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VALVE ACTUATORS

Harness Electricity to Operate Valves

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Actuators automate valves by converting an input signal into motion. This article explains the basics of electric actuator design and explores the different types of electric actuators.

Valves control the flow of a fluid through a piping system by opening, closing, or partially obstructing a flow path. All valves require actuation, which may be manual (*i.e.,* by a person) or automated — *i.e.,* powered by pneumatic or hydraulic pressure or by electricity. This article focuses on electric valve actuators.

An electric actuator is an electromechanical device that interprets a signal from the control system, generates torque or thrust via a motor, and positions a valve accordingly. Electric actuators are operated by a three-phase or single-phase alternating-current (AC) or direct-current (DC) power source, and they have a manual override device, such as a hand wheel, chain wheel, or operation nut, for use in the event of a power loss. They can be operated locally or from a central control room.

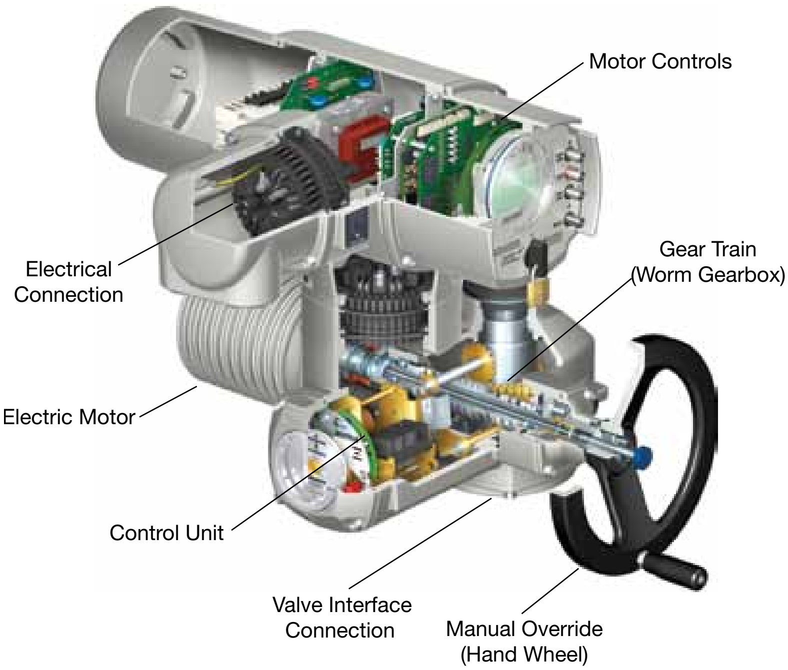
The basic electric actuator consists of an electric motor, a gear train, a control unit, a manual override device, motor controls, and a valve interface connection where the actuator's motion is transferred to the valve (Figure 1). It may also have integral local or remote-mounted controls.

Electric motor

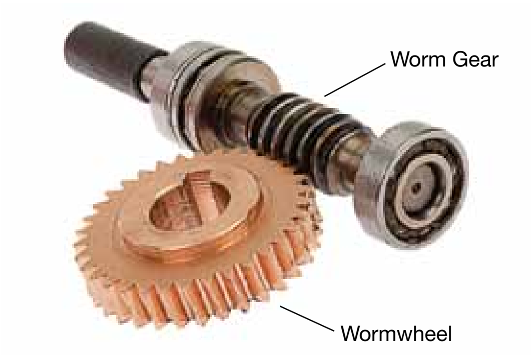
All electric actuators have an electric motor that generates torque. These motors are three-phase AC, single-phase AC, or DC powered. They are specially designed to have high starting torque, and are mechanically coupled with the actuator gear train. Most electric actuator motors are thermally protected to prevent overheating and damage from excessive valve and actuator operation.

Gear train

The gear train multiplies the torque generated by the electric motor and reduces the speed of the electric motor at the valve interface. The gear train is characterized by a gear train ratio, which is the number of input turns divided by the number of resulting output turns. For example, a gearbox with a ratio of 8:1 requires eight turns at the input of the gearbox to yield one output turn.

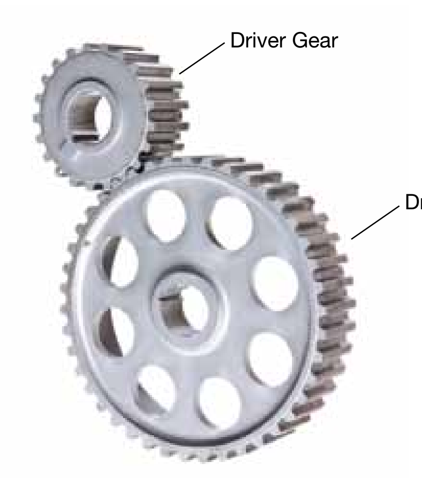


▲ **Figure 1.** Electric actuators generate torque or thrust with a motor, and position a valve according to an input signal.



