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EXCELLENCE IN MOTION

Electric actuators vs. pneumatic cylinders: A comparison based on total cost of ownership

Factor in utility costs, maintenance costs and product yield when considering the service life of a technology choice.

Tolomatic is a leading supplier of electric linear actuators. Tolomatic's 60+ years of expertise covers a wide range of industries and linear motion applications.

INTRODUCTION

Pneumatic cylinder actuators, known for their low initial cost and ease of deployment, have been a staple in factory automation equipment for decades. They are simple and provide reasonable control over machine movements in industrial plants. However, since the development of more flexible, precise and reliable electric actuators, there has been an ongoing debate over which technology offers the best overall solution for industrial plant optimization. The case for switching to electric actuators has focused on the ability of electric actuators to achieve more precise control of motion (position, speed, acceleration and force), along with providing superior accuracy and repeatability. While it's true that electric actuators excel in performance and have a higher initial cost, this paper will instead focus on the factors that contribute to making an electric actuator solution a more economical option than air cylinders over the life of the device or machine. Factors such as efficiency, electric utility costs, air leaks, moisture in pneumatic system, maintenance, product replacement, product quality, changeover time and cycle times will be examined along with other factors that determine the total "cost of ownership" for a technology.

This paper defines "total cost of ownership" as:
total cost of ownership (TCO) = initial purchase cost + years of service X (yearly replacement costs + yearly maintenance costs + yearly electric utility costs + yearly product scrap + yearly lost production due to changeover time and cycle time).

Determining efficiency and electric utility costs

An Internet search for 'pneumatic system efficiency' returns a virtually endless list of studies and reports. Almost all of them concentrate on efforts to make a pneumatic system more efficient. While making existing pneumatic systems more efficient is admirable, there is, however, little mention in these papers of improving the overall efficiency (electric utility consumption) of the plant by considering non-pneumatic solutions that offer lower operating costs and production-boosting performance.

The following sources confirm the inefficiencies of pneumatics.

"Compressed air is one of the most expensive sources of energy in a plant. The over-all efficiency of a typical compressed air system can be as low as 10%-15%."

U.S. Department of Energy: Energy Tips-Compressed Air, August 2004

"Only 23%-30% energy efficiency is achieved for pneumatic systems, against 80% for electrical systems and 40% for hydraulic systems."

British Fluid Power Association: New developments and new trends in pneumatics, FLUCOME Keynote lecture 2000

For most applications requiring linear motion, the efficiency differences between an electric and pneumatic system can result in significantly different electric utility costs over the lifetime of the device.

"According to the study *Compressed Air Systems in European Union* (Radgen and Blaustein, 2001), the EU-15 was spending 10% of the total electricity consumed in the industry for the production of compressed air. The electricity consumption of CASs (compressed air systems) in Chinese enterprises goes from 10% up to 40% (Li etal., 2008) of the total industrial electricity consumed."

European Union "Motor Challenge Problem" study report on Increasing Energy Efficiency in Compressed Air Systems, Radgen and Balsten, 2001

What does all this mean?

For most applications requiring linear motion, the efficiency differences between an electric and pneumatic system can result in significantly different electric utility costs over the lifetime of the device. Let's assume that every pneumatic system has an efficiency of 20% and every electric system has an efficiency of 80%. With pneumatic systems, efficiency can vary from 10 to 30% depending on air quality, seal quality and wear, leaks in the system infrastructure and a variety of other factors. All of these factors require constant attention and maintenance or system efficiency will suffer. By comparison, electric actuator efficiency does not really change over time due to the accuracy and repeatability of control.

Consider the following pneumatic cylinder applications, for a 1" bore (25mm), a 3"bore (80mm) and a 5" bore (125mm) cylinder.
By simplifying the power costs of a sample application to some simple

formulas, a good estimation of the electric utility cost associated with a single axis of motion can be achieved.

