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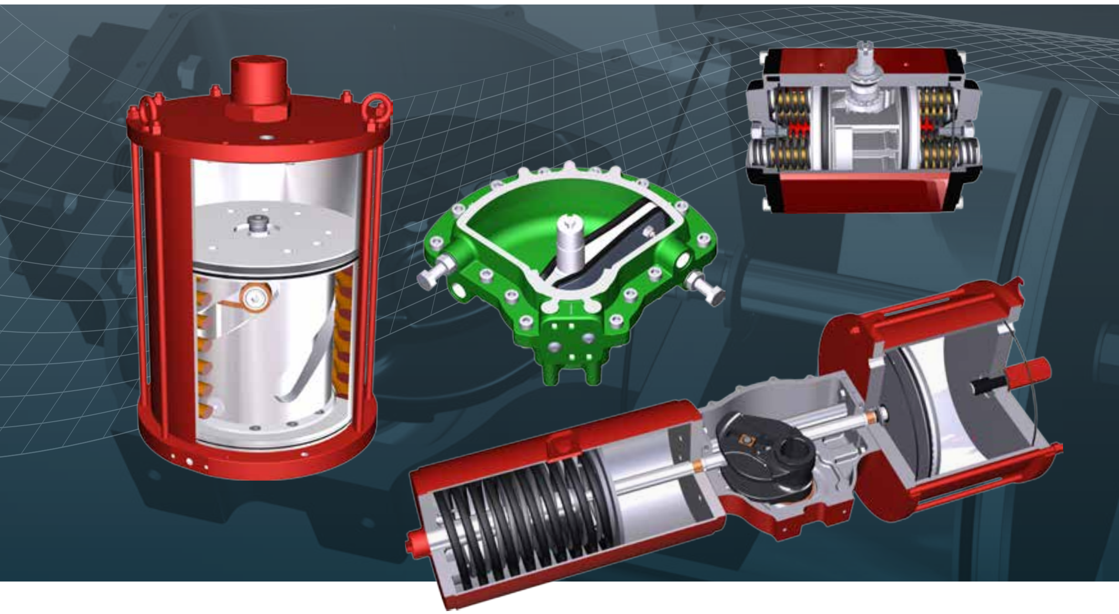
Fluid Systems

Fluid Power Actuators Explained



Keeping the World Flowing

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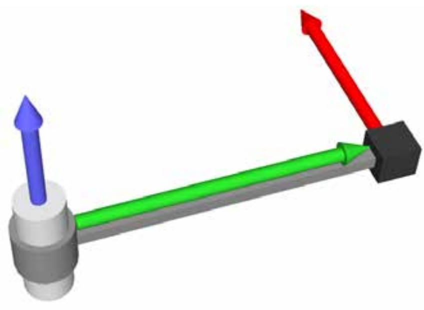
Definition of Torque

The product of a rotary actuator is torque, a rotary motion produced by exerting a force on a moment arm. Torque is defined by the formula:



Torque = **force** x **arm** [*Nm*]

Where:

force [*N*] = air or oil pressure [*Pa*] x piston area [m^2]

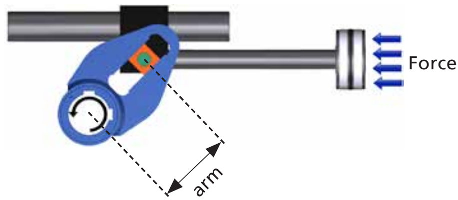
arm [*m*] = distance from the center of rotation to where the force is applied

1 MPa = 10^6 Pa = 10^6 N/m^2 = 10 bar

Scotch Yoke Actuators

Definition of Scotch Yoke

The scotch yoke is a mechanism that converts the linear motion of a bar sliding back-and-forth into a rotational motion. The sliding bar is directly coupled to a piston and to a yoke with a slot that engages a sliding block. When a force is applied to the piston, the sliding block moves in the yoke slot, causing the yoke to rotate.



Scotch Yoke Actuator Components and Working Principle

A scotch yoke actuator may be defined as a mechanical device that converts linear force into torque to motorise quarter-turn valves.