▲ **Figure 2.** Worm gearboxes typically have high gear train ratios, as there are many more teeth on the wormwheel than on the worm gear.

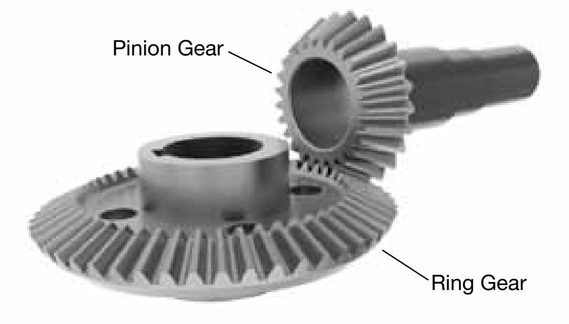
▼ **Figure 3.** Spur gearboxes typically have low gear train ratios and high efficiencies.



Depending on the size and speed requirements of the application, various gear types, such as worm gears, spur gears, and bevel gears, can be used within the actuator gear train.

A worm gearbox consists of two components, a wormwheel and a screw-shaped worm gear (Figure 2). The gear train ratio of a worm gearbox is defined as the number of teeth on the wormwheel divided by the number of threads on the worm gear. Typically, the worm gear can be considered a single tooth, because it acts like a screw with a single start that meshes with the wormwheel. This simplifies the gear train ratio to the number of teeth on the wormwheel.

A spur gearbox consists of two gears mounted on parallel shafts, a smaller driver gear and a larger driven gear (Figure 3). The gear train ratio of a spur gear is the number of teeth on the driven gear divided by the number of teeth on the driver gear. For example, if the driven gear has 64 teeth and the driver gear has eight teeth, the gear train ratio is 8:1. This ratio defines the number of driver gear revolutions required to turn the driven gear one complete revolution.



▲ **Figure 4.** Bevel gearboxes typically have low gear train ratios and have rotating shafts oriented at an angle up to 90 deg.

Similar to the spur gear, a bevel gearbox has a smaller pinion gear that drives a larger ring gear (Figure 4). However, instead of being mounted on parallel shafts, the shafts of a bevel gearbox are oriented at an angle of up to 90 deg. A bevel gearbox's gear train ratio is the number of teeth on the ring gear divided by the number of teeth on the pinion gear.

The efficiency of a gear train depends on the type of gearing selected, the lubrication used on the gearing, and other factors such as friction and heat. To calculate a gear train's actual output torque, the input torque is multiplied by the gear train ratio and the efficiency. The efficiency of the gears is determined by comparing the friction factor associated with the gearing material to the angles of the gear teeth themselves. Spur and bevel gearboxes typically have efficiencies of around 90%, while worm gearboxes are generally about 35% efficient.

The overall mechanical advantage of a gearbox is the output torque divided by the input torque. The mechanical advantage is an important parameter because it allows either the output torque of a gearbox to be calculated based on the input torque provided, or the necessary input torque to be calculated based on the output torque required by the application. Alternatively, the mechanical advantage can also be calculated by multiplying the ratio and efficiency of the gear train.

Control unit

The actuator gear train interfaces with the control unit. The control unit measures the number of actuator output revolutions and compares that to a setpoint to determine the valve's position. It has a position feedback device, and position and torque limit switches that protect the valve and actuator against overload and damage. Limit switches operate via a simple electrical circuit — when the switch is on, the circuit is closed, and electricity travels to the actuator motor; when the switch is off, the circuit is open, and electricity does not flow to the actuator, which stops the valve's motion.

Position limit switches are provided at a minimum for both the full-open and full-closed valve positions. Limit switches can also be used to stop the valve at predetermined intermediate positions. For example, during process startup and shutdown, intermediate position switches can be used to regulate flow through the valve and pipeline.

Torque limit switches prevent damage to the valve by measuring the actuator's output torque and shutting off the motor if the output torque rises above a preset value. Depending on the application, the actuator can be configured to stop based on either position or torque limit switches.

Electric actuators may either be intrusive or nonintrusive. The conventional intrusive electric actuator utilizes an electromechanical control unit in which both valve position and required torque are mechanically measured and micro switches are activated when the end of travel or a maximum torque value is reached. Position and torque limits are mechanically set inside the actuator with a tool, typically a screwdriver.

Electronic nonintrusive actuators use high-resolution magnetic transmitters instead of micro switches to measure valve position. Both position and torque limit settings are made with the local controls at the actuator or with remote controls at a computer. These settings are configured without physically opening the actuator (hence the name nonintrusive).