Power-OUT(kW) = Velocity (m/sec) X Force (kN)
Power-IN((kW) = Power-OUT(kW) ÷ Efficiency (%)
Electric Utility Cost of Application = (Power-IN) X (Hours/year) X(Electricity Cost per kW-hr)
Assuming $0.08 (8 cents) per kW-hr

Duty cycle (time working ÷ (time working + time at rest)) plays a large role in calculating the cost of electricity for a pneumatic cylinder or electric actuator.

Application #1: 1" bore or 25mm bore equivalent @ 80 psi (5.5 bar)
Force: 0.33 kN (or ~62 lbf)
Speed: 0.3 m/sec (or ~12 in/sec)
Power-OUT(kW) = 0.1kW

Application #2: 3" bore or 80mm bore equivalent @ 80 psi (5.5 bar)
Force: 2.5 kN (or ~565 lbf)
Speed: 0.2 m/sec (or ~8 in/sec)
Power-OUT = 0.5kW

Application #3: 5" bore or 125mm bore equivalent @ 80 psi (5.5 bar)
Force: 7.0 kN (or ~1570 lbf)
Speed: 0.15 m/sec (or ~6 in/sec)
Power-OUT = 1.0kW

As with any device consuming electric power, the number of times the device works or is cycled is directly related to the amount of electricity it uses. Therefore, duty cycle (time working ÷ ((time working + time at rest)) plays a large role in calculating the cost of electricity for a pneumatic cylinder or electric actuator. Note in the graphs below that since efficiency is much lower in pneumatic systems, energy costs rise more steeply as the duty cycle increases.

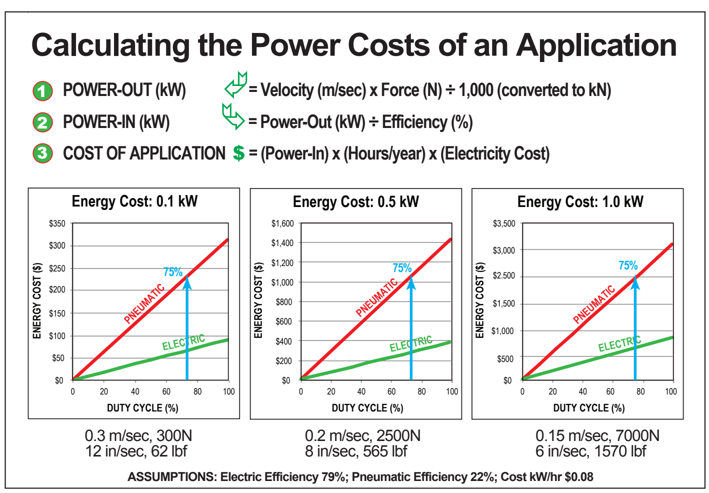

Figure 1: Calculating the power costs of an application

As with most factory automation equipment, the duty cycle of equipment is normally high in order to maximize machine utilization and plant output. Table 1 below compares duty cycles of 50% and 80% with respect to these three pneumatic applications. In a 0.1kW application, the annual operating costs for electric actuators are approximately $130 (at 50% duty) and $210 (at 80% duty) over pneumatic. In a 0.5kW application, that increase grows to approximately $655 (at 50% duty) and $1050 (at 80% duty). Considering there are now many lower priced motion control solutions (actuators, motors, drives) available in today's market to do these applications, the total cost of ownership picture is starting to move towards an electric actuator advantage.