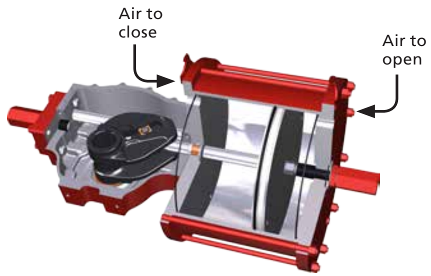
A **single-acting** scotch yoke actuator is made of three main components: housing containing the yoke mechanism, pressure cylinder containing the piston and spring enclosure.

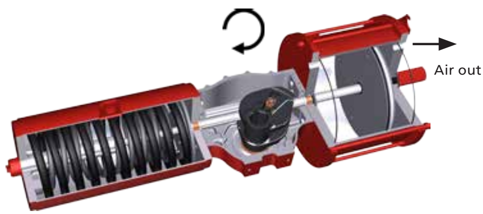
When air pressure is supplied into the cylinder chamber, a linear force is applied on the piston surface. Thanks to the movement of the sliding block in the yoke slot, an anti-clockwise rotation is generated on the yoke and the valve is driven to the open position. At the same time the actuator spring is compressed.

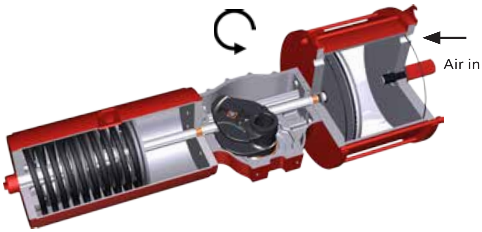
When air pressure is removed, the spring is automatically released, the yoke moves clockwise driving the piston back to the starting position and thus the valve to the fail-safe close position.

A **double-acting** scotch yoke actuator requires air pressure for both the open and close stroke, as the spring is missing.

Double-acting actuators do not have an inherent fail-safe action. If pneumatic power is lost, then the actuator will remain in its last position.



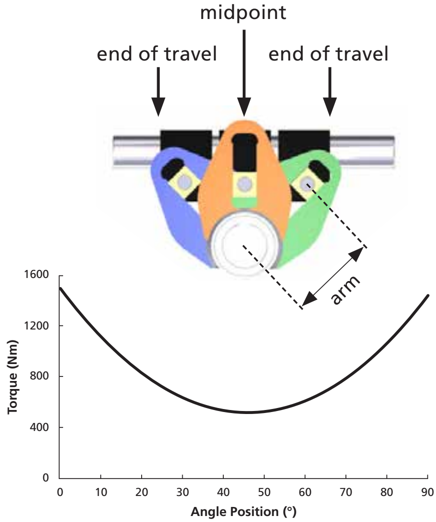




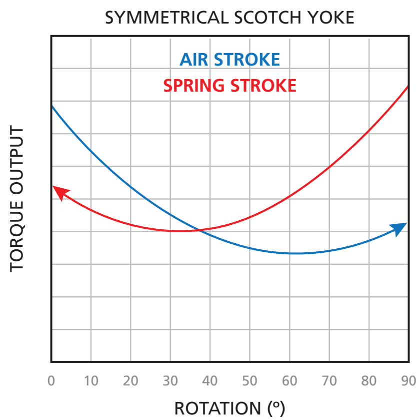
Scotch Yoke Actuator Torque Profile

The dimension of the arm is greatest at both ends of travel (open and close). The dimension is shortest at the midpoint. Applying these various dimensions the torque formula produces a U-shaped output torque characteristic.

To generate more torque from a scotch-yoke actuator at a given pressure, the piston surface and/or the movement arm must be increased.



The classic **symmetric yoke** delivers peak torque at both ends of stroke.



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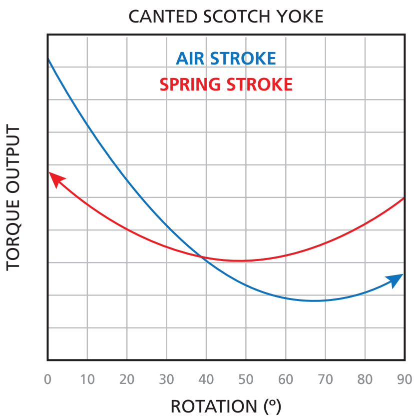
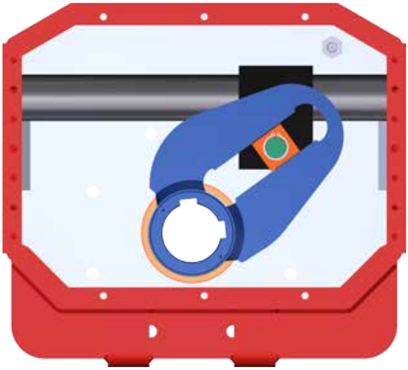
Scotch Yoke Actuators

The **canted yoke** delivers peak torque at only one end of stroke. Canted yoke has a torque advantage in application where higher break to open torque is required to unseat the valve. Use of canted arms can often reduce actuator size, weight and cost for valves with appropriate torque demand characteristics.





