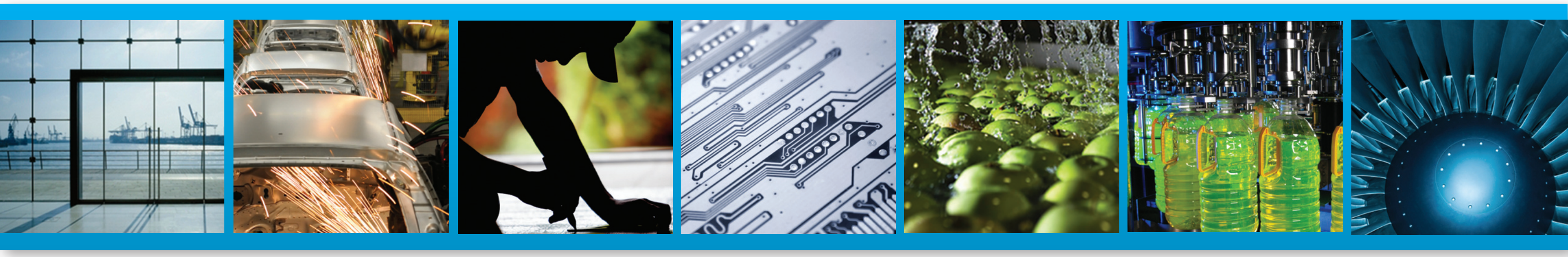

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Debunking “Conventional Wisdom” in Actuator Selection and Deployment

Understanding all the costs in pneumatic and electric actuators — and recognizing their very different capabilities — can save tens of thousands of dollars.

Author: Bob Kral
Bimba Manufacturing Company

Debunking "Conventional Wisdom" in Actuator Selection and Deployment

Overview

It's in the news. Everyone is talking about it. Pneumatic or electric?

Are you considering replacing a compressor and 200 pneumatic cylinders with electric actuators to save compressor costs? Thinking about building a new machine with pneumatics because 30 electric actuators cost a whopping $34,000?

You might be making the wrong decision and as a result wasting tens of thousands of dollars a year. This article provides an analysis of cost components for both pneumatic and electric actuators, and gives examples of cost estimations. Cost calculations are provided in the appendix for readers who wish to evaluate costs for their machines or facilities.

Electric and pneumatic actuators embody distinctly different technologies

Pneumatic or Electric – Evaluating and Comparing Competing Technologies

The choice of pneumatic or electric actuators involves an evaluation of performance, component costs, system costs, and productivity gains. The two technologies are so different that one cannot be a drop-in replacement for the other. Each has inherent advantages and disadvantages.

Pneumatic actuators provide high force and speed at low unit cost in a small footprint. Force and speed are easily adjustable and are independent of each other. The typical pneumatic application employs over-sized cylinders as a safety factor. This is common because pneumatic cylinders are inexpensive and stepping up to the next larger diameter is feasible and practical. Prices for non-repairable rod-type cylinders range from $15 to $250 depending on body diameter, stroke and options.

Pneumatic cylinders provide more force and speed per unit size than any other technology except hydraulic.

Pneumatics are most economical when the scale of deployment matches the capacity of the compressor. Small compressors are efficient and economical when used to power a small number of pneumatic devices. Large compressors are efficient and economical when powering a large number of pneumatic devices. Unused compressor capacity is very costly. Time that a compressor sits idling at no load is also costly.

While pneumatic component costs are low, maintenance and operating costs can be high, especially if a serious effort has not been made to quantify and minimize the costs. Maintenance and operating costs include replacement cylinder costs, air line installation and maintenance, and electricity for the compressor. According to the Department of Energy, 24% of the annual cost of compressed air is due to maintenance, equipment and installation while 76% is due directly to the cost of electricity for the compressor.

Typically, compressor efficiency is lower when the compressor is partially loaded. Furthermore, if during the work week, the compressors are left powered on at no load, a substantial amount of electricity is wasted. Waste is increased by inadequate maintenance (air leaks) and non-essential use of the compressor. Over-sized compressors and cylinders, common today, are costly to operate.