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ANNUAL ELECTRIC UTILITY COST		
0.1 kW APPLICATION		
DUTY CYCLE	**50%**	**80%**
Pneumatic	$ 175.20	$ 280.32
Electric	$ 43.80	$ 70.08
0.5 kW APPLICATION		
DUTY CYCLE	**50%**	**80%**
Pneumatic	$ 876.00	$ 1,401.60
Electric	$ 219.00	$ 350.40
1 kW APPLICATION		
DUTY CYCLE	**50%**	**80%**
Pneumatic	$ 1,752.00	$ 2,803.20
Electric	$ 438.00	$ 700.80

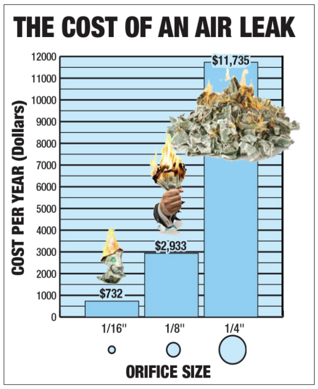
Table 1: Pneumatic vs. electric cost comparison based on duty cycle and kW

With respect to improving efficiency in manufacturing facilities, this table makes it clear why managers need to identify all of the higher duty cycle pneumatic cylinders in the plant and discontinue the practice of basing actuator selection simply on initial cost.

Leaks add to electric utility costs

All pneumatic systems or infrastructures experience leaks, and these leaks are a major contributor to the poor efficiency of pneumatic systems. Leaks can be problematic to identify and fix. Large leaks are more readily detected and corrected, but small leaks are challenging to identify. In fact, the accumulation of many small, unidentified air leaks can significantly increase the cost of electric bills for manufacturing companies. According to the U.S. Department of Energy, about 30% of air supply created for production is lost to leaks.* Additionally, it is estimated that the cost of operating an efficient compressor over its life results in 76% of the total cost coming from electricity. See Figure 2 below. Furthermore, the cumulative size of leaks also affects cost and, depending on location, kW-hr rates can vary. The illustration at left show a cumulative series of leaks equal to ¼-inch in size (~6mm) results in approximately $11,735 per year (@ $0.07 kW-hr) in wasted electricity to feed that leak.

Compressed air systems fact sheet, April 1998



Cumulative air leak in a facility from all sources. Costs calculated using the industrial electricity rate of $0.07 per kWh*, assuming a consistent operation and an efficient compressor.

* From U.S. Energy Information Administration, December, 2012 Electricity Consumption Report

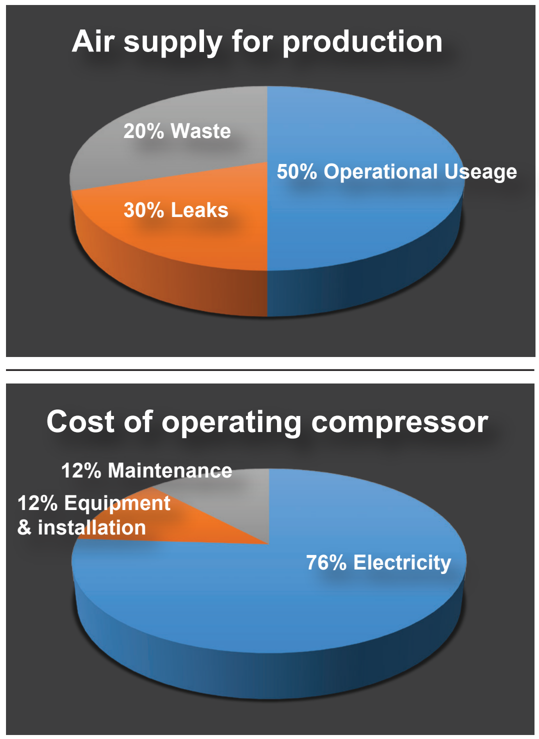


Figure 2: Percentages of operational costs

Maintenance and replacement

Pneumatic actuators rely very heavily on tight rod and piston seals to prevent air leaks. As the actuator strokes back and forth many thousands or even millions of times, seal wear and leaks are inevitable, which degrade the performance of the pneumatic cylinder and increase costs. As a result, efficiency, force output, speed and/or responsiveness of the cylinder decrease as air leakage increases. All of these factors inhibit the consistent manufacturing processes required for high quality, high volume production. Furthermore, predicting when the seals may fail or anticipating their effect on performance can be almost impossible to determine. Maintenance personnel and operators in plants can spend endless hours adjusting the flow or regulation of air into individual devices to get proper operation. Once this process begins, many plants and manufacturing facilities start to put pneumatic cylinders on a preventative maintenance replacement or repair schedule to get more consistent operation. This process introduces costs for time, labor and effort repairing pneumatic cylinders and managing a preventative maintenance schedule. These