Scotch Yoke Mechanism Advantages

- The scotch yoke principle is characterised by high torque at the beginning and end of each operation. This matches with the typical torque request of quarter-turn valves and increases safety, especially in applications where a valve remains stationary throughout long periods.
- When compared with the rack and pinion system, a scotch yoke using the same cylinder bore and equal air supply pressure develops a higher torque which also reduces the air consumption on site
- Good regulating features – no play in force transmission and low friction because the transmission passes over bearings.

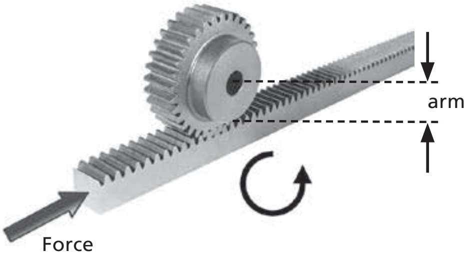
Scotch Yoke Mechanism Disadvantages

- Wear of the slot/sliding block in the yoke caused by sliding friction and high contact pressures
- Unbalanced side loads on the centre body generated by the action of cylinder and spring on opposite sides
- Only 90º rotation is achievable, i.e. the scotch yoke mechanism is not suitable for 3 way valves

Rack and Pinion Actuators

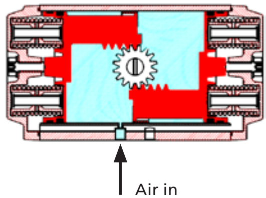
Definition of Rack and Pinion

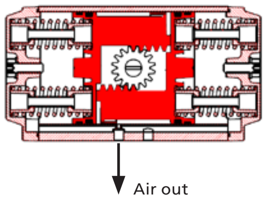
A rack and pinion is a pair of gears which converts linear motion into rotational motion. The circular pinion engages teeth on the rack. A force applied to the rack will cause the rack to move to the side, up to the limit of its travel and the pinion to rotate.

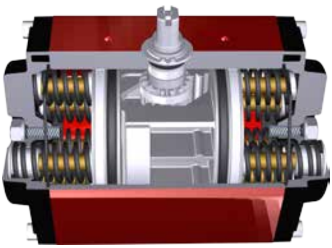


Rack and Pinion Actuator Components and Working Principle

In a rack-and-pinion actuator a piston with one side machined into a rack engages a pinion to turn the output shaft. The picture shows an example where double pistons and racks are responsible for the pinion movement. Multiple springs are mounted in the dedicated grooves machined on the piston surface.



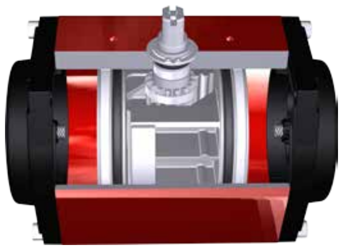




When air pressure is supplied into the actuator body, the linear force applied on the piston surface generates the pinion anti-clock wise rotation, driving the valve to the open position. At the same time the actuator springs are compressed.

When air pressure is removed, the springs are automatically released, driving the rack and pistons back to the original position with a clockwise rotation and thus the valve to the fail-safe close position.

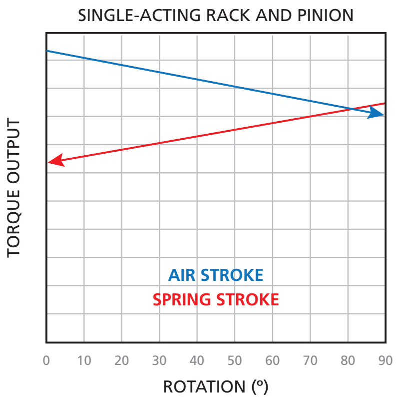
The double-acting execution can be obtained by removing the spring packages. Air pressure will be responsible for both the open and close stroke.