Two smaller compressors often are less expensive to run than one larger compressor

Determination of the operating cost per pneumatic device deployed in a facility can be eye opening, especially if cost calculations have not been done for a while and the scale of operations has shrunk. If there are 500 pneumatic devices using a compressor, cost per device may average $100 per year, but if there are only 50 devices then cost per device increases ten times to $1,000.

In contrast to pneumatics, electric actuators provide precise control and positioning, help adapt machines to flexible processes and have low operating cost. They are most economical when deployed in a moderate scale in processes where their performance advantages can be a benefit and when the electronics are separate from the actuator to segment and minimize replacement costs.

Electric actuators consist of a ball, acme or roller screw connected via a coupler to an electric motor. As the screw turns, it moves a piston, which is connected to the rod or carriage. The rod or carriage moves the load. Performance varies depending on materials used. Commonly used motors include steppers and servos. Brush DC motors and AC motors are sometimes used with limit switches when positioning accuracy is less critical. Step motors are an economical choice for accurate positioning at lower speeds. However, steppers might lose synchronization with the controller when employed open loop without an encoder or if they are undersized for an application. Servos by definition are closed loop and provide superior performance at high speeds, albeit at a higher cost. High precision screws and anti-backlash mechanics can provide accuracies to ten-thousandths of an inch. Standard precisions with standard components range from a few hundredths to a few thousandths of an inch.

Speed and thrust are related in the physics of an electric actuator. Speed is surrendered for thrust and thrust for speed. This is an important distinction from pneumatic cylinders. For a given electric actuator, more thrust will be available at low speeds and less thrust at high speeds. This characteristic is more pronounced with step motors and less with servos. For this reason, accurate sizing in an application is critical. Increasing thrust at the same speed requires different designs using different components and materials. An increase in thrust and speed requires larger and more powerful components and materials, which increase costs. Understanding and evaluating loading in the application under real conditions ensures specification of the right actuator while minimizing expense. Not understanding application loading leaves the engineer vulnerable to poor performance and high costs.

Components of an electric actuator include the mechanical actuator that translates motor rotation to linear speed and thrust, the motor, an electronic driver or amplifier to power the motor, and a controller to control motion. The total cost for these components ranges from $800 to $3,000 and up.

Operating costs of electric actuators are largely due to motor power draw. Controllers' and drivers' low voltage circuitry consumes power to a far lesser degree.

Implementing modular actuators helps to control replacement costs.

While component costs of electric actuators are high, operating costs are low. High component costs often deter the use of electric actuators. Savings in operating costs compared to pneumatics are not adequately considered or ignored.

For example, manual changeovers (adapting a production line to a different product) can be expensive in terms of both lost production and man-hours required to implement the change. Over the course of a year, if changeovers are required once a week and each changeover requires two people for four hours at $50 per hour, man-hour costs amount to $20,800 per year. If products are produced one per minute and the value of each product is $10, lost production costs amount to $124,800 . The total annual cost of changeovers amounts to $145,600 . Electric actuators can substantially reduce changeover costs. The annual cost savings must be considered as part of the implementation decision.

When replacement cost, operating cost and process efficiency are considered, electric actuators' annual costs are comparable to pneumatics'. It helps when the scale of deployment is moderate and when motion system components can be replaced separately as they wear rather than replacing an entire integrated actuator motion control system.

Making an Application Performance and Cost Comparison

(See appendix for a discussion of assumptions and details of the calculations)

Example 1 – The Case for Electrics

Situation

A plant uses a 100 HP compressor operating at full load 2,000 hours per year at 90% efficiency. It powers 20 pneumatic actuators, which average $50 apiece. When the compressor is not being used, it is idling at 25% power and 85% efficiency. The pneumatic actuators average a three-year life. Cost of electricity is $0.10/kWh.