Efficiency, force output, speed and/or responsiveness of the pneumatic cylinder decrease as air leakage increases.

costs need to be factored into the total cost of ownership of a piece of equipment over the life of that machine.

Pneumatic systems are also prone to moisture retention inherent in the compressed air which creates multiple issues. Condensed water and water aerosols can lead to severe contamination for applications in the food & beverage, pharmaceutical, medical and other industries that require clean automation systems. Moisture in a compress air system will also result in condensation forming inside piping, pneumatic tools and other pneumatic devices which leads to damage and premature failure of these components. To control moisture condensation in the compress air system, dryers are recommended to help prevent corrosion and inhabit organism growth. However, there are a variety of types which requires careful consideration, field experience in selecting, additional maintenance and additional energy costs of the overall pneumatic system.

Electric actuators demand very little or no maintenance.

By comparison, electric actuators demand very little or no maintenance. With some actuators an occasional re-lubrication may be required, but for the most part, electric actuators require no ongoing maintenance. Furthermore, electric actuators primarily utilize ball screw and ball bearing technology which can provide a more predictable estimation of service life compared to pneumatics, as the dynamic load rating of the device can be utilized along with an industry standard ball bearing L10 life calculation. This allows electric actuators to be properly sized for the desired life of the equipment.

Any change in the performance of a pneumatic cylinder can directly relate to the quality and yield of the product being produced in the manufacturing process.

Achieving product quality

As discussed previously, the performance of a pneumatic cylinder varies over time as the seals wear. As a result, many adjustments of the pneumatic system may be required to get repeatable or accurate performance over the life of the device. Any change in the performance of a pneumatic cylinder can directly relate to the quality and yield of the product being produced in the manufacturing process.

Even though cushions or shock absorbers can be added to pneumatic cylinders to help soften the vibration at the end of each move, in many cases the motion of the pneumatic cylinder is less controlled than its electric actuator counterpart.

To illustrate this, imagine a process that requires the cylinder to cut a product at a certain speed to ensure the edges do not fray or get damaged. A pneumatic device would have to be monitored and adjusted over time by maintenance personnel or equipment operators to maintain the repeatable speed. In contrast, the electric actuator equivalent would give repeatable speed performance throughout the life of the device without any intervention by plant personnel. As another example, imagine a process that requires repeatable or accurate force to complete a process. As seals wear and air pressure changes, the pneumatic cylinder's force output will change and will need to be monitored and/or adjusted. Again, the electric actuator counterpart will maintain its performance throughout the life of the actuator and can actually out-perform the pneumatic cylinder by instantaneously developing force. A pneumatic cylinder, on the other hand, has to wait for air pressure to build up to achieve the desired force.

System vibration can also be a performance concern. Typically, pneumatic cylinders are deployed in "bang-bang" end-to-end applications where they move to two positions to perform the desired operation. Even though cushions or shock absorbers can be added to pneumatic cylinders to help soften the vibration at the end of each move, in many cases the motion of the pneumatic cylinder is less controlled than its electric actuator counterpart. A good example would be an inspection application or pick-and-place application where vibration in the system could cause a bad measurement or misplacement of a part. The pneumatic cylinder can easily send shock and vibration into the mechanical structure of the equipment. An electric actuator, however, has full control over the motion profile (position, velocity, acceleration/deceleration, force), and can prevent introduction of shock or vibration disturbances into the system caused by the motion.

