

M66

Cylinder and Vane Actuators and Controls— **Design and Installation**

First Edition



American Water Works
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Cylinder and Vane Actuators and Controls— Design and Installation



**American Water Works
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Cylinder and Vane Actuators and Controls— Design and Installation

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Library of Congress Cataloging-in-Publication Data

Cylinder and vane actuators and controls: design and installation. — First edition.

pages cm — (AWWA manual; M66)

Includes bibliographical references and index.

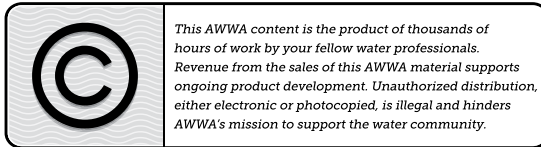
ISBN 978-1-62576-116-3 (alk. paper)

1. Slide-valves. 2. Hydraulic servomechanisms. 3. Pneumatic control valves. 4. Blades. 5. Waterworks. I. DeNileon, Gay Porter, editor. II. American Water Works Association.

TD491.C95 2015

628.1028'4--dc23

2015035968



ISBN-13 978-1-62576-116-3

eISBN-13 978-1-61300-347-3

Printed in the United States of America
American Water Works Association
6666 West Quincy Avenue
Denver, CO 80235-3098
awwa.org



Contents

Figures, v	
Tables, vii	
Preface, ix	
Acknowledgments, xi	
Chapter 1 Introduction	1
History, 1	
Purpose, 2	
General Application, 3	
Supply Medium, 3	
References, 5	
Chapter 2 Principles of Operation	7
General Descriptions, 7	
Thrust Calculations, 9	
Torque Characteristics, 11	
Position Characteristics, 13	
Sizing Considerations, 13	
Actuator Torque Characteristics, 14	
References, 16	
Chapter 3 Types of Construction	17
Linear Cylinder, 17	
Quarter-Turn Scotch-Yoke, 19	
Quarter-Turn Rack-And-Pinion, 20	
Quarter-Turn Pivoting Cylinder, 21	
Quarter-Turn Link-Lever, 21	
Quarter-Turn Vane, 22	
References, 23	
Chapter 4 Controls	25
Valve Control Concepts, 25	
Control System Components, 26	
Solenoid Valves, 26	
Flow-Control Valves, 28	
Control Circuits, 29	
Positioners, 31	
Position Feedback Devices, 33	
Fluid Power Supply Systems, 33	
Air Compressor Systems, 33	
Hydraulic Oil Supply Systems, 34	
Electro-Hydraulic Actuators, 35	
Water Supply Systems, 36	
References, 37	

Chapter 5	Special Equipment	39
	Handwheel Override, 39	
	Lockout Mechanism, 39	
	Spring Return, 40	
	Accumulators, 42	
Chapter 6	Installation and Adjustment	45
	Storage, Handling, and Mounting, 45	
	Setting of the Travel Stops, 47	
	References, 48	
Chapter 7	Maintenance and Safety	49
	Regular Maintenance, 49	
	Troubleshooting, 50	
	Safety Concerns, 51	
	Glossary, 53	
	Index, 57	
	AWWA Manuals, 61	