Electric actuators are being considered as replacements. The electrics average $900 apiece plus another $1,200 for controls and power supplies. Each actuator draws 6A fully loaded at 48 V DC 30% of the time. The remaining time the actuators draw 3A. The power supply used draws 6A at 120 VAC under full load, producing 9A at 48 VDC. The mechanical actuators have a three-year life span, while the electronics have a ten-year life span.

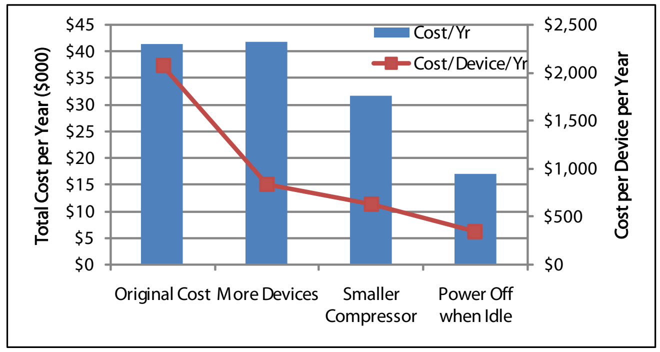
Life spans identified here are assumptions. Actual life spans of components will vary.

Additionally, electrics will automate a line change that consumes two hours every week for two people at $30 an hour apiece and causes a loss of production. For every hour of production, 100 products can be produced at $1 each.

Cost of Pneumatics:

Annual cost of compressed air, compressor at full load = $21,822
Annual cost of compressed air, compressor at 25% = $19,351
Replacement costs of actuators = $333 per year
Total cost for pneumatic solution per year: $41,506.

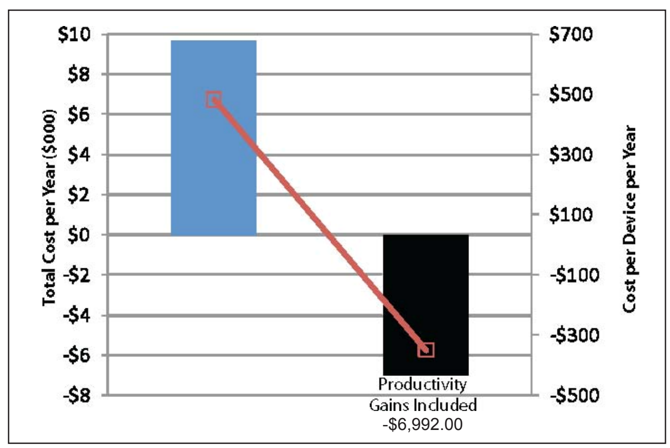
If we are able to replace the old 100 HP compressor with a smaller 50 HP unit, costs will drop as shown in the following chart. A new compressor pays for itself in about a year and a half. If the compressor is turned off when not in use, costs would decrease even more. These relationships are shown in the graph below. Savings could be as high as $25,000 per year. Note that the actual cost per pneumatic actuator deployed drops from over $2,000 to about $300 apiece due to efficiencies in deployment.



Cost of Electrics:

Annual cost at full load = $576
Annual cost at idle = $672
Annual operating costs for 20 actuators = $1,248
Replacement cost for actuators = $6,000
Replacement cost of electronics = $2,400
Total cost for electric solution per year: $9,648

Savings: elimination of change over labor = $6,240
Savings: elimination of lost production due to changeover = $10,400



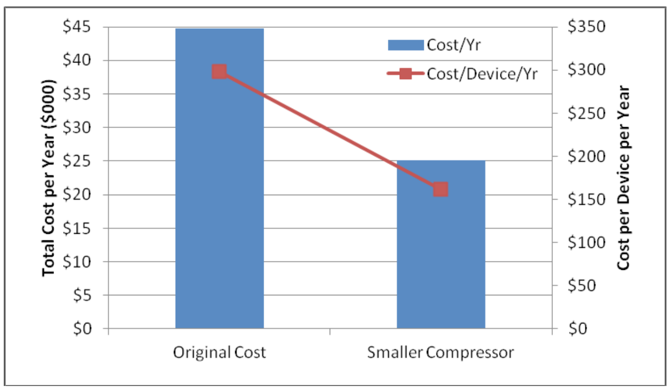
Conclusions

In this instance, operating and maintenance costs clearly present the electric solution at a substantial advantage. Notice that total cost per year is $9,648, not including savings obtainable from increased adaptability of the machinery. Once we consider the gains from eliminating changeovers, implementation of the electric actuators actually reduces cost, rather than adding to it, by about $7,000 per year.