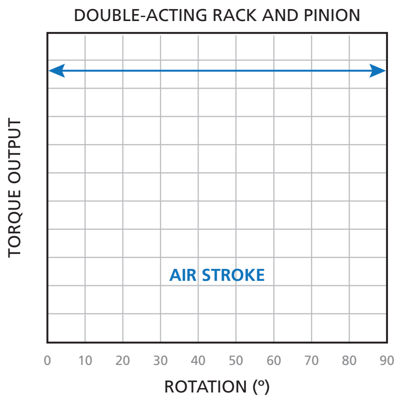


Rack and Pinion Actuators

Rack and Pinion Actuator Torque Profile

Due to the constant arm length along the full stroke, the output torque characteristic is a straight line, sloping downward. The inclination depends on the spring elastic constant. A constant profile is generated by a double-acting actuator.





Rack and Pinion Mechanism Advantages

- Compact design, with balanced distribution of the weight on the valve
- With two pistons in a given size cylinder, torque is doubled and the linear piston forces cancel one another so that the actuator output is purely torsional with no side loads on either the valve components or actuator bearings. This allows seals and bearings to last longer, both in the valve and in the actuator (millions of cycles).
- Well suited for modulating control application as well as on-off service
- The possibility of up to 180° (higher available upon request), by using a simple longer rack design, makes them suitable for 3 way valves actuation

Rack and Pinion Mechanism Disadvantages

- The flat torque profile is not ideal for ball and butterfly valves, where the parabolic output of the scotch yoke mechanism is more appreciated
- Higher air consumption when compared to a scotch yoke actuator producing equal break to open torque

Helical Actuators

Definition of Helical Mechanism

The transformation of a linear movement of the piston into quarter-turn is performed by combining a set of three concentric cylinders, as shown in the picture.

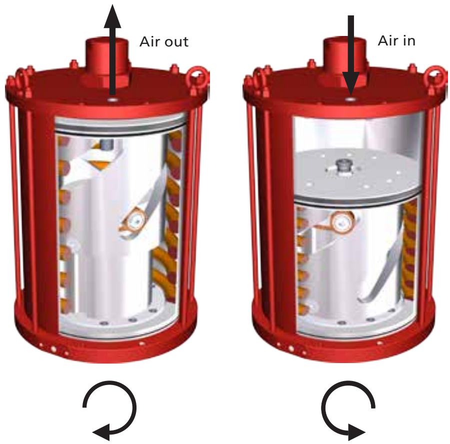
A set of three rotary pins is positioned on the upper part of the inner cylinder (drive shaft) and three helical slots are machined on the external tube. The cylinder is integral to the piston and application of force on the surface of the piston moves the cylinder vertically. The pins transmit a rotary movement to the drive shaft by rotating and moving along the helical slots of the external tube.

The rotation of the tube with helical grooves is inhibited by three keys fixed on the lower part of the tube itself and moving along vertical grooves in the intermediate cylinder.

Helical Actuator Components and Working Principle

When air pressure is supplied into the cylinder chamber, a linear force is applied on the piston surface. Thanks to the rotation of the three pins and movement of the same along the helical slots, an anti-clockwise rotation is generated on the tube where the pins are installed and the valve is driven to the open position. At the same time the actuator spring is compressed.

When air pressure is removed, the spring is automatically released, pushing up the piston to the starting position and thus the valve to the fail-safe close position.

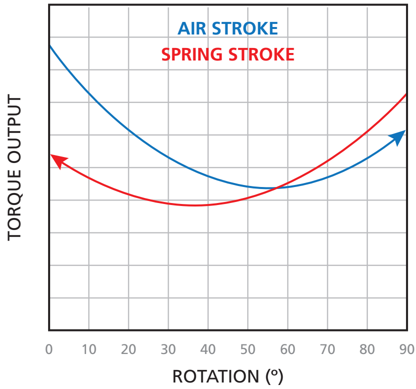


The double-acting execution requires air pressure to both open and close the actuator.

Helical Actuators

Helical Actuator Torque Profile

The arm is constant along the actuator stroke as given by the distance between the body centre and the rotary pin, while the force is not due to the helical profile. This produces a U-shaped output torque characteristic.