Figures



- 1-1 Quarter-turn vane-type actuator provides remote control of a ball valve, 2
- 2-1 Cylinder actuator provides linear thrust, 8
- 2-2 Various quarter-turn mechanisms, left to right: lever; link-and-lever; rack-and-pinion; scotch-yoke, 9
- 2-3 Rack-and-pinion mechanism, 10
- 2-4 Vane mechanism, 10
- 2-5 Typical slide gate for waterworks applications, 10
- 2-6 Typical globe valve geometry, 11
- 2-7 Both forces A and B produce a torque of 20 ft-lb, 11
- 2-8 Torques for a butterfly valve, 12
- 2-9 Torque characteristics of various cylinder and vane actuators, 14
- 3-1 Hydraulic cylinder, 18
- 3-2 Slide gate with cylinder actuator, 18
- 3-3 Scotch-yoke lever actuator, 19
- 3-4 Slotted lever mechanisms, 20
- 3-5 Rack-and-pinion actuator, 20
- 3-6 Rack-and-pinion actuator with double-acting external cylinder, 21
- 3-7 Pivoting cylinder actuator, 22
- 3-8 Link-lever actuator, 22
- 3-9 Vane actuator, 23
- 4-1 Basic hydraulic symbols, 27
- 4-2 Four-way solenoid valve and schematic, 28
- 4-3 Flow-control valve, 29
- 4-4 Basic control circuit for double-acting cylinder, 30
- 4-5 Basic control circuit for double-acting cylinder with timed stroke, 30
- 4-6 Control circuit for a pneumatic spring return actuator, 31
- 4-7 Valve positioner, vane actuator, and handwheel override worm gear unit mounted on a butterfly valve, 32
- 4-8 Pneumatic valve positioner, 32
- 4-9 Electro-pneumatic valve positioner, 33
- 4-10 Smart valve positioner, 33
- 4-11 Valve feedback unit with position beacon, 34
- 4-12 Air compressor system, 34
- 4-13 Air distribution system, 35
- 4-14 Low- and high-pressure oil hydraulic system, 35

- 4-15 Electro-hydraulic quarter-turn actuator, 36
- 4-16 Water supply system, 37

- 5-1 Worm-gear manual override with declutch mechanism, 40
- 5-2 Jackscrew manual override for cylinder, 40
- 5-3 Hand pump manual override for cylinder, 41
- 5-5 Cylinder actuator with spring return, 41
- 5-4 Example of lockout mechanism on cylinder actuator, 41
- 5-6 Vane actuator with spring return, 42
- 5-7 Water accumulator tank, 43
- 5-8 Hydraulic oil accumulators, 43

- 6-1 Actuator data form in part from [AWWA C541](#), Appendix A, 46
- 6-2 Open and closed adjusting screws on a ball valve hydraulic actuator, 47

- 7-1 Cylinder head with tie rod nuts, 50
- 7-2 Cylinder actuator limit screws, 51

Tables



- 1-1 Summary of media properties, 4
- 2-1 Actuator application factors, 13
- 2-2 Typical sizing chart for spring return cylinder actuators, 15

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Preface



This new AWWA Manual of Water Supply Practices presents the general principles of hydraulic and pneumatic power actuators for use with waterworks valves. The principles used for selecting, sizing, and installing actuators are detailed. This is a discussion of recommended practice, providing guidance on generally available actuators and their application, not an American Water Works Association (AWWA) standard. Questions about specific situations or applicability of the guidance provided here to specific valves and actuators should be directed to the manufacturer or supplier.

Operators, technicians, and engineers will find the information contained in this manual useful for understanding the use and application of hydraulic and pneumatic power actuators. There are many special actuators that are beyond the scope of this manual and require special consultations with those suppliers. The valve thrust and torque information is generic, and actual data from the valve manufacturer should be obtained before making the final selection of actuator size and options. This manual provides information on the hydraulic and pneumatic actuators listed in [AWWA Standard C541 Hydraulic and Pneumatic Cylinder and Vane-Type Actuators for Valves and Slide Gates](#), latest edition, including the following:

- Linear cylinder actuator
- Quarter-turn cylinder actuator
- Quarter-turn vane actuator

This manual refers to AWWA standards, which are available for purchase from AWWA by calling (800) 926-7337 or online at www.awwa.org.

Manufacturers graciously provided valve illustrations and other documentation. AWWA does not endorse any manufacturer's products, and the names of the manufacturers have been removed from the material provided.

Metrification note: Cylinder sizes are listed in their current US designation: inches. To obtain an approximate metric equivalent, use a conversion factor of 25.4 mm per inch.

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Acknowledgments

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Chapter **1**

Introduction

Hydraulic and pneumatic actuators are externally mounted on ball, plug, and butterfly valves, and on slide gates to provide automatic control of these devices in water and wastewater applications. When combined with control devices such as solenoid valves or positioners, the valves and gates can be used to remotely control water and wastewater treatment processes or process variables including flow and pressure. Many of these actuators also have the feature of providing field-adjustable operating times and, when equipped with pneumatic or hydraulic power systems, can continue to operate after loss of electrical power.