Example 2 – The Case for Pneumatics

Situation

A plant has a 200 HP compressor installed for pneumatics, operating at full load 2,000 hours per year at 93% efficiency. It will be used to power 150 pneumatic actuators, which average $50 apiece. When the compressor is not being used, it is turned off. An alternative is to use electric actuators. The replacement actuators cost $1,200 apiece, which includes built-in drivers and controls but not power supplies. Each actuator draws 6A fully loaded at 48 V DC, which is about 30% of the time. The remaining time the actuators operate at 3A. The power supply used draws 6A at 120 VAC under full load, producing 9A at 48 VDC.



Cost of Pneumatics:

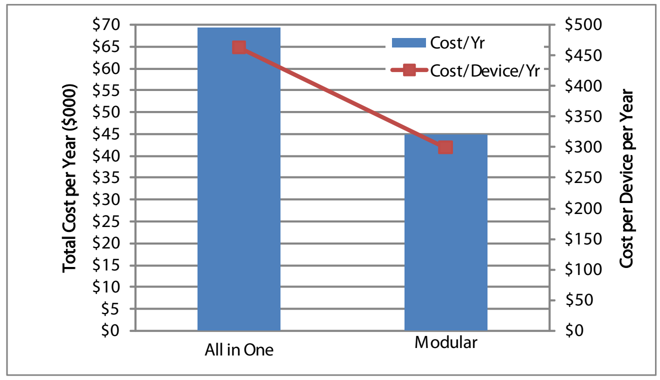
Annual cost of compressed air = $42,237
Replacement costs of actuators = $2,500 per year
Total cost for pneumatic solution per year: $44,737
Cost per pneumatic device per year = $298

Even with a large 200 HP compressor cost per device is extremely low, benefiting from the large scale of deployment. If a 100 HP compressor could be used instead costs can be cut further, as shown in the following chart.

Cost of Electrics:

Annual cost at full load = $4,320
Annual cost at idle = $5,040
Annual operating cost for 200 actuators = $9,360
Replacement cost for actuators = $60,000
Total cost for electric solution per year: $69,360

Because of the large scale of deployment, replacement costs of actuators increase the annual system cost, making electric actuators impractical. The solution needs a productivity improvement to make it worthwhile pursuing.



Conclusions

In this instance, pneumatics proved to be the more economical alternative. Compressor utilization is more efficient because of the higher number of pneumatic actuators deployed. Electric actuator replacement costs drive up the electric system costs. Even with a modular electric actuator design, costs are substantially above pneumatic.

Summary

The initial cost of actuators is only one small consideration in a list of issues for intelligent and cost-efficient automation implementation. The high cost of electric components can be misleading, but so can high compressor operating costs. Neither tells the whole story. Pneumatic operating costs can be controlled by sizing the compressor to fit the scale of pneumatic device deployment. Electric actuator costs can be minimized by accurate sizing, buying motion control components separately, and selection for applications where their use improves process efficiency. Pneumatic actuators have advantages in cost, size, thrust and speed, but electrics have advantages in accuracy, flexibility and control, making machinery and processes more efficient. An upfront estimated assessment of an application can prevent oversights and produce considerable cost savings in the long run while also ensuring that equipment matches the tasks at hand.