▲ **Figure 5.** A hand wheel is one type of manual override device provided for electric actuators.

Manual override

In the event of a power outage, a manual override such as a hand wheel, chain wheel, or operation nut can be used to control the valve. A hand wheel (Figure 5) is sized to minimize the rimpull, *i.e.*, the amount of force required to manually operate the valve. A chain wheel (Figure 6) is typically utilized when the actuator is mounted in a remote or inaccessible location. An operation nut (Figure 7) is appropriate when a large number of rotations (*e.g.*, more than about 100 turns of the handwheel) or a large rimpull (*e.g.*, more than about 80 lb) is required to operate the valve. An operation nut can also be used as an alternative to a chain wheel when the actuator is not easily accessible.

For safety reasons, the manual override must not be engaged while the electric motor is operating — *i.e.*, the hand wheel, chain wheel, or operation nut should not rotate while the actuator is being operated electrically. Thus, most manual overrides have a local declutch mechanism to remove the electric motor from the actuator gear train and engage the manual override device. Upon return of electric power to the actuator, the declutch mechanism automatically engages the electric motor and disengages the manual override device.

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▲ **Figure 6.** A chain wheel manual override may be used if an actuator is located in a remote or inaccessible area.

▼ **Figure 7.** When a large torque is required to operate the valve, an operation nut may be used as the manual override device.

Motor controller

Electric actuators require a motor controller to direct the performance of the electric motor. The motor controller (which is separate from the control unit) is responsible for starting and stopping the motor and selecting forward or reverse rotation. It consists of a control power supply, reversing motor contactors, and local operation controls (*e.g.*, push buttons and lights to indicate actuator operation). The control power supply, used for safety reasons, is typically 24 VDC or 115 VAC and supplements the main three-phase, single-phase, or DC motor power supply.

The control power supply acts as a signal and links the actuator and control room (*i.e.*, its voltage runs between the push buttons and the electric actuator). When the actuator receives a control signal, the reversing motor contactor allows power from the main motor power supply to flow to the actuator, which moves the valve in either the open or closed direction. Low-voltage power supply is used at the push button because it is safer than the main power supply. Furthermore, the cost to wire the control power supply is less than the cost to wire the main power supply from the push button to the actuator because the required wire size is smaller.

Plant engineers and operators can monitor the valve and actuator on a local display (Figure 8) or in a control room. Many actuators display the current valve position; some have the ability to display and store complete diagnostic information, such as the number of operations in the previous 24 hours or the amount of torque required to complete a valve stroke. This information helps the operator monitor the performance of the process and predict maintenance requirements.

Electric actuator controls can be as simple as a push button with indicating lights to signal when the valve reaches the open or closed position, or as complicated as a full LCD display with remote control capabilities.

▲ **Figure 8.** Electric actuators can be operated via manual switches or a local display panel.

Output motion

An electric actuator and the valve it operates are typically directly connected. A direct-mount electric actuator is bolted to the valve's mounting flange. However, the actuator can be mounted separate from the valve and connected via a drive shaft or an extended threaded stem. This typically is required when the valve is buried or in a vault and the operator needs easy access to the actuator.

The actuator output mechanism can vary and depends on the valve interface. For torque-only applications, a shaft with a keyway is often used to operate the valve. For thrust applications, a threaded stem translates the torque produced in the actuator to a linear force at the valve. Special bearings within the actuator support the linear force.

If the application involves high temperatures, the actuator must be able to withstand thermal expansion of the valve stem. Actuator drive train damage can be avoided by incorporating an output drive with a linear spring to allow for valve stem expansion.

The actuator's output motion may be linear or rotary; rotary output may be multi-turn or part-turn.

Multi-turn actuators

Gate, globe, pinch, and diaphragm valves are the most common types of multi-turn valves. A multi-turn valve requires more than one full revolution of the actuator to operate the valve. In other words, it requires more than 360 deg. of rotational motion to complete one full valve stroke (*i.e.*, to run from the fully open position to the fully closed position).

Depending on the type of valve, the actuator may operate an input shaft or a threaded stem on the valve. Valve stem threads convert the torque generated by the actuator into a linear force or thrust. This force is typically measured in pounds, ounces, or kilo-Newtons.

In some large multi-turn applications, the use of an electric actuator alone may not be cost effective or generate enough torque. In either of these cases, a multi-turn gearbox can be inserted between the multi-turn actuator and the valve. This increases the overall output torque generated by the actuator, but also increases the number of turns and the time required to stroke the valve. The torque increase generated by the multi-turn gearbox is defined by its mechanical advantage, which depends on the type of gearing, the gear ratio, and the efficiency of the gearing. The number of turns increases by the overall gear train ratio of the multi-turn gearbox. Most multi-turn gearboxes use either spur or bevel gearing due to their inherently high efficiencies. However, worm gears can also be used for specific multi-turn applications. An example of a large application that requires a multi-turn gearbox is a main steam isolation valve at a power plant.