HISTORY

Simple gate valves date back to ancient times in Greek and Roman water and irrigation systems. These gates were mostly operated by manual levers or screws. It was not until the industrial revolution and the use of steam power that valves became automated with power actuators. Since then, hydraulic and pneumatic actuators have been a staple in water and wastewater systems, particularly as valves grew in size and became extremely difficult to operate manually. The advent of automation made it desirable to operate valves remotely with computerized process control systems. Figure 1-1 illustrates a ball valve equipped with a pneumatic vane-type actuator that controls the flow from a high-service water pump.

Given the increased use of automatic process systems, the use of power actuators continues to grow. The power actuator positions the valve in response to system-control signals to complete a system-control loop. When flow or pressure must be controlled as part of a process, a sensing device such as a pressure transmitter or flowmeter sends a signal to a process controller, which in turn compares the signal to the desired system parameter and sends a position signal to the power actuator. The power actuator is directly coupled to the closure member of the control valve and is therefore an essential element of the control loop (Skousen 1997).

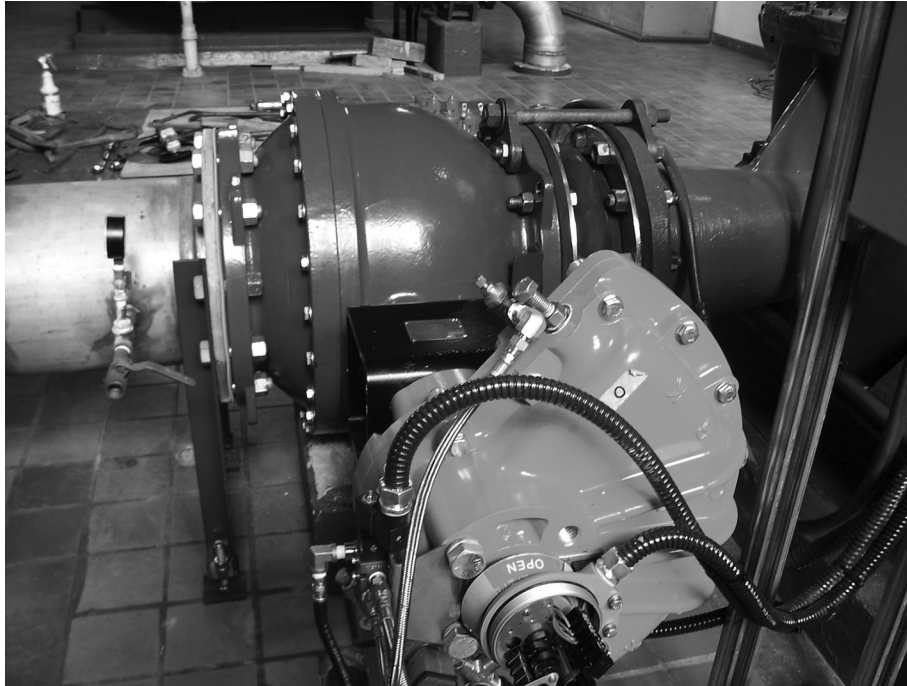


Figure 1-1 Quarter-turn vane-type actuator provides remote control of a ball valve

Source: Courtesy of Val-Matic Valve & Mfg., Corp.

Since a number of valve types are used to control processes, a similar number of various actuator types are used to control these valves. In response, the valve industry has developed actuators for both linear and rotary valves. When automated valves are needed, either hydraulic actuators or electric motor actuators are specified. Electrical actuators provide great versatility in valve automation, but hydraulic actuators provide the ability to store energy and operate the valve without electrical power. Hydraulic systems also provide safe operation of valves, which may be located in hazardous environments. Furthermore, in the event of an electrical power outage, hydraulic and pneumatic systems can still function to provide safe shutdown or isolation of the system.

Electric and hydraulic actuators are used regularly in many industries, including oil, gas, and power, but their use for the waterworks industry was standardized by [AWWA Standard C540](#) in 1987. In 2008, [AWWA C540](#) was withdrawn and replaced by standards [AWWA C541](#), Hydraulic and Pneumatic Cylinder- and Vane-Type Actuators for Valves and Slide Gates, and [AWWA C542](#), Electric Motor Actuators for Valves and Slide Gates. Note, like all AWWA standards, [C541](#) and [C542](#) are updated regularly, as necessary depending on new technology and requirements.