The control (accuracy and repeatability) of an electric actuator system is superior to its pneumatic counterpart, which leads to better overall control of the manufacturing process and higher product quality and yield. By calculating the amount of cost savings that process improvements or product yield improvements in high volume manufacturing would accrue, plant managers will better understand the benefits of electric actuators.

Applications that require product changeovers and multiple setups will often benefit from conversion to electric actuators.

Machine changeover/setup time

Applications that require product changeovers and multiple setups will often benefit from conversion to electric actuators. For example, if a process or machine requires changeover or setup to run different sizes or different products in the same machine, then an electric actuator can automate that changeover. If the application involves adjusting hard-stops for pneumatic cylinder positioning, this too can be automated with programming in an electric system. While a pneumatic system often requires adding rod-lock spacers to the cylinder or other manually adjusted stops to gain different or multiple positions, in an electric system, this can simply be programmed.

With any of these examples, there is a good chance an electric actuator will solve problems with the changeover processes. The adjustment of hard-stops or addition of spacers on rods for positioning can be time consuming, prone to human error and can reduce process quality if adjustments are not accurate or the wrong rod spacers are used in some or all axes of motion. Electric actuators can be used either in lower duty cycle setup axes or they can be used in high-cyclic, process-important axes due to their complete control over position and motion profile (velocity, acceleration/deceleration, force). This control can be achieved through an HMI or PLC (batch process file) so little or no operator intervention is needed. Of course, every process is different, but it logically follows that if changeovers become much quicker then there is less time spent adjusting machines and more time spent producing product. Additionally, there are potential savings from reduced manual labor and the elimination of human errors into the production process.

Compare the profitability of investing in improvements to cycle time and the overall throughput and efficiency of the equipment.

Cycle time/throughput

Another important factor to consider is cycle time. Compare the profitability of investing in improvements to cycle time and the overall throughput and efficiency of the equipment. That will help in weighing the benefits of replacing pneumatic actuators with electric actuators.

Compare the profitability of investing in improvements to cycle time and overall throughput and efficiency of the equipment.

Pneumatic cylinders are typically deployed as two-position devices. If a process has any tooling which must be moved out of the way for a changeover process or other process reason, then the pneumatic cylinder must be purchased with the full stroke in mind. During runtime, this means that the pneumatic cylinder must cycle back and forth across its full stroke even if it is not required for the runtime process, which increases production time. Furthermore, if the pneumatic cylinder is required to develop force in this process, additional delays can be introduced because the cylinder must build up air pressure to achieve the desired force. Typically this doesn't take a lot of time (usually 10s or 100s of milliseconds) but it is nonetheless wasted time in every cycle and it is cumulative. Again, an electric actuator can eliminate both of these problems. The electric actuator can stroke the tooling only as much as is needed (not the full stroke) to get the tooling out of the way for the product to move into position, saving valuable cycle time. Additionally, electric actuators can develop force almost instantaneously because their force is directly equivalent to electrical current through the motor. This eliminates any wait time in the process for developing pressure in the pneumatic cylinder to achieve force. If these factors are important to machine performance, consider an electric actuator to improve efficiencies.

Application Examples

Considering all these factors, illustrated below are two example applications to demonstrate the TCO generated for both pneumatic and electric actuator solutions.

Electric actuators can develop force almost instantaneously because its force is directly equivalent to electrical current through the motor.

Application #1: Noodle cutting

Industry: Food & beverage

Requirements:
1) Stainless Steel, IP69K construction
2) Load: 5 lbf (22.5 N)
3) Motion Cycle: Move out 100 mm and back 100 mm in 0.5 seconds with minimal to no dwell. Speed=0.67 m/sec

APPLICATION #1 COSTS		
COSTS	PNEUMATIC CYLINDER	ELECTRIC ACTUATOR
Purchase Cost	~$110 + valve/etc. = ~$400 total - 1 mo. life	~$1500 (actuator, drive, motor) - 3 year life
Annual Electricity Costs*	$50.40	$8.10
Annual Maint. Costs	? - Not accounted	$0
Annual Repl. Cost	$1320 - no labor, just cylinder	$0.00
3 Year TCO estimate**	$4111	$1524