Helical Mechanism Advantages

- The pin and helical slot principle is characterised by high torque at the beginning and end of each operation. This matches with the typical torque request of quarter-turn valves and increases safety, especially in applications where a valve remains stationary throughout long periods
- The pin and helical slot principle is suitable for both pneumatic and hydraulic solutions
- Extremely compact design when compared to a scotch yoke execution, particularly suitable in applications where the available room is the main concern
- Overall dimensions within the valve footprint, with weight equally distributed on a round surface
- Available, upon request, for up to 180° rotation
- The helical profile can be customized to suit specific valve torque profile

Helical Mechanism Disadvantages

- Heavier when compared to a scotch yoke execution delivering same torque
- High torque hydraulic execution requires the installation of a top hydraulic cylinder, resulting in an increase of the assembly height

Vane Actuators

Definition of Vane

The force applied to the vane surface directly produces the rotation of the shaft, no conversion of linear to rotary motion is involved.

Vane Actuator Components and Working Principle

Vane actuators are quarter-turn devices using a vane with integral rotary output shaft to produce the torque. The vane is installed inside an enclosure and divides the chamber in two compartments.

Rotary motion is produced directly by applying air pressure to one side of the vane, the only moving part of the assembly.

The system does not convert linear motion to rotary, resulting in true rotary control.

The picture shows an example of a double-acting unit, where air is applied for both the open and closed stroke.

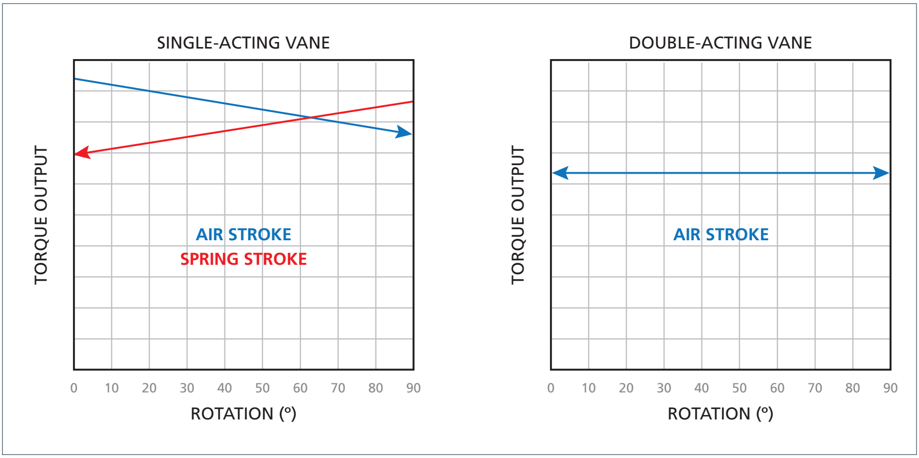
The dual opposed lip seals mounted on the vane provide effective, air-assisted seal for low friction and long, maintenance-free life.

Clock type torsion springs can be added to provide a fail-safe spring-to-close or spring-to-open actuator.

Vane Actuators

Vane Actuator Torque Profile

Due to the constant arm length along the full stroke, the output torque characteristic is a straight line, sloping downward. The inclination depends on the spring elastic constant. A constant profile is generated by a double-acting actuator.



Vane Advantages

- Since vane actuators do not convert linear to rotary motion, no side load is transferred to the actuator housing/valve stem, resulting in a true rotary control and increased life expectancy of butterfly, ball and plug valves
- High torque output in a small size, within the valve footprint
- The absence of pressure retaining o-ring seals increases the service life
- The dual opposed lip seals are low friction, reducing or eliminating “stick-slip” and “hunting” when in modulating service
- Designed for high cycle and precise modulating service

Vane Disadvantages

- The flat torque profile is not ideal for ball and butterfly valves, where the parabolic output of the scotch yoke mechanism is more appreciated
- The spring-return execution is limited to a maximum operating pressure of 5,5 bar
- The spring-return execution results in an increased height of the whole assembly, which has to be taken into account in the plant layout

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UK
Rotork plc
tel +44 (0)1225 733200
fax +44 (0)1225 333467
email mail@rotork.com

USA
Rotork Controls Inc.
tel +1 (585) 247 2304
fax +1 (585) 247 2308
email info@rotork.com

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