PURPOSE

The purpose of this manual is to explain the fundamental concepts of hydraulic and pneumatic power actuators so users with a technical background can understand, specify, and install these actuators on valves and slide gates. The information in this manual must be used in conjunction with data from actuator and valve manufacturers to select and size the correct actuator models for specific applications.

Sizing parameters such as thrust and torque are explained so the sizing methodologies recommended by actuator manufacturers can be applied to specific applications. Also, the effects of certain valve application parameters, such as flow rate or differential pressure, on actuator operation are discussed.

Finally, installation and operation guidelines are presented for startup procedures and troubleshooting power actuators in the field.

GENERAL APPLICATION

Cylinder-type actuators produce a linear motion to operate a slide gate. Hydraulic or pneumatic pressure is applied to either side of the cylinder piston to generate linear force or thrust. The cylinder rod is attached to the gate and causes it to rise and fall inside the gate frame.

Quarter-turn cylinder-type actuators produce a rotary motion to turn the valve stem and operate the closure member of the butterfly, plug, or ball valve. Quarter-turn cylinder actuators convert the linear motion of a cylinder to rotary motion using link-and-lever, rack-and-pinion, or scotch-yoke mechanisms. Each of these mechanisms is discussed in chapter 2, “Principles of Operation.”

Quarter-turn vane-type actuators also produce a rotary motion. However, instead of a cylinder, the vane acts like a lever and generates rotation from the pressure applied to either side of the vane.

When specifying power actuators, consideration should be given to the effects of valve operational speed on the creation of pipeline hydraulic transients (surges), especially on long pipelines. The power actuator stroke time may vary based on actual pipe operating fluid conditions (e.g., pressure, flow, and pipe size) and the power source capacity.

SUPPLY MEDIUM

All of these actuators are powered with a supply medium of air, water, or hydraulic oil pressure. Specific requirements for the supply media, including pressure, flow, and cleanliness, will be discussed further in this manual. When accessories and control devices such as solenoid valves are added to the actuator, the supply media requirements become more critical.

All three supply media—air, water, and oil—provide reliable sources of energy to operate valves, even after loss of electrical power. The supply systems can be installed near the valves or up to several hundred feet away if required. Both indoor and outdoor installations for these systems are available from either the valve or control system supplier. A comparison of the most relevant properties of these three supply media is summarized in Table 1-1.

Air Supply Medium

Air is a common power supply medium because it is relatively inexpensive and often readily available at water and wastewater plants to operate pneumatic power tools. Compressed air systems consist of an electric motor-driven compressor and a receiver tank for air storage. These systems commonly provide air pressure in the 80–100 psig (552–689 kPa) range with a maximum recommended pressure of 150 psig (1,034 kPa).

The supply output from the compressor system should be equipped with filters and dryers so debris down to a size of 40 microns and water droplets are removed from the air supply before distribution. When the valve is equipped with modulating controls or positioners, filtration down to 5 microns is recommended to prevent clogging of the control orifices. When recommended by the valve or actuator manufacturer, lubricators can be used to add lubrication to the cylinder actuator, but they should not be added to vane actuators or when positioners are employed. It is important to check with the actuator manufacturer first because most vane actuators are permanently lubricated and lubricated air may displace the manufacturer’s supplied lubricant from the actuator.

Table 1-1 Summary of media properties

Property	Air	Water	Oil
Relative cost of media equipment	Moderate	Low	High
Pressure ranges	80–100 psig (552–689 kPa)	60–150 psig (414–1,034 kPa)	60–150 psig (414–1,034 kPa) 1,000–2,500 psig (689–17,237 kPa)
Speed control	Poor (large cylinders)	Good	Good
Required cylinder maintenance	Low	High	Low

While air is an economical and reliable power supply medium, its use should be limited to smaller valves. If used on large valves, the size of the actuator cylinders can become too large to dispense the required actuator force because of the 80–100 psig (552–690 kPa) pressure range limitation. Also, if the valve needs to be moved slowly (i.e., over one minute), the motion of the cylinder may not be smooth. Air is compressible, and the forces from the valve vary with position, which causes the pressures in the cylinder to fluctuate, preventing smooth motion of the cylinder piston. Also, when air is released from the cylinder, it can produce uncomfortable or irritating noise levels if not fitted with proper sound-reducing mufflers.

