators. Simple Stepper/Indexer systems have offered a method of programming actuators that was relatively easy, and appeared to be a good choice for those with little control systems experience. Although they were open loop, the acceleration and velocity profiles could be programmed with at least some reasonable assurance of accuracy.

Steppers however, had a tendency to lose synchronization if the speed/torque curve was not fully understood, especially those related to resonance. Additionally, they were not a good solution for very fast air cylinder actuators used in many applications.

With the advent of servo indexers, the ability to actuate a mechanical device with the precision of a servo system and the predictable speed torque curve of the DC brushless motor has given rise to an increase in the use of servo actuators. The closed loop features of such a system, as well as the speed/torque improvements, make this a most practical solution. We have successfully incorporated actuation accelerations of up to 12 g’s in an automation application. The controlled acceleration and deceleration accounted for a measurable difference in performance, but more importantly, service time was reduced because of reduced wear encountered with servo-controlled deceleration.

**Accuracy and Repeatability**
Accuracy and repeatability are not always partners. With a servomechanism, velocity, positional accuracy and repeatability can all be achieved. While an air cylinder can be adjusted to achieve certain repeatability, its accuracy, in terms of velocity or position, is not a guarantee with the open loop systems typically implemented today. Environmental conditions such as altitude, temperature, and humidity can affect the system.

The velocity and acceleration of a servo driven mechanism is a programmed, repeatable value. The system will follow the profile time and time again. With 15% headroom of the system common to most designs, variances in friction and heat will have little impact on the programmed parameters.

On its first excursion after setting, an air cylinder will incur a large frictional force. This breakaway friction (referred to as “Stiction”) can cause an interesting effect. The system will build up pressure behind the air cylinder while the backside exhausts. There will be a moment of no motion as the build-up occurs, and since the backside has exhausted somewhat, a jerk results. To counter this, pneumatic systems have employed “floating O-rings” for below 100 psi. These floating O-rings are housed in an over-sized captive area of a piston, allowing them to break ahead of the piston and using their inertia, to help with the breakaway force. Of course, when the system has been cycled and the O-ring
lubricant has been spread across the cylinder, the breakaway forces are different. As a result, consistency and repeatability are not a given.

This does not imply that there are no static friction issues with a servo system. Quite often the current of a closed loop system reveals that the first move of an actuator requires as much as 10-20% more current than the next move. With the system operating in closed loop however, there is no difference in time.

The successive, repetitive cycling of air cylinders can be inconsistent. The speed and reaction time of the air cylinder varies with each turn-on of the valve, the amount of air pressure, the backpressure, and the atmospheric changes. To counter these variances, DC valves are sometimes “Hot Fired”. This means that a 12 volt valve will be hit with as much as 48 volts on turn-on, then dropped to the required 12 volts for holding the valve open. The valve is basically a coil and is subject to the electrical limitations of inductance. AC valves on the other hand, are subject to the limitations of the AC cycle, 50 or 60 Hz. In a worst-case scenario, they may not be able to engage for anywhere from 10ms for 50Hz and 8ms for 60Hz.

**Maintainability**
The use of valves in an air cylinder system requires oil. Typically speaking, there are atomizers involved in maintaining an oiled air environment for the valve. If one uses too much oil the air cylinders will wash out their lubricant (O-ring Lube), resulting in a cylinder failure. Too little oil and the valves fail. Gravity oil systems may also be employed.

The amount of oil is typically set with a certain number of drops/min, and needs to be monitored daily. In most environments, there will also be a need for a muffler/re-classifier. This is a device that muffles exhaust noise and removes the oil from the air, re-classifying it to the specifications for the environment. Dispensing of hydrocarbons in the air must be avoided.

**Shock, Vibration and Wear**
The stops of an air cylinder may be internal or external, but are typically an adjustable hard stop with a damper. The damper is often a polymer of a certain durometer (measure of hardness of polymers) that compromise the final position, noise and vibration of the motion. Sometimes a metal stop is necessary. In order to accommodate this, the impact needs to be reduced by a deceleration method.

Due to variance in velocity and acceleration in air cylinder systems, extra care must be taken to reduce the threat of inordinate amounts of wear. This wear can occur on the mechanism that is being controlled, as well as the air cylinder itself. Cushioned air cylinders are manufactured with the ability to take some of the backpressure of the cylinder and use it as a cushion to the hard stop of the cylinder. There are air cylinders that use an ingenious method of a ball bearing to accomplish this. There are adjustment screws on the side of the cylinder to adjust the cushion. Note that if there is a pressure
change for any reason, the cushion will change and require adjustment again. Other systems fire a solenoid with a smaller venturi space timed at the end of the stroke of a cylinder to reduce shock. Once again these are subject to all of the tolerances of the air. All this complication to accomplish what a servo system does automatically. These are also added costs, sometimes forgotten or ignored by the designer in the original cost estimates.

