Parker

The Straight Story on Linear Actuators

Linear actuators can be powered by pneumatics, hydraulics, or electric motors. Which is best for your job? Let's find out.

Linear actuation is employed everywhere, for packaging, life sciences, transportation, and factory automation jobs. Pneumatic and hydraulic linear actuators operate on pressure differentials; electromechanical actuators are either linear motors or rotary motors driving a screw or belt. The selection and use of these technologies is greatly influenced by the user's technical knowledge, the project's budget, energy sources, and performance tradeoffs.

This hydraulic cylinder features tie-rod construction for extended life under high working pressures, and pressure-energized body seals to prevent leaks.

For example, pneumatic actuators don't deliver high force output, but are well suited when a cost-effective, easy start-up solution is required. Hydraulic linear actuators generate a lot of noise and can leak nasty fluid, but are ideal for high force applications that require precise control. Electromechanical actuators have high energy requirements and are more difficult to install and maintain, but are preferred for complex, multi-axis, motion control applications. Let's look at all of this in more detail.

Electromechanical linear actuators can produce thrust to 5,500 N. Timing belt or rack and-pinion configurations are two options.

Pneumatics: Nice and easy

Pneumatic actuation is the conversion of compressed air into linear force. Forms of this technology have been employed for centuries; bellows in basic metal forming is one example. However, pneumatics were largely manual until the advent of electricity and the mechanical compressor in the early 19^{th} century.

The interaction of pressure, volume, and temperature of a gas are governed by the perfect gas laws, courtesy of Boyle, Charles, and Gay Lussac. Combining these is the general gas law:

$$P_1 \times V_1 / T_1 = P_2 \times V_2 / T_2$$

This relationship, plus the resultant force derived from pressure acting on an area, governs the use of pneumatics: Force = Pressure x Area.

Typical applications (die casting, extrusion, injection molding, and precision machining) involve extreme temperature, safety and inspection, and magnetic systems — because pneumatic actuators don't have the magnetic field issues of motors. Too, there have been several recent improvements in pneumatic design.

Position feedback with proximity sensors and LPSOs is used for part location, inspection, or control-loop feedback, taking pneumatics beyond simple bang-bang applications, moving parts from point *A* to point *B*.

Better sealing from contamination, with wiper and metallic scraper options that remove external debris and adherents, has increased the use of pneumatic linear actuators in applications requiring wash down — such as food processing and packaging — as well as applications involving weld flash, paint, or concrete. And, enhanced surface coatings, such as powder coat, lectrofluor, and anodizing of the two typical pneumatic cylinder materials (aluminum and steel) are expanding pneumatics use in caustic wash down environments.

Pressure losses and the compressibility of air do sometimes make pneumatics less efficient than other linear technologies. Too, compressor and delivery system limitations dictate that pneumatic systems operate at lower pressures, providing lower forces than other linear systems. Component materials (mostly aluminum) and construction of fasteners and threaded end covers dictate lower operating pressures. As a result, pneumatic cylinders typically operate with compressed air at 100 psi or less, in contrast with hydraulic cylinders, which operate on pressurized hydraulic fluid at over 500 psi. So, speed ranges from a couple of inches per second to 60 in./sec. Force output is dependent on maximum pressure rating and related bore size: Aluminum actuators have a maximum pneumatic pressure rating of 150 psi with bore sizes ranging from ½ to 8-in. for approximately 30 to 7,500 lb. Most steel actuators have a maximum pneumatic pressure rating of 250 psi with bore sizes ranging from approximately ½ to 14 in. — translating to about 50 to 38,465 lb of force.

Hydraulics: Rugged choice

Forms of hydraulic cylinders have been used for centuries to generate force and motion. Their operation is based on Pascal's principle: *Pressure applied to an enclosed fluid is transmitted undiminished to every portion of the fluid and the walls of the containing vessel.* So, the amount of force applied by the cylinder is the product of the hydraulic input pressure times the area of the cylinder's piston.