Water Supply Medium

Water is also a common power supply medium because it is typically available at plants and pumping stations, especially if the plant or pumping station is feeding the water distribution system. A reliable water supply for powering actuators can often be obtained by connecting to a pump discharge header. However, it is important to realize that during system startup, the water source may not yet be available, and a temporary water supply source may be needed to operate the valves. If potable water is used as the supply medium, care must be taken to prevent backflow of the supply and drainage water back into the potable water system. Depending on the source of the water, providing filtration to remove particles larger than 20 microns may also be necessary. Other properties of the water, such as salinity, hardness, pH, and conductivity, should be reviewed to protect the cylinder and controls from corrosion, degradation, and excessive maintenance. A minimum water pressure of 60 psig (414 kPa) is common and a maximum pressure of 150 psig (1,034 kPa) should be used to match the standard pressure rating of the cylinders.

Water is not compressible and therefore can provide smooth operation of cylinders at extremely slow operating times, such as five minutes. It may be necessary to open or close a valve this slowly to prevent surges in long distribution pipelines. Water in general is corrosive, so its use dictates the need for corrosion-resistant supply tubing and cylinders. Water supply tubing to the actuator is usually brass and copper. Similarly, the cylinder barrel should resist corrosion and be constructed of materials such as stainless steel, bronze, fiberglass, or coated steel. The cylinder rod should be of corrosion-resistant material as well, such as hard-chrome or electroless-nickel-plated stainless steel. Water-powered actuators are not generally certified to drinking water standards such as NSF 61,

Drinking Water System Components – Health Effects, so the exhaust media from the actuator should not be returned to the potable water source.

Hydraulic-Oil Supply Medium

The hydraulic-oil supply medium is typically a petroleum-based fluid, but it can also be certified as food grade per FDA requirements for cases where it may possibly infiltrate into the water system. Hydraulic oil is typically filtered and the piping cleaned to a specified level of cleanliness recommended by the equipment manufacturer and furnished with a viscosity of 135 to 165 Saybolt Seconds Universal (SSU), similar to automatic transmission fluid in vehicles. Hydraulic oil systems can be obtained in the low-pressure range of 60 to 300 psig (414 to 2,070 kPa) for smaller valves or in high-pressure systems ranging from 1,000 to 2,500 psig (6,890 to 17,200 kPa) for large valves. Standard heavy-duty hydraulic cylinders have a minimum working pressure rating of 3,000 psig (20,680 kPa). The use of the higher-pressure systems greatly reduces the size of the cylinders and the cost of the hydraulic power system required to operate large valves. The construction of oil power systems is explained in chapter 5.

Hydraulic oil offers superior operating characteristics because it inherently lubricates all of the cylinder and control components that it contacts. Like water, hydraulic oil is not compressible, and therefore it can provide smooth cylinder motion during slow valve operating times.

Hydraulic oil must be ultra clean, especially for high-pressure systems, to avoid clogging or scoring of cylinders and solenoid valve surfaces. Manufacturers may specify a cleanliness level in accordance with industry standards such as ISO 4406. A typical ISO 4406 cleanliness level may be “19/17/14” where the three numbers specify that there shall be less than 5,000 4-micrometer, 1,300 6-micrometer, and 160 14-micrometer or larger particles per 100 milliliter of fluid. The ISO standard contains tables with many levels of cleanliness. The cleanliness level is measured by looking at a small sample of the fluid under a microscope to size and count the particles. New hydraulic oil rarely meets this level; hence, new oil should be filtered before use. Users contemplating a hydraulic oil system should familiarize themselves with other standards and practices concerning cleanliness, such as SAE J1165 and [ASTM D4174](#).

Fluid used for flushing or filling hydraulic systems should be filtered using at least a 10-micron pressure filter system. Hydraulic tanks, fittings, and tubing should also be flushed thoroughly before installation. Once the system is running, it stays clean and trouble-free because of the lubricity and noncorrosive properties of hydraulic oil.