APPENDIX

Assessing Pneumatic Performance and Costs

Pneumatic cylinders provide more force and speed per unit size than any other technology except hydraulic. Force is proportional to piston surface area. To calculate force:

F = (piston diameter inches)^{2}x(0.785)x(air pressure pounds/in^2)

For example, a 1-1/16 inch diameter cylinder with 100 lbs/in^2 pressure produces 89 pounds of force. If more force is needed, increase air pressure. If less force is needed, decrease air pressure. If speed needs to be reduced, use flow controls.

Speed and force can be controlled independently. For more or less force, raise or lower the air pressure using a regulator. For reduced speed, use a flow control. These factors combine to make application sizing very simple.

Pneumatic Operating Cost Calculations

To make cost estimation simpler and faster, the equation below is a simplified estimate of compressor operating cost.

Annual cost of a compressor = ((HP)*(0.746)*(annual operating hours)*($/kWh))/(efficiency)

HP represents the compressor horsepower, annual operating hours represents the number of hours the compressor operates fully loaded per year, ($/kWh) represents the cost of electricity calculated from an electric bill (divide the bill amount by kilowatt hours consumed) in dollars per kilowatt hour, and efficiency is the efficiency of the compressor motor, as stated in the compressor specifications. According to the Department of Energy, 24% of the total operating cost of the compressor is due to maintenance while 76% is due to electricity. Using this information, the cost of compressed air including maintenance may be estimated as follows.

Annual cost of compressed air = ((HP)*(0.982)*(annual operating hours)*($/kWh))/(efficiency)

If the compressor is rated at 200 HP and it operates fully loaded for 8 hours a day, 5 days a week, and if the cost of electricity is $0.10/kWh, and if the compressor is 90% efficient fully loaded, the calculated annual cost of compressed air is given below.

Annual cost of compressed air = ((200)*(0.982)*(8*5*52)*($0.10))/(.9) = $45,390.24

The equation above assumes that the compressor is either on at full load or off. In reality, compressors are often on consuming electricity at no load while they are not being used, in the amount of about 20 to 30% of the full load usage, and compressor efficiency is lower when it is partially loaded (85% instead of 90% in our example). If during the week the compressors are left powered on at no load, we might add to that:

No load cost of compressed air = ((HP)*(0.982)*(annual operating hours)*($/kWh)*(.25))/(efficiency)
= ((200)*(0.982)*(16*5*52)*($0.10)(.25))/(.85)
= $24,030.12

Total operating cost is found by adding the full load and no load costs, which amounts to over $69,000. If the actual compressor shaft horsepower is 5% greater, then the costs above each increase by 5%. If the compressor is shut off instead of left on continually, costs drop to $45,000.

The cost of replacement cylinders must also be considered:

Annual replacement costs of cylinders = (qty)*(cost each)/(life in years)

Fully loaded compressor operating costs, no load compressor operating costs and total replacement cost of the cylinder are added to determine total system cost. Divide this number by the number of cylinders deployed to find the average cost per cylinder.

Electric Actuator Operating Cost Calculations

We will use the following equation to estimate the operating cost of an electric actuator.

Annual cost of an electric actuator = ((I)*(V)*(0.001)(annual operating hours)*($/kWh)*(duty cycle)

(I) represents the current draw of the power supply or controller that provide power to the motor windings, (V) represents the AC line voltage, while (duty cycle) represents the percentage of time the motor is drawing the current specified. Typically, a motor draws full current part of the time, a portion of the full current part of the time, and is idling another percent of the time under no load, when most of the current draw is due to the control electronics.

Assume that we are using a DC power supply to provide power to the actuator (a DC power supply is not built into the controller). This power supply provides 48 V DC at a maximum of 12 A. From the manufacturer's data sheet, the power supply draws a maximum of 8 A at 120 VAC. Our electric actuator cost calculation assumes that the motor of our actuator draws 6 A DC fully loaded, and 1 A DC at idle. Also assume that half the current draw of the actuator translates linearly to half the current draw of the power supply. Annual operating hours and cost of electricity are from our previous example. Also assume we are idling half the time and drawing full load half the time. Assumptions for specific applications must be evaluated independently.