* Power Out = 0.67 m/sec x 0.0225 kN = 0.015 kw; Power In (pneumatic) = 0.015 kW/20% = 0.075 kW; Power In (electric) = 0.015 kw/80% = 0.0121 kw; Assuming $08. per kW/hr and 8400 hours/year

** Pneumatic: 3 x (1320 + $50.40) = $4111.20. Excludes maintenance and assembly labor for replacement, excludes purchasing, receiving and stocking of pneumatic cylinder; Electric: ($1500 + 3) x $8.1 = $1524.30.

Figure 3: Application #1 Noodle cutting costs

In this real-world example, the pneumatic cylinder was actually being replaced every week on preventative maintenance (or PM). Understanding this is an extreme case, the application calculation above uses a one month preventative maintenance period where the cylinder is replaced. As stated earlier, pneumatic cylinders are commonly put on preventative maintenance replacement plans which span from 1 month to 1 year. Oftentimes no plan is in place which leads to downtime when cylinders fail. With a one month life and $110 purchased cost of pneumatic cylinder, the ROI for this application is less than 13 months for an electric actuator with a $1500 cost / 3 year life.

Application #2: Resistance spot welding

Industry: Automotive

Requirements:
1) Force: 1,000 to 2,500 lbf (4.45 to 11.1 kN)
2) Motion cycle: Small loaded passes (~0.25 in) to clamp metal every 3 seconds. 5M welds/year

APPLICATION #2 COSTS		
COSTS	PNEUMATIC CYLINDER	ELECTRIC ACTUATOR
Purchase Cost	~$1250 - 3M weld life	~$5000 - 20M weld life
Annual Electric Cost	$596	$141
Annual Maint. Cost*	1250: $250/1M welds	$375: $750/10M welds
Annual Repl. Cost**	2083: $1250/3M welds	$0.00
4 Year Costs	$15,812	$7063

* 1/2 maintenance in first year **No replacement in first year

Figure 4: Application #2 Resistance spot welding

For this example, a pneumatic actuator with a total cost of $1250 with a life of 3M welds is compared to an electric servo actuator with a cost of $5000 and a life of 20M welds. The pneumatic cylinder total cost of ownership is over twice as much as the electric servo actuator option. Considering that most automotive plants have hundreds of actuators performing welds at any given time, the cost, increased quality and performance along with maintenance savings can be substantial over time.

Ignoring TCO will definitely result in short-term equipment cost savings, but it will come with increased utility costs, increased maintenance costs and increased product yield issues over the long run.

Conclusion:

Total cost of ownership is a popular corporate buzz word and many large companies have corporate initiatives to lower TCO within divisions or product lines. Yet, departments within these corporations have varying goals and may be unable to view their operation from a TCO perspective. For example, corporate purchasing's goal may be to negotiate the purchase of capital equipment with lowest initial purchase cost. In the plant, engineers and maintenance personnel focus on expertise in systems and technology so they will be able to get equipment running when problems arise. Finally, plant management may have the most holistic view of equipment TCO because they manage the plant capital equipment and operations budget. Yet, it is not uncommon for plant management to anguish over the higher initial purchased cost of electric technology even though they are aware of the benefits: higher quality product, higher product yields, higher throughput, lower operating costs, lower maintenance costs, and shorter changeover times.

Ignoring TCO will definitely result in short-term equipment cost savings, but it will come with increased utility costs, increased maintenance costs and increased product yield issues over the long run. Considering TCO early in the process of specifying equipment is all about considering the entire service life of a technology choice, not just the initial purchased cost. If the TCO concept is truly embraced by manufacturing companies, the analysis would show that in most cases choosing electric actuators over equipment requiring compressed air (pneumatic devices) will almost always provide a lower TCO.