REFERENCES

[ASTM D4174](#), “Standard Practice for Cleaning, Flushing, and Purification of Petroleum Fluid Hydraulic Systems.”

ISO 12100, “Hydraulic Fluid Power – Fluids – Method for Coding the Level of Contamination by Solid Particles.”

SAE J1165, “Reporting Contamination Levels of Hydraulic Fluids. ”

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Chapter 2

Principles of Operation

This chapter covers three basic types of hydraulic and pneumatic actuators used in the water and wastewater industry that are included in [AWWA C541](#), Hydraulic and Pneumatic Cylinder- and Vane-Type Actuators for Valves and Slide Gates, latest edition. The mechanics and the physics behind how linear cylinder, rotary cylinder, and vane actuators perform their intended functions are explained so users can determine which actuators best suit their particular needs.

GENERAL DESCRIPTIONS

The primary function of cylinder actuators is to produce linear motion to restrain or operate the closure member of valves and gates. A cylinder actuator consists of a pressure-retaining barrel bolted between head and cap ends, as shown in Figure 2-1. The piston includes seals on its outside diameter to contain pressure between the piston and either end of the cylinder. Important dimensional information for cylinders is the *bore* or inside diameter of the barrel, the *stroke* or maximum travel of the piston, and the *rod diameter*, which changes with cylinder bore and operating pressure.

When supply pressure is directed through one of the ports and applied to one side of the piston, the opposite side vents to drain, creating a differential pressure across the piston. The differential pressure is applied over the area of the piston, resulting in a force or thrust on the rod. It is important to recognize that the areas on either side of the piston are not the same. The piston area on the left side of the figure is reduced by the cross-sectional area of the rod. Hence, a cylinder will produce more thrust when pressure is applied to the cap end than the head end.

In a linear cylinder actuator, the head of the cylinder is rigidly mounted to the valve body and the rod is attached to the valve stem or closure member to mechanically create thrust, operating the valve or gate closure member in a linear manner. Thrust is the linear force on the valve stem or slide gate, generally expressed in units of pound-force (lb-F) or