Annual cost at full load = ((120)*(4)*(0.001)(8*5*52)*($0.10)*(.5) = $49.92

Annual cost at idle = ((120)*(.67)*(0.001)(8*5*52)*($0.10)*(.5) = $8.36

For total operating costs, add the costs together, which amounts to about $58 annually per actuator or $2,900 for 50 actuators.

We also have to estimate replacement costs.

Replacement costs of actuator = (cost of actuator)*(quantity)/(life span)

Replacement costs of electronics = (cost of electronics)*(quantity)/life span

If the actuator system costs total $1,200, of which the actuator itself costs $900 and has a 3-year life span, total annual costs are about ($900/3)+$58 or $358 for every actuator deployed. If the electronics are buried in the actuator and the whole unit must be replaced when the product fails, the total costs per year of ownership amount to $458 per year per actuator. Typically, electronics will have a longer life span and their contribution to maintenance expenses will be smaller. Life spans identified here are assumptions. Actual life spans of components will vary.

Example 1 from Article

Pneumatic Cost Calculations

Annual cost of compressed air, full load = ((HP)*(0.982)*(annual operating hours)*($/kWh))/(efficiency)
No load cost of compressed air = ((HP)*(0.982)*(annual operating hours)*($/kWh)*.25)/(efficiency)
Replacement costs of cylinders = (qty)*(cost each)/(life in years)
Total cost per year = sum of above

Annual cost of compressed air, full load = ((100)*(0.982)*(2000)*(.1))/(.9) = $21,822
No load cost of compressed air = ((100)*(0.982)*(6700)*(.1)*.25)/(.85) = $19,351
Replacement costs of cylinders = (20)*(50)/(3) = $333
Total cost per year = $21,822 + $19,351 + 333 = $41,506

Electric Operating Cost Calculations

Electric actuator annual cost, full load = (I)*(V)*(0.001)(annual operating hours)*($/kWh)*(duty cycle)*(qty)
Electric actuator annual cost, no load = (I)*(V)*(0.001)(annual operating hours)*($/kWh)*(duty cycle)*(qty)
Replacement costs of actuator = (cost of actuator)*(quantity)/(life span)
Replacement costs of electronics = (cost of electronics)*(quantity)/life span
Changeover labor savings = (hr/week)*(qty workers)*($/hr pay)*52
Lost production savings = (hr/week)*(parts/hr)*($/part)

Electric actuator annual cost, full load = (4)*(120)*(0.001)(2000)*(.1)*(.3)*20 = $576
Electric actuator annual cost, no load = (2)*(120)*(0.001)(2000)*(.1)*(.7)*20 = $672
Replacement costs of actuator = (900)*(20)/(3) = $6,000
Replacement costs of electronics = (1,200)*(20)/10 = $2,400
Changeover labor savings = (2)*(2)*(30)*52 = $6,240
Lost production savings = (2)*(100)*(1)*52 = $10,400
Total cost of electric deployment = $576+$672+$6000+$2,400 = $9,648
Net SAVINGS due to process efficiency improvement = $10,400+$6,240-$9,648 = $6,992

Example 2 from Article

Pneumatic Cost Calculations

Annual cost of compressed air, full load = ((200)*(0.982)*(2,000)*(.1))/(.93) = $42,237
Replacement costs of cylinders = (150)*(50)/(3) = $2,500
Total cost per year = $42,237 + $2,500 = $44,737

Electric Operating Cost Calculations

Electric actuator annual cost, full load = (4)*(120)*(0.001)(2,000)*(.1)*(.3)*150 = $4,320
Electric actuator annual cost, no load = (2)*(120)*(0.001)(2,000)*(.1)*(.7)*150 = $5,040
Replacement costs of all-in-one actuator = (1,200)*(150)/(3) = $60,000
Total cost per year = $4,320+$5,040+$60,000 = $69,360

RESOURCES/BIBLIOGRAPHY

US Department of Energy, Determine the Cost of Compressed Air for Your Plant (http://www.energystar.gov/ia/business/industry/compressed_air1.pdf)