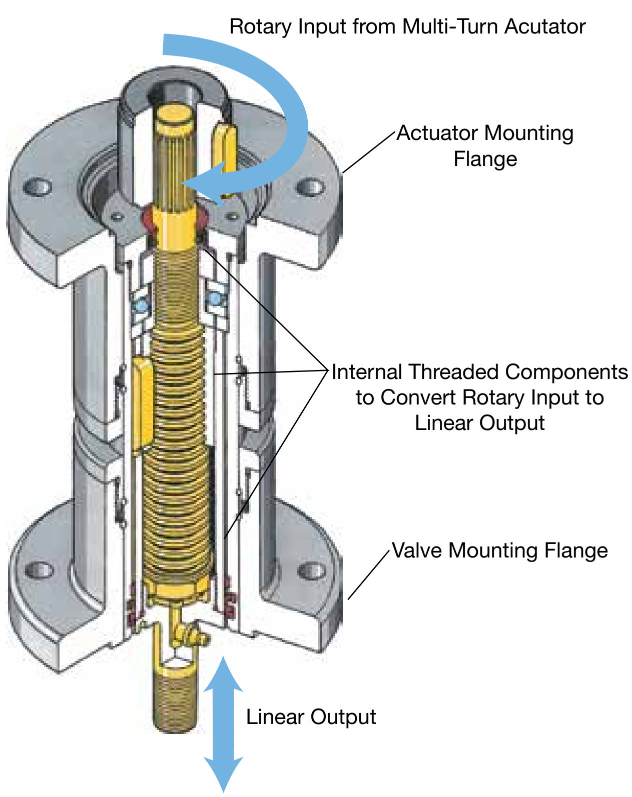
Part-turn actuators

Part-turn actuators are used with valves that require less than one full output revolution to complete the valve stroke, such as butterfly, plug, and ball valves. The quarter-turn actuator, which provides approximately 90 deg. of actuator output rotation, is the most common part-turn actuator. Part-turn actuators provide only torque; they do not generate thrust.

Direct-mount part-turn electric actuators are suitable for many part-turn applications. Part-turn gearboxes can be selected to increase the output torque. Because part-turn gearboxes utilize worm gearing, multiple input turns are needed to generate 90 deg. of output at the valve interface. Therefore, a part-turn gearbox must be coupled with a multi-turn actuator in order to generate the large torque required for a part-turn valve. It is usually more cost-effective to couple a multi-turn actuator with a part-turn gearbox than it is to purchase a large direct-mount part-turn electric actuator.

Linear actuators

Linear actuators use linear motion to produce thrust, rather than torque, to open and close a valve. Linear valves include gate, globe, pinch, and diaphragm valves. In true linear actuators, a rod or cylinder pushes and pulls the valve open and closed instead of a threaded stem.



▲ **Figure 9.** Linear gearboxes convert the torque generated in multi-turn actuators into linear thrust via threaded components.

One way to generate a linear force is with a multi-turn actuator coupled to a linear gearbox. The linear gearbox converts the rotation and torque from the multi-turn actuator into a linear motion and force by means of threaded components within the linear gearbox (Figure 9).

Linear applications can have size requirements similar to those of either multi-turn or part-turn applications. However, only thrust is considered when selecting a suitable linear electric actuator.

Applications

Electric actuators can be found anywhere a fluid process is automatically controlled by a valve. This can include water and wastewater treatment plants, power plants, and petrochemical plants, among other industrial applications. For example, at a conventional power plant, electric actuators can control the volume of discharged water from a boiler, the ratio of air to fuel fed into an incinerator, the flow of high-pressure steam to a turbine, and they can operate dampers that control the amount of exhaust that exits the power plant. Solar-powered electric actuators have recently been used in remotely located farm irrigation systems.

Based on the application, the environment in which the electric actuator operates can drastically vary. Actuators can require coatings, greases, seals for high- or low-temperature processes, and special industry approvals. For example, in a petrochemical plant where explosive gases may be present, explosionproof actuators may be required.

Closing thoughts

It is important to remember that electric actuators are ultimately responsible for automating and controlling valves, and they are often added to existing manual valves to improve automation control in a system. Electric actuators are a critical tool for industrial applications that require the precise control of fluids and chemicals. CEP

Additional Reading

1. **Gordon, B.,** "Valves 101: Types, Materials, Selection," *Chem. Eng. Progress,* **105** (3), pp. 42–45 (Mar. 2009).

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