Even under the best operating conditions, wear issues will affect air cylinders. The O-ring is a compliant portion designed to wear before the cylinder is scored or damaged. Considering operational friction and heat, a life expectancy of 10 million cycles may seem like a large number, but in the case of automated electronic placement machines (Typically 30,000 – 60,000 placements/hr) it can equate to as little as 170 hours of operation before the cylinder must be rebuilt. With Brushless DC motors, system reliability is dictated by the bearing life.

The spectrum analysis of the metal-to-metal impact of some pneumatic actuated systems reveals important information. Since the impact contains an appreciable amount of high frequencies, there exists a chance to damage collateral equipment. Such damage can occur to bearings. This occurs when the high frequency is transmitted to frame members and components. Bearings can be vibrated and can cause a phenomenon known a false brenelling. This is when the small balls are vibrated internal to the bearing. This vibration wipes away the grease and creates a groove at the ball location, resulting in a damaged bearing.

No such stop is necessary in servo systems. The servo will continue to the final destination and stop. If necessary, the system can actuate a brake mechanism at the final destination. No subsequent damage from shock or vibration occurs and system maintenance is not compromised.

**Audible Noise**

Certainly, all mechanical systems generate noise. The jerk forces, or changes in acceleration, contained within the system compound that noise. With the typical hard stops required for a pneumatic system, the audible noise can be extreme.

Air cylinder exhaust requirements also generate a white noise spectrum that can be damaging to the ears since it contains all harmonics at equal power. Since our hearing is not equal at all frequencies (Fletcher-Munson curve), damaging amplitudes can occur with one broken airline.

Although certainly not noise-free, the servo system offers significant more quiet operation by any standard of measure. A typical iron-core linear motor that is used as an actuator can be quiet enough to hear the rolling of the bearings in the system. Even ballscrews can fall below the 60dB level, which is the equivalent of normal office noise, or close conversation.
Diagnostics/Troubleshooting
The ability to diagnose problems and troubleshoot a system at the component level is a significant servo advantage. In this regard, pneumatic systems simply don’t compare. Many of the servo/indexers have a multi-channel oscilloscope option that allows for display of certain parameters during the cycle of operation. These include but are not limited to current, velocity command, velocity-actual, and position. Status of the drive may also be available. An example of an output of an oscilloscope plot from a Danaher Motion Servostar CD drive shows the actual velocity profile when a step function has been input. The velocity, velocity command and current plots are visible, and can be used for tuning the system to achieve the tightest possible control.

Types of Actuators
There are many types of actuators to consider when considering the replacement of a cylinder. Electric cylinders with ball screws, rodless actuators with belts, or direct drive linear systems are available. Danaher Motion’s electric cylinders range from approximately 30lb continuous thrust force to well over 4000 lbs. Linear motor forces can range as high as 2700 lb force, but at significantly higher velocity. There are rotary possibilities using carriage assemblies that contain a small leadscrew with a rotary mount. These can be used to replace a reciprocating linear action, and when mated with a NEMA17 motor and indexer, can be a very cost effective precision system.

Expense
The expense of incorporating a servo system may not be as great as one might expect. Considering all of the valves, air cylinders and various support requirements of the pneumatic system, one finds that it is significantly more expensive than the $50.00 air cylinder. Factoring in the costs of manufacturing inconsistencies, support requirements and specialized design, a great deal of it can be a wash.

Guide rollers that are not required with rodless cylinders are eliminated. If a linear stage is used, bearings are included in the cost. With pneumatics, the additional controls for exhaust, noise abatement, and re-classification of air for environmental reasons must also be accounted for. Specialized valve control for high speed applications may have to be
employed. Proximity switches or Hall effect devices to determine the actuation state can be eliminated with the servo system. These are just a few of the often-overlooked costs.

**The Correct Choice**

When confronted with the actuation of a mechanical member, the correct choice has to be made by the engineer in light of the application requirements. Certainly there are many non-critical operations that are better suited for an open loop air cylinder. However, when the operation requires reporting information or is a time-qualified operation, closed loop servo actuation should be considered as a viable alternative. Given the variety of products available in the marketplace today, the choice has been somewhat simplified. Good, cost-effective options found in servo indexers, electric cylinders and linear motors exist to supply the designer with a variety of options, limited only by his creativity.