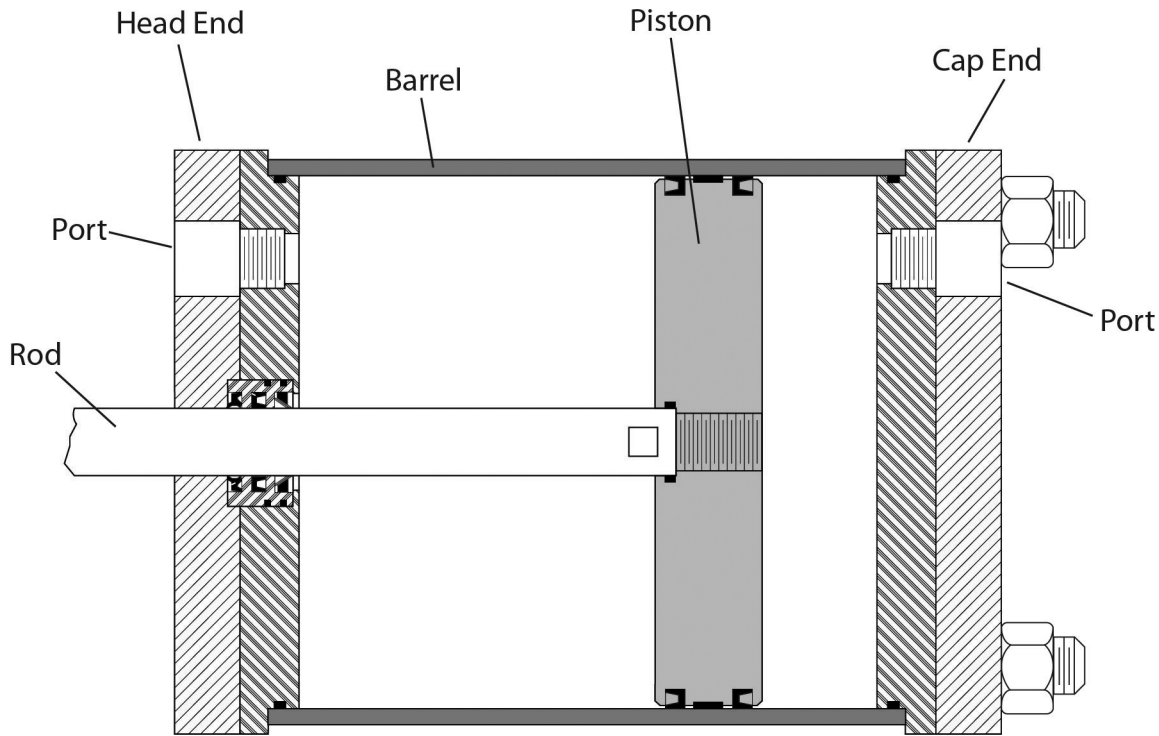


Figure 2-1 Cylinder actuator provides linear thrust

Newton (N). During lifting (opening) of the gate, the head end of the cylinder will be pressurized, with reduced area and reduced thrust.

A quarter-turn cylinder actuator converts the linear cylinder thrust into torque using one of the mechanisms shown in Figure 2-2. Torque is a twisting or turning movement on the valve stem or shaft, generally expressed in foot-pounds (ft-lb) or newton-meters (N-m). The required torque must overcome the frictional and flow-induced forces in the valve to permit mechanical operation of the valve.

The lever mechanism uses a special cylinder whose head pivots about a trunnion or post. The cylinder rod is attached to a simple lever with a rotatable pin. As the cylinder rod extends, it pushes on the pin end of the lever, thereby rotating the lever 90 degrees.

The link-and-lever mechanism is similar except a link is used between the rod and the lever to provide an additional mechanical advantage when the link is perpendicular to the lever. This mechanism produces high lateral side loads on the cylinder rod, so the pin must be supported along its travel by a guide slot in the actuator housing or with a support bar.

The rack-and-pinion mechanism has a straight gear rack attached to the cylinder rod. As the cylinder rod is extended, the rack rotates the pinion gear. This mechanism also produces high lateral side loads on the cylinder rod, so the rack must be supported along its travel.

The scotch-yoke mechanism consists of a cylinder rod and pin that travel in a slot contained within the lever. In most scotch-yoke mechanisms, the cylinder rod is extended across the housing to provide support for lateral side loads.

Another version of the rack-and-pinion mechanism (Figure 2-3) consists of linear racks that mate with a rotating splined-pinion gear inside the cylinder. As air pressure is applied to either end, the pistons in the actuator are sealed against the cylinder housing, driving the two racks and rotating the pinion gear. This type of rack-and-pinion actuator is relatively compact and typically used on smaller valves.

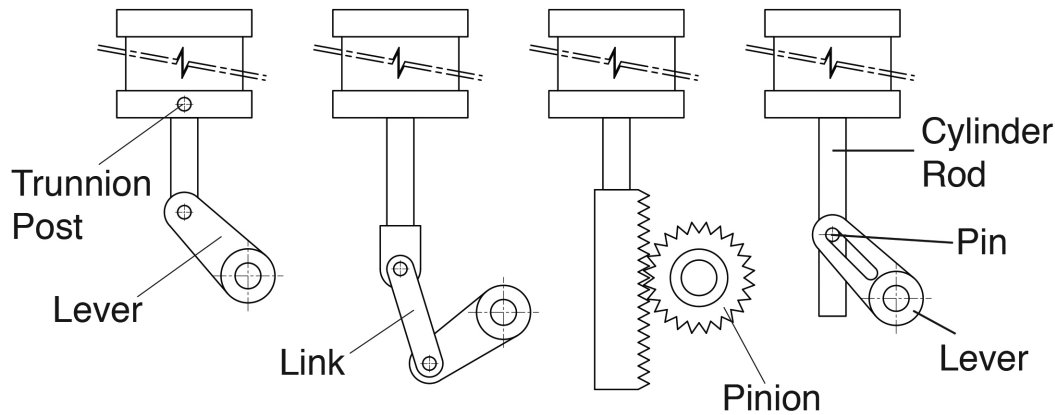


Figure 2-2 Various quarter-turn mechanisms, left to right: lever; link-and-lever; rack-and-pinion; scotch-yoke

Vane actuators (Figure 2-4) act like a lever and directly produce torque through a 90-degree arc to rotate the valve stem when there is supply pressure on one side of the vane. The vane is enclosed in a pie-shaped housing and has resilient seals around its periphery to maintain the differential pressure necessary for converting the applied pressure to torque. Hence, the vane actuator is compact and has only one moving part.