Hydraulic systems are suitable for rugged applications that require high force output. However, hydraulic systems generate noise and, without proper maintenance, they can leak. If a pneumatic system leaks air, efficiency falls. But if

Technology Comparison

Attribute	Electromechanical	Hydraulic	Pneumatic
Cleanliness	High	Low	Med
Cost Effectiveness	Low	Med	High
Ease of Start-up	Low	Med	High
Energy Requirements	High	Med	Low
Energy Storage	N/A	High	Low
Force Output	High	High	Low
Environmental Leaks	N/A	High	Med
Motion Control	High	Med	Low
Noise Generation	Low	High	Med
Ruggedness	Med	High	Med
Serviceability	Low	Med	High

They all put F = ma or T = Ia into action, but every linear actuator technology has specific strengths, and is only best for certain applications.

a hydraulic system leaks, it's much more serious. Fluid is lost, causing cleanliness issues and possible damage if it gets on other system components or products.

More equipment is needed as well. A compressor, regulator, and directional valve are all that's needed for a pneumatic system. But hydraulic systems require a fluid reservoir, motors and pumps, release valves, and equipment to reduce noise and heat levels. They must be connected to a motor or gasoline engine-powered pump to draw fluid from a reservoir, a pressure relief valve to control maximum system pressure, and a directional valve to control the flow of hydraulic fluid into and out of the cylinder.

Controls: In a simple two-position unit, the directional-valve spool moves to an end and not an intermediate position — and it cannot control cylinder velocity. Systems using this type of directional valve regulate piston velocity with a flow control valve that allows free flow of oil into one side of the piston and controlled flow (by adjusting an orifice) from the opposite side of the piston.

More complex cylinders fitted with electronic sensors generate electrical signals that reflect off magnets during motion — a signal that locates piston position along the cylinder stroke. Then, the electronic signal can be processed to determine piston velocity or acceleration, and a servo directional-control valve can control the cylinder piston speed and stop it at any point in the cylinder's stroke.

What's their strength? Hydraulic systems deliver much tighter control than pneumatic systems and their spongy-acting, compressible air. When available space is a concern, hydraulic systems can deliver significantly higher force density.

Electromechanical: Controllable
When driven by a rotary motor, these linear motion systems employ one of four rotary-to-linear conversion systems: ballscrew, roller screw, Acme (lead) screw, or belt drive. But another electromechanical actuator is the linear motor. Let's review these first.

A linear motor is like a rotary motor that has been unwrapped. The motor coils make up the forcer. Depending on the design, one or two rows of magnets comprise the magnet track. Now, in a rotary motor, the rotor spins while the stator is fixed. But in a linear motor, either the forcer or the magnet track can be the moving component, which is then integrated with an appropriate linear bearing. By sending electrical current to the forcer, the resulting magnetic field interacts with the magnet track and drives the linear motor carriage forward and back.

Linear motors have high dynamic performance, with acceleration of greater than 20 *g*s at velocities of 10 m/sec and higher. Due to the direct drive nature of linear motors, there are no mechanical components to add backlash, torsional windup, or other positioning errors to the system. Sub-micron resolution and repeatability are commonplace. And, because the motor is directly coupled to the load, there are fewer components to fail, which adds long term value.

Application demands typically dictate what type of linear motor is most suitable. Iron core linear motors use one row of magnets and a forcer with windings that are wrapped around iron poles.

The nature of these windings provides a very efficient magnetic path in the motor that produces the highest forces within the linear motor family.

On the other hand, in ironless motors, windings are wrapped flatly and ride in a balanced, U-shaped magnet track. So, ironless motors are ideal where smooth motion and a higher degree of accuracy are required, and for applications involving extremely high accelerations.

Slotless linear motors are a hybrid design between ironless and iron core motors. The design uses only one row of magnets on the track, resulting in a motor with lower attractive forces and less cogging than iron core motors. They are lower in cost per package size than ironless motors.

Piezomotors use crystals to actuate a linear stage. Electrical excitation to the motors causes the crystals to slightly change shape and distort, pushing the stage a tiny distance, usually measured in nanometers. Exciting the crystals at a high frequency generates smooth, precise motion, making piezomotor positioners suitable for applications with very fine positioning requirements — metrology and ultra-fine focusing of optical assemblies, for example.

Ballscrews

The majority of linear motion applications convert motor torque to linear thrust using ballscrews. High thrust (to 2,000 lb) is their calling card, and they generate high speed at shorter stroke lengths, to 70 in./sec. Ballscrews can be precise to 10 to 50 mm and some manufacturers rate them for 100 to 2,540 km of travel.

Sometimes, their bearings ride on the flights or leads of the screw for 95% efficiency or better; the ball nut uses one or more circuits of recirculating steel balls that roll between the nut and ballscrew threads. Rolled ballscrews are lower cost, whereas ground ballscrews deliver higher critical speeds.

In some models, reengineered recirculating ball tubes are designed especially for screws, including lubrication seals on the ball nut end, which reduces noise as much as 7 dB.

Many positioning tables on the market today use designs that integrate the ballscrew for robustness. Other updates to screw positioning tables include motors integrated onto the end of the screw itself. This reduces backlash or windup by eliminating the coupling from the motor shaft to the screw shaft. The rotor is on the screw, and the stator wraps around that.

Roller screws

This is the ballscrew's newer cousin. The latest roller screws incorporate multiple roller bearings in the nut, which operate like planetary gears around the screw itself. Roller screws provide high efficiency, duty cycle exceeding 50%, and acceleration from one to two *g*s. Typical stroke lengths range from 5 mm to 2 m; speeds can reach 70 in./sec. In short, roller screws have the speeds of ballscrews, but much higher thrust capacity and force density because of the line (not point) contact on the screw flights.

Roller screws are being put to use in many small machine presses and injection molding machines.

The downside of roller screw technology is its low availability: Because the technology is relatively new, there are few manufacturers, so lead-time and prices are typically 40 to 100% higher than those of ballscrews.

Acme screws

Acme screws, also known as lead screws, are one of the simplest mechanisms for converting rotary power to linear. They employ a plastic or bronze solid nut that slides along the threads of a screw like an ordinary nut and bolt. However, because there are no rolling ball bearings, as on a ballscrew or roller screw, Acme screws transfer only 30 to 50% of the motor's energy to driving the load. The remaining energy is lost to friction and dissipated as heat. This heat generation limits the duty cycle of Acme screws to less than 50%. But Acme screws are useful for applications with low speeds and duty cycles below 50%, and those that must hold position while the motor power is off — holding a vertical load, for example.

Acme screws are low cost. The screw can be rolled or ground depending on the need for precision, and the nut can also be pre-loaded to reduce backlash. Some newer screws are incorporated into the rotary motor shaft for an integrated motor positioner, resulting in a much shorter package. By eliminating a coupling, length can be reduced one to two inches.

However, when integrating a motor onto a lead screw, the motor requires adequate shaft support. Traditional coupling design, which uses angular contact bearings or thrust bearings to handle the load, frees the motor bearings exclusively for rotation. But when the screw is integrated into a motor, the thrust on the screw is concentrated on the motor bearings. Because these radial bearings are not designed for high axial loads, these motors can wear out much faster than on non-integrated designs.

Belt drives

Belt drives are another method for converting rotary to linear motion. They offer many of the benefits of ballscrews, but have fewer moving parts and no critical speed limitations, for higher travel speeds with minimal component wear. Belt-drive designs, however, have lower repeatability and accuracy and often require a gearbox-fitted motor, to overcome the inertias of the load and actuator. Thrust capability is also less than that of a screw drive, because of belt tensile strength limitations.

Still, belt-driven linear actuator maintenance is generally low. Some product designs allow tensioning at the carriage. Others allow tensioning at the idler end cap of the actuator, because it eliminates the need to remove any load while tensioning the belt.

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