THRUST CALCULATIONS

Slide-gate cylinder actuators are required to generate thrust to lift and lower the slide gate, as shown in Figure 2-5. The thrust should be provided by the gate manufacturer with consideration given to the weight of the gate, the weight of the stem, and the friction on the frame due to the differential pressure acting over the area of gate. Thrust values can vary greatly depending on the types of seats and gate wedges employed in the valve design, so the thrust requirements from the manufacturer are needed to properly size the actuators.

Typically, the maximum thrust required to operate a vertical slide gate occurs while opening the valve, during the release from the wedges and lifting the weight of the gate. The force is in part empirically determined by the manufacturer and normally presented in the following equation (AWWA C560). The 1.5 factor applied to the P_1 term represents the thrust needed to overcome the friction from the wedges used to seat the gate.

$$F = (D_w \times f \times A \times H) + (1.5 \times P_1) + P_2 \quad \text{Eq 2-1}$$

Where:

- F = total force required to open, lb (N)
- D_w = weight density of water, 62.4 lb/ft³ (1,000 kg/m³)
- f = friction factor of slide against the seat = typically 0.35
- A = area of the gate opening, ft² (m²)
- H = differential head of water at gate centerline, ft (m)
- P_1 = weight of slide, lb (kg)
- P_2 = weight of stem, lb (kg)

When cylinder actuators are sized for slide gates, a sizing safety factor of at least 1.3 should be applied to the overall thrust.

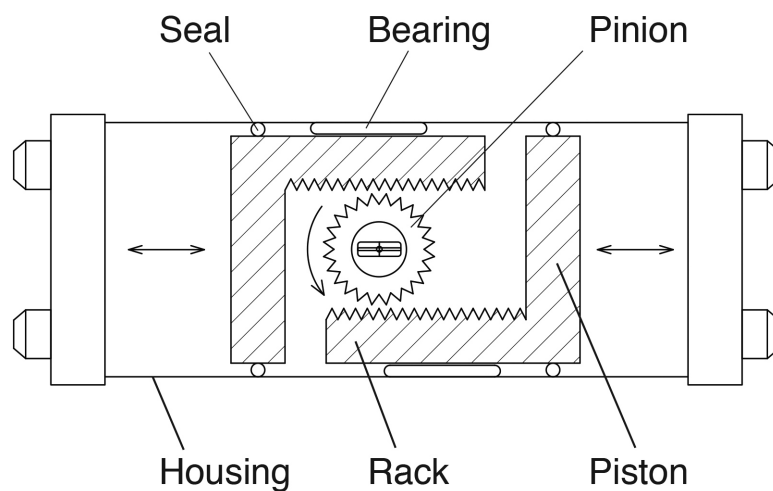


Figure 2-3 Rack-and-pinion mechanism

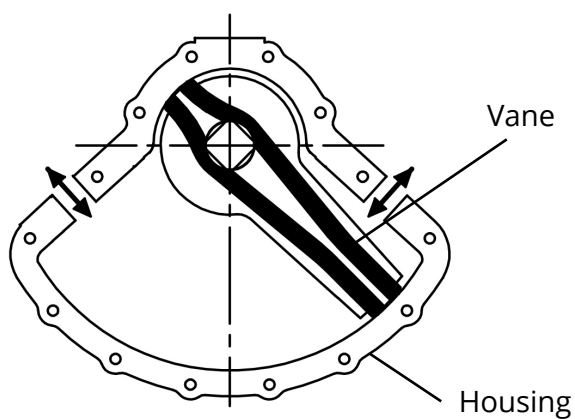


Figure 2-4 Vane mechanism



Figure 2-5 Typical slide gate for waterworks applications

Source: Courtesy of Rodney Hunt